POCUS series: Focused transoesophageal echocardiography, a view from the inside

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Abstract
In the last decade, ultrasound has found its place in the intensive care unit (ICU). Initially, ultrasound was used primarily to increase the safety and efficacy of line insertion, but now many intensivists use point-of-care ultrasound (POCUS) to aid in diagnosis, assess therapy and support therapeutic interventions. In this series, we aim to highlight one specific POCUS technique at a time, which we believe will prove to be useful in your clinical practice. Focused cardiac ultrasound (FoCUS) is an important tool for the intensivist and can help in, among other things, diagnosing undifferentiated shock, evaluating the response to therapy and guiding procedures. FoCUS has, until recently, been performed with transthoracic echocardiography (TTE). FoCUS-TTE is, however, not always possible and not without problems. In this issue, we aim to describe the merits and pitfalls of focused transoesophageal echocardiography (FoCUS-TEE) in the ICU.

Introduction
This article is part of the POCUS series in the Netherlands Journal of Critical Care, in which we want to highlight POCUS techniques that will improve decision-making in daily clinical practice in the intensive care unit (ICU). We aim to provide intensivists with an overview of easy, quick, and reliable methods which may be useful in their practice. In this issue, we will focus on the application of focused transoesophageal echocardiography (FoCUS-TEE). Focused cardiac ultrasound (FoCUS) has become an indispensable tool not only for intensivists, but also for emergency physicians, anaesthetists and even cardiologists.1-3 One might even argue that FoCUS is currently a ‘mandatory’ tool for the frontline intensivist: delaying its use could result in a malpractice claim.4-5 FoCUS can aid the intensivist in diagnosing the cause of shock states, to haemodynamically evaluate the patient, to assess the response to therapy and to guide procedures (e.g., pericardio-centesis, ECMO cannulation).

Until recently, FoCUS was mainly performed via the transthoracic route (FoCUS-TTE). Although FoCUS-TTE is a non-invasive imaging technique, it is highly operator dependent and takes time to master.6 Furthermore, its use is frequently tempered by limited view quality caused by, for example, obesity, hyperinflation (emphysema, high positive end-expiratory pressure), presence of chest drains and dressings, and an inability to position the patient properly. Even in experienced echocardiography hands, TTE can be challenging. Vignon et al. evaluated several echocardiographic indices of fluid responsiveness in 540 mechanically ventilated patients: changes in the inferior vena cava (IVC) – assessed by TTE – could only be measured in 78.1% of cases. In contrast, changes in the superior vena cava (SVC), assessed by TEE, were measurable in 99.6%.7 Hence, the interest in critical care TEE has increased in recent years and has become part of both basic and advanced critical care echocardiography.8,9 In recent critical care studies, the percentage of TEE examinations performed because of insufficient TTE image quality ranged between 50 and 70%.10,11 TEE findings led to a change in management in an average of 60% of cases (range between 38 and 80%).10-12 Superior image quality and prediction of fluid responsiveness are only two of ten reasons why TEE should be performed in critically ill patients, according to Vignon et al.13 A full cardiological TEE examination consists of acquiring 28 standard views;14 however, this is seldom necessary in a critical care setting. Critical care and perioperative echocardiography only require the mastery of 15 and 11 views, respectively.8,15 Focused ‘goal-directed’ or resuscitative TEE requires the mastery of even fewer views: three- to six-view protocols have
been proposed.\cite{12,16,17} We prefer a four-view evaluation which is very similar to the four-view FoCUS-TTE approach. This makes it possible, with little additional effort, to incorporate TEE in a focused TTE/TEE assessment of the critically ill. This article aims to give an introduction to FoCUS-TEE; we will briefly focus on safety, indications and contraindications. Technique, probe manipulation, and image acquisition will be discussed in more detail. Lastly, we will give some advice about training.

