A novel acoustic window for trans-oesophageal echocardiography by using a saline-filled endotracheal balloon

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Background. The main structures anterior to the trachea are frequently poorly visualized by trans-oesophageal echocardiography (TEE) because of the tracheal air column. We studied a new acoustic window for TEE imaging of large vessels anterior to the trachea by using a saline-filled endotracheal balloon.

Methods. Cardiac surgery patients were studied. After ventilation was discontinued at the beginning of cardiopulmonary bypass, a saline-filled latex balloon was inserted into the trachea through the tracheal tube. The structures anterior to the trachea were imaged with and without the endotracheal balloon. TEE images of the proximal aortic arch and innominate artery were classified into three grades according to the quality of images: 1, vessel not visible; 2, part of vessel wall visible; 3, entire vessel wall visible. Grade 3 was categorized as good visualization while grades 1 and 2 were categorized as inadequate. TEE images with and without balloon were compared using the Mann–Whitney U-test and Chi-square analysis. \( P < 0.05 \) was considered statistically significant.

Results. In 20 patients, 84% had good visualization of proximal aortic arch with presence of endotracheal balloon compared with 11% without (\( P < 0.001 \)). A total of 94% had good visualization of the proximal innominate artery with presence of endotracheal balloon compared with 0% without (\( P < 0.001 \)).

Conclusions. A new ‘TEE trans-tracheal acoustic window’ was established by usage of a saline-filled endotracheal balloon. This window partially eliminates the TEE blind zone and provides improved visualization of the proximal aortic arch and innominate artery.

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Trans-oesophageal echocardiography (TEE) is frequently used in cardiac surgery for evaluating structures of cardiac chambers, valves and great vessels. Intraoperative TEE imaging of the aortic arch and its branches may provide important information on conditions such as aortic dissection, aneurysm or vascular injury. Detecting position of atherosclerotic plaques,¹–³ entry and exit sites of aortic dissection,⁴ and traumatic injury to aorta¹⁵–⁷ may have prognostic and therapeutic significance. But because of the interposition of trachea between the oesophagus and the great vessels, TEE visualization of proximal aortic arch and innominate artery is usually fraught with difficulty.¹⁸⁻⁹ A novel approach utilizing a saline-filled endotracheal balloon was developed to improve visualization of these structures in the ‘blind zone’. The purpose of the present study was to evaluate whether application of the saline-filled endotracheal balloon would lead to improved TEE visualization of the proximal aortic arch and innominate artery during cardiopulmonary bypass (CPB).

Patients and methods

Patients

After approval from the institutional research ethics committee, written informed consent was obtained from each participating patient. Patients on warfarin therapy,
with weight of less than 40 kg, a history of recent surgery on oesophagus or stomach, gastro-oesophageal abnormalities, such as diverticuli, ulcers and varices, were excluded from the study. For these patients undergoing cardiac surgery, after placement of radial artery catheter, pulse oximetry probe, electrocardiogram and non-invasive blood pressure cuff, anaesthesia was induced using i.v. midazolam (0.1–0.2 mg kg\(^{-1}\)), fentanyl (5–10 \(\mu\)g kg\(^{-1}\)), vecuronium (0.1 mg kg\(^{-1}\)) and propofol (0–1.0 mg kg\(^{-1}\)). Anaesthesia was maintained at the discretion of the attending anaesthesiologist. A tracheal tube was initially inserted into either left or right main stem bronchus as evident by unilateral air entry with auscultation. The tracheal tube was subsequently withdrawn until breath sounds were first heard bilaterally. At this point, the tip of the tracheal tube was considered to be located immediately proximal to the carina. The depth of tracheal tube as indicated by marking between the teeth was recorded. This recorded depth would be used for positioning of the tracheal tube after the initiation of CPB. The tracheal tube was withdrawn 3–4 cm from the carina and fixated using tapes.

**Endotracheal balloon**

The endotracheal balloon was made with the shaft of a #37 Univent\(^\text{®}\) (Fuji Systems Corporation, Tokyo, Japan) blocker and part of a latex surgical glove. First, the blocker cuff of a Univent\(^\text{®}\) blocker was removed using a pair of surgical scissors. The glove segment over the middle digit of a size 8 latex glove was cut to a total length of 8 cm. The glove segment was attached to the distal part of the Univent\(^\text{®}\) shaft using a #4 silk suture. The balloon was made to have a diameter of approximately 1.8 cm and a length of 6 cm while fully inflated with saline (Fig. 1). The balloon without saline could be passed through a 7.0 ID tracheal tube easily. A manometer was connected to the balloon shaft so that when the balloon was being filled, the pressure in the balloon could be monitored. The balloon was pressure tested in vitro using saline up to 30 mm Hg to ensure that there was no leakage.

Before tracheal intubation, the endotracheal balloon was passed through the tracheal tube until the balloon tip was located exactly at the tracheal tube tip. A mark was made on the balloon shaft for identification. After initiation of CPB, the tracheal tube was withdrawn so that its tip was located 6 cm above the carina as described previously. The balloon was inserted 6 cm beyond the above noted marking on the balloon shaft. At this point, the distal end of the balloon was considered to be located immediately above the carina.

**Trans-oesophageal echocardiography**

TEE was performed in the operating room after anaesthesia induction by the study anaesthesiologist with a 4–7 MHz phased array probe (Hewlett-Packard, Model 21396A, Andover, MA) and an ultrasound system (Hewlett-Packard Sonos 4500, Andover, MA). The cardiac structures, ascending aorta and thoracic aorta were routinely examined before CPB. After median sternotomy, systemic heparinization was administered. Venous and aortic cannulation was performed. When the ventilator was disconnected at the beginning of CPB, the tracheal tube was withdrawn and the balloon was inserted so that its distal end was positioned at the carina as described previously. The process of filling the balloon was monitored by TEE and saline was injected until the outline of the trachea was seen or the balloon pressure reached 30 mm Hg.

