Transthoracic echocardiography in the perioperative setting

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Purpose of review
A need for further assessment of patients in the perioperative setting and an increasing availability of ultrasonography equipment have facilitated the diffusion of ultrasonography and lately focused transthoracic echocardiography (TTE) in anesthesiology practice. This review will discuss the possible use of focused TTE in the perioperative setting and provides an update on present and future perspectives.

Recent findings
Several studies focusing on patient management and diagnostic accuracy of perioperative, focused TTE, have been published recently. Several multidisciplinary guidelines addressing use and educational aspects of focused ultrasonography are available, yet guidelines focusing solely on the use in the perioperative setting are lacking.

Summary
Hemodynamically significant cardiac disease or pathophysiology can be disclosed using TTE. Focused TTE is feasible for perioperative patient management and monitoring and will be an inevitable and indispensable tool for the anesthetist. Future research should focus on the outcome of perioperative TTE performed by anesthesiologists, using rigorous study designs and patient-centered outcomes such as mortality and morbidity.

Keywords
anesthesia, cardiac physiology, hemodynamic determinants, pathophysiology, perioperative setting, transthoracic echocardiography

INTRODUCTION
Maintaining sufficient tissue oxygenation is a key issue for the anesthesiologist in the perioperative period. To ensure this, hemodynamic monitoring tools are applied, including continuous electrocardiogram, systemic and central venous blood pressure, arterial blood samples, central venous oxygenation and cardiac output. However, standard hemodynamic monitoring provides markers of overall circulatory status, but adds little in terms of the underlying physiology \cite{1–3}. The determinants of cardiovascular physiology; preload, afterload, contractility, diastolic function and heart rate can be thoroughly evaluated, in addition to disclosing obvious cardiac disease by cardiac ultrasonography.

Transesophageal echocardiography (TEE) has been used by cardiac anesthesiologists for more than 35 years. It is recognized as a pivotal monitoring tool to guide surgical and anesthetic decision-making \cite{4,5}. However, TEE exposes the patient to some risk and has limited value after extubation. To overcome these limitations, we introduced focused transthoracic cardiopulmonary ultrasonography in anesthesia and critical care in the late 1980s \cite{6}. The ‘surface approach’ \cite{7} allows cardiac visualization throughout the entire perioperative period, including the preoperative anesthetic evaluation, intraoperative hemodynamic guidance and postoperative assessment of cardiopulmonary status \cite{5,8\textsuperscript{**},9–13, 14\textsuperscript{**},15–19}.

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The growing enthusiasm regarding transthoracic echocardiography (TTE) for noncardiologists has led to several focused scanning protocols for cardiopulmonary optimization. Protocols, named by acronyms, include Focused Assessed Transthoracic Echocardiography (FATE) [6], FEEL [20], H.A.R.T. [21], CLUE [22], FUSE and RUSH [23]. They all share the same key features being problem-oriented, attempting to answer simple dichotomous questions, limited in time consumption, easily repeatable and without a need for transporting the patient. Implementation has been facilitated by technological progress resulting in enhanced image quality, high portability and lower equipment costs.

Thus, after a period in which focused TTE by noncardiologists has met criticism and concern, it has disseminated into anesthesia, critical care and emergency medicine because of a self-explanatory clinical need. Moreover, clinical studies and perioperative case series report that focused TTE prevents adverse events and has direct clinical impact [5,9–13,14],15–18,24,25]. Acknowledging the accumulating evidence, several leading academic societies now promote and recommend focused TTE as a mandatory tool for all physicians sufficiently trained to improve patient care [26**].

The introduction of a new, advanced and observer-dependent technique constitutes an educational challenge to the anesthesia community. International consensus has to be obtained on levels of education and criteria for certification. This review will briefly discuss this issue, and will also explain how cardiac ultrasonography is used to quantify the key determinants of cardiovascular function. Additionally, this review will provide an overview of the literature on focused TTE in the perioperative period.