**Indications, contraindications and safety of FoCUS-TEE**

The main indications for FoCUS-TEE are poor image quality with TTE, undifferentiated shock and cardiac arrest (table 1). Importantly, as also applies to TTE, FoCUS-TEE has limited scope (finding gross pathology) and is only designed to answer binary questions:\cite{18}

1. Is the left and right ventricular (LV, RV) systolic function normal (qualitative assessment - ‘eyeballing’)?
2. Is the left or right ventricle dilated (qualitative)?
3. Are there signs of RV strain (dilated right ventricle, septal shift, dilated SVC)?
4. Is pericardial effusion present?
5. Are there signs of fluid responsiveness (respiratory variations in SVC)?

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<td>Poor image quality with TTE: e.g., obesity, chest drains and dressings, high positive end-expiratory pressure, hyperinflation</td>
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**Contraindications, absolute and relative, are described in table 2.** In a patient with a history of gastrointestinal disease or bleeding, an oesophagogastroduodenoscopy before TEE could impact risk stratification for TEE and patient management, but the strict indication for oesophagogastroduodenoscopy is still controversial.\cite{21,22} Another controversial issue is whether or not to stop anticoagulation before a TEE examination; in our practice we do not usually stop heparin, but maintain thrombocytes at >50 x 10⁹/l.\cite{21}

TEE is a minimally invasive imaging technique with a good safety profile. We would gladly refer to the article by Hilberath et al. for a detailed description of complications encountered during TEE examinations.\cite{23} In the largest safety analysis of perioperative TEE to date, major complications were found in only 0.08% (17 of 22,324 examinations): soft palate laceration, perioperative TEE to date, major complications were found in only 0.08% (17 of 22,324 examinations): soft palate laceration, and cardiologists. In critical care patients, only small case series have been reported. A complication rate of 2.6% was found in a cumulative analysis of 2508 patients, without any related mortality.\cite{26} In more recent studies, with 611 patients in total, there were eight complications (1.3%), none of them fatal.\cite{10-12}

TEE during cardiac arrest, or resuscitative TEE, have gained a lot of interest in recent years.\cite{16,17,19} TEE-guided cardiopulmonary resuscitation (CPR) provides better image quality, uninterrupted CPR, and above all leads to shorter compression pauses as compared with TTE.\cite{28}
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Technique

**TEE probe**

A TEE probe looks very similar to an endoscope and can be manipulated equivalently - the first TEE probes were modified endoscopes. Early TEE probes were monoplane probes (only transverse images); biplane (transverse and longitudinal images) and multiplane (continuous of transverse and longitudinal images) probes were introduced later. Modern TEE probes specially designed for echocardiographic purposes have a motor-controlled phased-array transducer at the tip of the probe. Multiplane TEE probes, now the standard in adult echocardiography, allow an uninterrupted 180° view of normal and abnormal cardiac structures. Remarkably, a miniaturised disposable monoplane TEE probe (ClariTEE, ImaCor, NY, USA) has recently been introduced. This TEE probe has received clearance to stay in situ for up to 72 hours and is designed for continuous focused haemodynamic monitoring.

A TEE probe consists of several components: the transducer connector, the handle with the control housing, a flexible shaft with an articulation section at the end of the probe and the tip with the transducer lens containing a phased-array of piezoelectric crystals (figure 1a). The two wheels to control flexion of the tip (anteroposterior and lateral flexion), the buttons to adjust multiplane angle rotation and the anterior/posterior flexion lock are located at the handle of the TEE probe (figure 1b). Furthermore, the TEE probe has a built-in temperature sensor: to protect the oesophagus from thermal injury the probe is automatically turned off when the temperature exceeds 42 °C.

**Patient preparation and probe insertion**

FoCUS and critical care TEE can be performed in both intubated and non-intubated patients. We think that the novice sonographer should start with intubated and mechanically ventilated patients. To mitigate the risk of injury to the oesophagus and stomach, proper preparation of both patient and probe, careful probe manipulation and gentle movements are necessary.

Before the start of the procedure, the patient should be deeply sedated; muscle paralysis is preferable when assessing fluid responsiveness but could also be of help when insertion of the probe is difficult. During the entire TEE examination blood pressure, oxygen saturation and ECG are monitored. The patient should be in a supine position with the head at 30°. Performing TEE in the prone position is feasible, but in our opinion should only be attempted by more experienced sonographers.