KEY POINTS

- Focused TTE is rapid, repeatable and noninvasive.
- Focused TTE reveals unexpected cardiac disease and pleural scanning reveals additional unexpected disease of hemodynamic importance.
- Full disclosure of hemodynamic status requires assessment of preload, afterload and systolic and diastolic function.
- Focused cardiac ultrasonography alters perioperative management and may have predictive value.
- We recommend an expertise pyramid in order to optimize education and structuring daily practice.

INDICATIONS, ULTRASONOGRAPHIC IMAGING AND FOCUSED PROTOCOL APPROACH

Indications

Indications for a preanesthetic-focused TTE have been suggested to include systolic murmurs, potential valve disease, hemodynamic instability, assessment of ventricular function, unexplained dyspnea, hypoxemia or limited functional capacity [29]. The Society of Critical Care Anesthesiologists has recently presented recommendations for standard clinical indications, learning goals and competencies regarding focused ultrasonography use within anesthesiology-critical care medicine [28**].

Imaging and scanning terminology

A focused TTE protocol for the perioperative setting should include a sufficient set of views to assess the key determinants of cardiovascular function. We recommend the FATE protocol, as it is among the most comprehensive focused transthoracic protocols allowing basic TTE (qualitative assessment and pattern recognition) as well as more advanced Doppler measurements if performed by skilled practitioners. Furthermore, pleural scanning is part of the protocol (Fig. 1).

Subcostal four-chamber view

The transducer is placed close to the midline and just beneath the thoracic curvature. The probe orientation marker points to the patient’s left and the image plane is directed toward the left shoulder.

Apical four-chamber view

The transducer is placed above the apex of the heart. The orientation marker points to the patients left, and the image plane is aligned with the axis of the heart.

Parasternal long-axis and short-axis

The transducer is placed just left to the sternum, on a line between the apex of the heart and the middle of the patient’s right clavicle. The long-axis will appear when pointing the orientation marker toward the patient’s right shoulder, and short-axis with 90 degrees clockwise rotation.

Pleural scanning

The transducer is placed on the posterior axillary line. Identification of the diaphragm facilitates separation of the thoracic and abdominal contents and potential pleural fluid will accumulate just cranially
to the diaphragm. Atelectasis of the lung can also be disclosed.

Subcostal vena cava view (extended view): is sought from the subcostal view by rotating the probe and hence the ultrasound image around the inferior vena cava’s entry into the right atrium.

Apical two-chamber and long-axis view (extended views): these views are achieved from the apical four-chamber view by rotating the transducer.

Apical five-chamber view (extended view): the view is obtained from the apical four-chamber view by tilting the transducer and thus presenting a more anterior scanning plane.

Parasternal short-axis at mitral plane and aortic valve level (extended views): these views are achieved from the regular short-axis view by moving the scanning plane along the axis of the heart.

**Focused transthoracic echocardiography protocol in daily clinical practice**

To perform a focused TTE, the examiner must, as a minimum, be able to obtain the basic views and recognize the most significant cardiopulmonary disease. Most hemodynamic significant disease and pathophysiology can be detected by basic two-dimensional (2D) echocardiography.

A focused protocol warrants a stepwise approach including obvious disease, assessment of wall thickness and chamber dimensions, assessment of biventricular function and visualization of pleura [9]. Preferably, patients should be examined at the point-of-care with portable equipment and examination should be repeated in the case of deterioration, allowing for immediate interpretation, by the performing hemodynamic specialist, in relation to the clinical context.

In the perioperative setting, wherein time is of the essence, TTE should be performed rapidly. Focused protocols have demonstrated an ability to ensure adequate images to assess hemodynamic status. This is possible despite frequent, limited acoustic windows, tachypnea and challenging patient positioning [5, 6, 9, 17]. If one view is difficult, the examiner should move on to the next. Changes in patient positioning and respiration will often optimize image quality [9]. The sequence of the views should reflect suspected positive findings; in some cases, one view may be adequate.

**FIGURE 1.** Focus assessed transthoracic echocardiography (FATE) protocol. Basic and extended views. AO, aorta; IVC, inferior vena cava; LA, left atrium; LV, left ventricle; PA, pulmonary artery; RA, right atrium; RV, right ventricle.
It should be emphasized that a focused protocol does not replace a comprehensive TTE performed by a cardiologist [30]; referral criteria for a comprehensive TTE need to be respected [28,31] and consultation by a cardiologist should be considered.

FOCUSED TRANSTHORACIC ECHOCARDIOGRAPHY FOR HEMODYNAMIC ASSESSMENT AND OPTIMIZATION

The following addresses the importance of 2D imaging and highlights the need for knowledge about cardiac dimensions, hemodynamic optimization based on basic physiological determinants and hence why focused TTE is superior to any other monitoring techniques.

Preload

Preload refers to the end diastolic volume of a ventricle and is a surrogate measure of sarcomere length. Perioperatively, preload can be estimated using simple one-dimensional, two-dimensional, or three-dimensional quantification of the left ventricular end-diastolic volume. As the left ventricular volume is prone to intersubject variation, this method is predominantly recommended for within-subject changes [32]. In extreme conditions, severely impaired ventricular filling can be visualized as ‘kissing walls’ when the papillary muscles touch each other at end-systole corresponding to full emptying of the ventricle (parasternal short-axis view). Conversely, a high left ventricular filling pressure will facilitate a fixed bulging of the interatrial septum into the right atrium [33].

In addition, the respiratory changes of the inferior vena cava (Fig. 2) can be used to predict volume responsiveness during positive pressure ventilation [34,35]. A variation above 12–18% exhibited high sensitivity and specificity; this finding has, however, later been questioned [36].

Afterload

Afterload is an elusive concept often defined as the force against which the ventricle contracts. It may be expressed as wall stress and is, by the law of Laplace, proportional to ventricular radius and ventricular transmural pressure, but inversely proportional to myocardial thickness. At the same systolic blood pressure, a hypertrophic ventricle with a small cavity will have a low afterload, whereas a dilated and thin-walled ventricle is subject to a high afterload [37]. The development of aortic valve stenosis implies a concomitant increased left ventricular pressure work ensuring an adaptive decrease in afterload (left ventricular hypertrophy and reduced left ventricular cavity). Progress in aortic stenosis will finally result in an increase in left ventricular afterload (thinning of the left ventricular myocardium and dilatation of the left ventricular cavity) when the left ventricular pressure work requirements exceed the capacity of the left ventricular myocardium.

![Figure 2](image_url)
Ventricular contractility

Ejection fraction remains the most common echocardiographic expression of left ventricular systolic function, although it may be affected by changes in both preload and afterload. Echocardiography most of the time relies on eyeballing for the estimation of ejection fraction. Eyeballing correlates well with quantitative techniques and allows us to categorize ejection fraction in subgroups [38,39]: more than 52%; normal, 41–52%; mildly abnormal, 30–40%; moderately abnormal and less than 30%; severely abnormal [40*]. Eyeballing of ejection fraction may be performed from the apical four-chamber and parasternal views. To minimize the effect of regional dyskinesia, we recommend using more than one view for assessment of ejection fraction. Intraoperatively, patient positioning and the surgical field often limit accessibility to the parasternal views.

If impaired image quality prevents precise endocardial border definition, semiquantitative methods can be applied. For example, ejection fraction can be approximated by use of the mitral annular plane systolic excursion (MAPSE). MAPSE is a reflection of left ventricular longitudinal contractility and is simply measured as the systolic excursion of the mitral valve annuli [41,42*,43]. MAPSE must be measured in the apical four-chamber view. If only the parasternal views are available, the mitral-septal separation may be used. A separation of less than 7 mm between the anterior mitral valve leaflet and the interventricular septum, in early diastole, is indicative of normal ejection fraction [44].

Tricuspid annular plane systolic excursion is a well-validated marker of right ventricular systolic function [45]. Because of its complex geometry, the right ventricle cannot be visualized sufficiently in 2D views precluding the quantification of volume changes. Thus, excursion distance can be measured at the lateral tricuspid valve annulus in the apical four-chamber view. Dilatation of the right ventricle, defined as a basal diameter more than 41 mm in the apical four-chamber or more than 30 mm in the parasternal long axis view [40*], is a sign of either right-sided heart failure or pressure or volume overload [46]; this should prompt further investigation prior to positive pressure ventilation.