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**Figure 1a.** Transoesophageal transducer, overview

**Figure 1b.** Transoesophageal transducer, focus on handle
The stomach should be emptied before probe insertion to allow better visualisation of cardiac structures. Removing the nasogastric tube, if present, is seldom necessary. It usually does not interfere with probe introduction and the quality of the images but can be of help when the introduction is difficult. The probe should be well lubricated before insertion and the controller in the off position to eliminate any fixed flexion of the probe.

The probe can be inserted from the head or side of the bed, depending on the clinical setting, available space and operator preference.[33] The use of a bite block is recommended: it holds the probe in the midline and protects it from damage if neuromuscular blockade is omitted. A ‘blind’ or guided (e.g., direct or video laryngoscopy) technique can be used to introduce the probe. The ‘default’ choice for most operators is a ‘blind’ technique. However, video laryngoscopy allows faster introduction, with fewer complications, according to a recent meta-analysis.[34] The probe is introduced gently via the mouth, with a slight anteflexion of the probe and the transducer lens facing anteriorly. If the introduction is difficult, a jaw trust manoeuvre can be performed. Neck flexion ‘reverse Sellick’s manoeuvre’ (forward lifting of the cricoid) or lateral neck pressure (compressing the piriform sinus and medially displacing the arytenoid cartilage, directs the probe medially into the oesophagus) can also be of help.[35] If these manoeuvres are unsuccessful, direct or video laryngoscopy can be used to aid introduction of the probe.

**Transducer manipulation**

There are four ways to manipulate the TEE probe and hence the obtained image (figure 2, video 1). We describe these movements in accordance with the 2013 American Society of Echocardiography guideline and recent critical care TEE articles.[9, 14, 33]

1. **Advance and withdraw.** By advancing, we mean pushing the probe distally into the oesophagus/stomach. Pulling the probe into the opposite direction more proximally is called withdrawing.

2. **Turning to the right or left.** The probe can be manually turned to the right or left (this is the right or left side of the patient). A clockwise rotation of the anterior part of the probe turns the probe to the right side of the patient. A counterclockwise movement will turn the probe to the left.

3. **Flexion.** The big wheel will anteflex or retroflex the probe: a clockwise rotation anteflexes and a counterclockwise rotation retroflexes the probe. Lateral flexion is achieved by turning the small wheel: clockwise turning flexes the probe to the left and counterclockwise flexes the probe to the right (Note: lateral flexion and therefore use of the small wheel is seldom necessary).

4. **Rotation.** Using the multiplane rotation buttons, the imaging plane of the transducer can be electronically rotated, with one-degree steps, between 0 °C and 180 °C.
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**Image acquisition**

It is important to realise that, by convention, the image display on the monitor is different than if TTE had been used. Images are displayed with the transducer location at the top of the images, with the near-field close to the transducer and the far-field at the bottom. There is a left-to-right orientation in the transverse (horizontal) plane. This means that with a transducer angle of 0° (imaging plane directed anteriorly), the patient’s left side appears at the right of the image display. In the longitudinal (vertical) plane, transducer angle between 0° and 90°, there is a superior-to-right orientation. This means that structures closer to the head (superior) are displayed towards the right of the screen.

Another important aspect is that near-field structures, such as the left atrium, mitral valve, and LA appendix, are much better visualised than far-field structures (e.g., apical LV segments). TTE or the use of contrast agents can be of help in visualising these far-field structures.

FoCUS-TEE consists of acquiring four core views: midoesophageal four-chamber, mid-oesophageal long-axis, transgastric short-axis and the bicaval view.

1. **Mid-oesophageal** four-chamber view (figures 3a and 4a). This view is often referred to as the ‘home base’: you can always come back to this view when you get disorientated. To obtain this view, gently advance the probe into the midoesophagus (approximately at a depth of 30-35 cm from the teeth) until the mitral valve is seen. In this view, as with the TTE four-chamber view, both ventricles and atria can be seen.

2. **Mid-oesophageal long-axis view** (figures 3b and 4b). From the four-chamber view, the multiplane is rotated to 120-140°, with the probe facing anteriorly. Slight adjustments may be necessary to obtain an optimal view. In this view, the aortic valve and root, left ventricle, mitral valve, left atrium and LV outflow tract can be seen. This view resembles the TTE parasternal long-axis view.