Diastolic function

Left ventricular diastolic function depends on passive ventricular compliance and active relaxation properties susceptible to ischemia. The significance of diastolic dysfunction on intraoperative hemodynamic stability has not been described, but the 5–7 fold risk of perioperative death seen with aortic stenosis [47,48], where diastolic dysfunction is often present, suggests a considerable impact. In cardiac ultrasonography, the presence of left ventricular hypertrophy in combination with left atrial enlargement is highly predictive of diastolic dysfunction [49,50]. Advanced methods for quantitative assessment of diastolic function have been developed and include pulsed wave and tissue Doppler imaging. However, the intraoperative validity of these indices has been disputed [51].

Heart valve disease

Unexpected valve disease has major influence on patient outcome [47,48], but is easily missed during clinical examination [52].

In aortic stenosis, the aortic leaflets appear thickened, hyperechoic because of calcification and restricted in motion. The aortic valve can be visualized in parasternal long-axis/short-axis, apical five-chamber and apical long-axis views. Quantitatively, significant aortic stenosis is defined as a maximum flow velocity across the valve of at least 3 m/s using continuous wave Doppler (Fig. 3) [53,54*]. We emphasize that flow velocity across the valve is proportional to stroke volume; in patients with tachycardia or low cardiac output, severity of aortic valve stenosis may be underestimated [28*].

The presence or absence of mitral valve insufficiency may be assessed with color Doppler. Whereas insufficiency jets are easily visualized, actual quantification of mitral regurgitation is complex and often precluded by jet eccentricity. Mitral valve stenosis may be seen as thickened, hyperechoic leaflets and restricted leaflet motion. Severity can be assessed quantitatively by using continuous wave Doppler to measure the diastolic transmitral pressure drop [53,28*].

Pericardial effusion

Pericardial effusion is easy to visualize (Fig. 4) [55]. Depending on the size and pace of accumulation, it may compromise circulation and in severe cases cause cardiac tamponade. An effusion with an echocardiographic systolic or diastolic free-space of less than 10 mm is considered insignificant [56]. However, the presence of tamponade is a clinical diagnosis, as chamber compression by the pericardial effusion may not be visible in available scan planes [57].

Pleural effusion

Case reports of large pleural effusions causing tamponade-like pathophysiology have been published.
[29,58–60] supported by recent studies [61,62]. Note that the positioning of the patient is relevant and pleural effusion is easier to locate when the patient is placed in the anti-Trendelenburg position (Fig. 5).

FIGURE 3. Maximum flow velocity across the aortic valve using continuous wave Doppler. Note a velocity more than 3 m/s and hence a significant valve stenosis. Further quantification showed a pressure gradient of 108 mmHg. White +, maximum transaortic velocity (AV Vmax) of 5.20 m/s.

CLINICAL STUDIES AND RESEARCH PERSPECTIVES
During the last decade, only a few studies concerning the perioperative use of focused TTE in anesthesiology have been published. These studies are
heterogeneous in study design and patient characteristics. The most interesting recent findings are highlighted below.

In recent years, perioperative case reports have indicated a requirement for additional preanesthetic evaluation and monitoring [9,15,18,63]. Perioperative studies addressing the clinical impact of focused TTE demonstrate alterations in perioperative management and a predictive capability of perioperative adverse cardiac events [5,10–12,17,24]. Alterations in anesthetic management constitute preoperative optimization (e.g. pleural drainage), supportive preoperative and intraoperative hemodynamic optimization such as volume infusion and use of vasoactive/cardioactive drugs, step-up or step-down in level of monitoring, change in anesthetic technique, change in surgical procedure, postponement of surgery, change in postoperative care or even cancelation.

Recently, Kratz et al. [14**] found focused TTE to be applicable in 91% of intraoperative cases. They discovered cardiopulmonary abnormalities in 95% of unstable patients and in 30% of stable patients [64].