3. **Trans-gastric midpapillary short-axis view** (figures 3c and 4c). The probe is advanced into the stomach at about 40-45 cm from the teeth and anteflexed to maintain contact with the gastric wall to improve image quality. The multiplane angle is between 0°-10°.

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**Figure 3.** The different FoCUS-TEE views (in patients): a) Mid-oesophageal 4CH view; b) Mid-oesophageal long-axis (120-140°) view; c) Trans-gastric short-axis view; d) Bicaval view. LA = left atrium; LV = left ventricle; RA = right atrium; RV = right ventricle; Ao = Aorta; IVS = intraventricular septum; IVC = inferior vena cava; SVC = superior vena cava.
4. Mid-oesophageal bicaval view (figures 3d and 4d). In the mid-oesophagus, the multiplane is rotated to 90°, and the probe is turned to the right (clockwise) to obtain this view. In this view, the SVC – visualised to the right of the screen – IVC, both atria, and the intra-atrial septum are seen.

Focused – ‘goal-directed’ examination

There is not a standardised sequence for conducting a FoCUS-TEE examination and this is probably not strictly necessary. In most cases, the purpose/ focus of the examination ‘dictates’ the order in which the views are obtained. We agree with others, however, that novice sonographers will benefit from a protocolised sequence (video 2, step 1-4). This makes it possible to learn (remember) the different views faster and ensures that the exam is complete.

After insertion, the probe is first advanced into the mid-oesophagus to obtain the mid-oesophageal four-chamber view (video 2, step 1). In this view, the function and dimension of both ventricles can be assessed, the pericardial space inspected, and the movement of the tricuspid and mitral valve evaluated. Secondly, the image is centred on the left ventricle and the multiplane angle is rotated to 120-140°, to visualise the mid-oesophageal long-axis view (video 2, step 2). Thirdly, the probe is further advanced into the stomach and anteflexed (multiplane of 0°) to get the trans-gastric midpapillary short-axis view (video 2, step 3). This view is ideal to assess LV volume and function, septal kinetics, and wall motion abnormalities. Finally, the probe is withdrawn (pulled) into the mid-oesophagus, and after the mid-oesophageal four-chamber view is found, the image is centred over the right atrium. The multiplane is then rotated to 90°, and the probe turned to the right (clockwise rotated) to get the mid-oesophageal bicaval view (video 2, step 4). This view is ideal to assess fluid responsiveness (SVC-collapsibility index) and to guide procedures (e.g. temporary pacing wire implantation, ECMO cannulation).

The SVC-collapsibility index = (maximum diameter on expiration - minimum diameter on inspiration)/ maximum diameter on expiration, is measured in M-mode and expressed as a percentage. In the study by Vignon et al., conducted in 540 sedated and mechanically ventilated patients with low positive end-expiratory pressure, a cut-off of ≥21% (61% sensitivity, 84% specificity) discriminated within responders and non-responders (≥10% increase in velocity-time integral after passive leg raising). Remarkably, when focusing on 90% specificity in patients in whom unwanted fluid loading could be harmful (e.g., ARDS), a threshold of 31% was found, very close to the 36% (90% sensitivity, 100% specificity) found in an early study.

It is important to remember to bring the probe into a neutral position when withdrawing the probe.

Training

There are several ways to learn FoCUS-TEE. Reading articles such as this one and following e-learning will only provide you with a theoretical background. However, mastering TEE also requires the development of hand-eye coordination and spatial orientation. The use of virtual (e.g., Virtual TEE, see http://pie.med.utoronto.ca/tee/) and mannequin-based simulators (e.g., CEA VMedix or Heartworks) is much encouraged since these are proven time and resource-saving methods to improve TEE learning. A combination of lectures (or online preparation), simulation training with a high-fidelity simulator, and ten supervised TEE examinations has proven to result in satisfactory basic mastery of FoCUS-TEE. Because the purchase of a simulator can be very expensive, web-based training could be an option. Attending a simulator-based TEE course such as the Resuscitative Workshop (see https://www.resuscitativetee.com) or an equivalent course is another, probably better choice. How much time does it take to become proficient in FoCUS-TEE? According to the American College of Emergency Physicians, a minimum of two to four hours of training and ten supervised examinations would suffice. Arntfield and colleagues were one of the first groups to investigate the efficacy of a four-hour training in focused TEE. Fourteen emergency doctors, trained in POCUS, received a two-hour lecture and a two-hour hands-on simulation training with a high-fidelity simulator. After six weeks, these physicians were able to successfully acquire the four basic views (95.8% success rate). In a subsequent paper, they demonstrated that these physicians were able to incorporate their training into daily practice: probe insertion was successful in all 54 performed examinations. In 78% of cases, findings influenced diagnostics, and in 67% of cases, it impacted therapeutic decisions. These findings have been reproduced in different settings. ICU trainees, emergency department residents and anaesthesiology residents can, with little to no previous knowledge of TTE, successfully perform a FoCUS-TEE examination after 2-16 hours of didactic and simulation training. Taken together, learning FoCUS-TEE is not a major undertaking and is easily obtainable by all intensivists.

Limitations

One of the major limitations to performing TEE is having access to a TEE probe. A modern TEE probe costs approximately €30,000, but with proper care, it can be used thousands of times. One option is to start with a refurbished probe or to use the ImaCor ClariTEE. In the end, however, it will be probably more cost-effective to purchase a new TEE probe. Another limitation is that, despite TEE having a good safety profile, the use of TEE is not without risks. With proper training, good preparation...
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Figure 4a. Mid-oesophageal four-chamber view (© CAE Vimedix high-fidelity simulator). Left: 3D animated anatomy; Right: Matched simulated ultrasound image; LA = left atrium; LV = left ventricle; RA = right atrium; RV = right ventricle. (© CAE Healthcare)

Figure 4b. Mid-oesophageal long-axis view (120-140°) view (© CAE Vimedix high-fidelity simulator). Left: 3D animated anatomy; Right: Matched simulated ultrasound image. LA = left atrium; LV = left ventricle; MV = mitral valve; AV = aortic valve; RVOT = right ventricle outflow tract. (© CAE Healthcare)
Figure 4c. Trans-gastric midpapillary short-axis view (© CAE Vimedix high-fidelity simulator). Left: 3D animated anatomy; Right: Matched simulated ultrasound image. RV = right ventricle; IVS = intraventricular septum; LV = left ventricle. (© CAE Healthcare)

Figure 4d. Bicaval view (© CAE Vimedix high-fidelity simulator). Left: 3D animated anatomy; Right: Matched simulated ultrasound image. IVC = inferior vena cava; RA = right atrium; SVC = superior vena cava. (© CAE Healthcare)
(patient and probe) and gentle handling of the probe, these risks are minimal. We think that the novice sonographer should use a direct or video laryngoscope or seek help from a more experienced colleague to introduce the TEE probe after a maximum of two unsuccessful attempts.

Conclusion

Competence in FoCUS-TEE is a useful addition to the POCUS repertoire of an intensivist. It is a minimally invasive technique, with a good safety profile, can be learned in a short time, and gives high-quality information independent of body type and other patient limitations. In the end, the intensivist can choose to look from the outside or can up the game and have a view from the inside.

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Disclosures

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References

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15. van IJzendoorn MA, van IJzendoorn (QRS Healthcare), for providing the CAE-Vimedix figures.

**Video 1.** Probe insertion and manipulation: insertion; advance & withdrawal; turning to the left and right; anteflexion & retroflexion; rotation of imaging plane.

https://njcc.nl/file/20-45-kraemer-video1mp4

**Video 2.** Focused – ‘goal-directed’ – examination: Step 1. Mid-oesophageal four-chamber (ME-4CH) view; Step 2. Mid-oesophageal long-axis (ME_LAX) view; Step 3. Trans-gastric midpapillary short-axis (TG-SAX) view; Step 4. Mid-oesophageal Bicaval (ME-Bicaval) view.

https://njcc.nl/file/20-45-kraemervideo2mp4