In a prospective study by Botker et al. [8**] on patients undergoing urgent surgical procedures, the FATE – protocol proved feasible. Unexpected disease was revealed in 27% of cases, leading to changes in anesthesia techniques or supportive actions in 43% of cases. Unexpected disease was only encountered in a patient subpopulation above 60 years and/or American Society of Anesthesiologists score of at least 2. It was suggested that focused TTE has a clinical impact in elderly people with physical limitations.

Cowie [24] retrospectively reviewed a group of 222 patients preoperatively evaluated with focused TTE to assess the predictive value of cardiac disease. Adverse events occurred in patients with pulmonary hypertension, ventricular dysfunction and stenotic valve disease. In contrast, no patients with a normal preoperative cardiac ultrasonography experienced adverse events.

Canty et al. [10] studied elective patients preoperatively and emergency noncardiac surgery patients and showed a step-up in treatment in 20 and 36% of patients, respectively, and equally interesting a step-down in 34 and 8%, respectively. The step-down consequences included no cardiology referral, no invasive monitoring and no cancelation of surgery [11].

Randomized-controlled trials with mortality or morbidity end-points of focused TTE protocols in the perioperative setting are still lacking and should be a focus of attention in the future.

**EDUCATION**

Within acute care specialties – emergency medicine and critical care medicine, various academic societies have published guidelines on education [26**,28**,65,66]. World Interactive Network Focused On Critical Ultrasound (WINFOCUS) recently published international recommendations including education, certification and accreditation of training programs. These are endorsed by various academic societies [26**].

Still, no recommendations focusing solely on perioperative TTE, performed by noncardiac anesthetists, have been published.

We believe that a pyramid structure could be feasible in anesthetic practice and training. A pyramid consisting of a broad-based bottom representing the majority of physicians, performing at a basic level, and on top an expert minority. In between these two levels, physicians would gradually acquire knowledge and skills. A pyramid structure would lead to efficient use of staff resources. Expertise could be assigned according to case complexity and the minority with a higher skill-level could supervise and teach the less skilled majority of staff.

Studies addressing training and achievement of technical skills in focused TTE indicate [20,28**,67–69] that only limited intervention is needed to obtain basic adequate images suitable for interpretation. Cardiac ultrasonography simulation and supervised scans of patients seem to be efficient learning methods [26**,70].

Background knowledge and disease recognition can be taught using interactive e-learning before or after focused practical hands-on training [71]. This is supported by the WINFOCUS organization [26**] endorsing a mixture of e-learning and formal face-to-face didactics to acquire background knowledge.
and training in image acquisition and interpretation through supervised examinations.

To ensure sufficiently trained staff in the future, education should start at an early level. In some countries, anesthesiology trainees receive formal basic-level training, and studies suggest that a focused perioperative bedside ultrasonography curriculum is feasible [72,73,74*]. Furthermore, studies regarding teaching of ultrasonography at the pregraduate level have been published [75–77].

CONCLUSION

Focused perioperative TTE is feasible preoperatively, intraoperatively and postoperatively. Focused protocols should be incorporated in the daily clinical patient evaluation and documented according to existing terminology. Focused TTE reveals real-time hemodynamics and physiological determinants, it holds immediate diagnostic capability, a possible predictive capability has been suggested and it facilitates clinical perioperative decision-making.

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Conflicts of interest

E.S. has given lectures for Sonosite, GE, and BK-medical and is co-owner of usabcd ltd. offering e-learning and hands-on courses in ultrasonography.

REFERENCES AND RECOMMENDED READING

Papers of particular interest, published within the annual period of review, have been highlighted as:

** of special interest
* of outstanding interest

29. A publication from European Association of Cardiovascular Imaging (EACVI) encouraging noncardiologists to use problem-oriented focused cardiac ultrasound.
31. Recent recommendations, by the society for Critical Care Anesthesiologists, regarding learning goals and competencies of focused ultrasound for specialists in training.
34. Familiarizes the readers with the minimum requirements of a comprehensive TTE.
36. Outlines the indications for TTE.
42. A recent study addressing MAPSE as a marker of systolic function.

43. Imaging cardiac chamber quantification.


55. Latest AHA/ACC guideline providing further background knowledge regarding valvular heart disease.