The transverse view of the trachea with the saline-filled balloon was detected as a round echo-free space that located at the tip of the fan shaped view. When the probe was placed at a depth of about 18–25 cm from the incisors, the sausage shaped aortic arch with its proximal part anterior to the trachea was viewed at a multiplane angle of \(0^\circ\). Using the longitudinal view of the aortic arch, the TEE probe was adjusted until the image with the maximal major diameter was obtained and recorded. To image the innominate artery, using the upper oesophageal aortic arch long axis, the probe was withdrawn gradually while visualization of the endotracheal balloon was maintained. As the aortic arch disappeared from the view, the transverse view of the innominate artery was seen anterior to the trachea at multiplane angle of about \(40^\circ\) (20–65\(^\circ\)). TEE probe was adjusted until the transverse innominate artery image, which was most circular in form, at 2 cm above the aortic arch was obtained and recorded. This plane was named upper oesophageal innominate short axis. The upper oesophageal innominate long axis was detected at multiplane angle of approximately 130\(^\circ\) (110–160\(^\circ\)). In this view, the innominate artery was seen to be arising from and connected directly to the proximal aortic arch.

After obtaining TEE images with the presence of the endotracheal balloon, the balloon was drained and

**Fig 1** A saline-filled endotracheal latex balloon (LB) made with a segment over the middle digit of a size 8 glove connected to a Univent\(^\text{®}\) shaft (US).
removed. Images of the aortic arch and innominate artery 2 cm above it were imaged again without the balloon under the same echo settings as described before.

Statistical analysis

The quality of echo images was graded by a three point scale formulated by consensus of two anaesthesiologists and one echocardiographer. The grading of images was as follows: 1, vessel wall not visible; 2, part of vessel wall anterior to the balloon visible; 3, entire vessel wall anterior to the balloon visible and the length of innominate artery detected was >4 cm. Grade 3 was categorized as good visualization while Grades 1 and 2 were categorized as inadequate.

All TEE images of aortic arch and innominate artery, with and without balloon were recorded and printed on hard copies for subsequent analysis. A white patch was used to conceal the presence of saline-filled endotracheal balloon in these images. For each patient, three sets of images (aortic arch: longitudinal view; innominate artery: transverse and longitudinal views) with and without balloon were analysed and scored by two senior independent echocardiographers blinded to the presence of the balloon. The image grading with and without balloon were compared by paired Mann–Whitney U-test. Images categorized as good or inadequate, with and without the balloon, were compared using Pearson χ²-test. P<0.05 was considered statistically significant.

Results

From January to March 2005, a total of 20 adult patients who underwent open heart surgeries were recruited. There were 11 men and 9 women with a mean (sd) age of 47.5 (10.7) yr. Patients’ mean (sd) weight was 57.1 (8.7) kg and their mean (sd) height was 164.5 (9.8) cm. Surgeries included 11 mitral and/or aortic valve replacement, 4 coronary artery bypass graft, 2 ventricle septal defect correction, 2 Bentall operations, and 1 left atrial myxomectomy.

The study was completed in all 20 patients. The insertion of saline-filled endotracheal balloon and TEE image acquisition required 6.20 (2.21) min. There was disagreement between the echocardiographers on the grading of images in five of 120 images. These five images were eliminated from comparative analyses. Visualization of the aortic arch was better with the balloon (median 3.0; range 2–3) as compared with without the balloon (median 2.0; range 2–3, P<0.001). More patients had good visualization (16/19, 84%) of the aortic arch with the balloon as compared with without the balloon (2/19, 11%, P<0.001). Representative TEE images of the aortic arch with and without endotracheal balloon are shown in Figure 2. Visualization of innominate artery was better with the balloon (median 3; range 2–3) as compared with without the balloon (median 1; range 1–2, P<0.001). More patients had good visualization (34/36, 94%) of the innominate artery with the balloon as compared with without (0/36, 0%, P<0.001). Representative TEE images of upper oesophageal innominate short axis and upper oesophageal innominate long axis with and without endotracheal balloon are shown in Figures 3 and 4.

Discussion

The present study shows that visualization of the proximal aortic arch and innominate artery was successful in 84–94%
of the subjects using intraoperative TEE with a saline-filled tracheal balloon. This new acoustic window is named ‘TEE trans-tracheal acoustic window’.

The main reason of the ‘blind zone’ for TEE is the tracheal air column which lies right and ventral to the oesophagus. Echo-waves are scattered completely by air. In patients undergoing cardiovascular surgery involving CPB, ventilation is terminated and saline-filled tracheal balloon insertion is feasible. The insertion of a saline-filled tracheal balloon eliminates the tracheal air column, thereby enabling the TEE imaging of great vessels anterior to the trachea.

TEE can detect the anterior wall of the middle and distal part of the aortic arch (Fig. 3a) routinely. However, the proximal aortic arch and the proximal two-thirds of the posterior wall of the aortic arch are not clearly delineated as the tracheal outline and tracheal–aortic interface are not visualized. When the ‘TEE trans-tracheal acoustic window’ is used, interference by the tracheal air column is largely eliminated. Now, the whole proximal aortic arch and the entire posterior wall of the aortic arch can be seen clearly (Fig. 2b).

There are a number of imaging techniques utilized for diagnosing aortic injuries and pathologies besides TEE, including angiography, helical computed tomography, trans-thoracic echocardiography, intraoperative epiaortic ultrasound and intravascular ultrasonography. Although aortic angiography and helical computed tomography is considered the ‘gold standard’ for diagnosing aortic pathology, TEE has been shown to be a more sensitive method than angiography or computed tomography in diagnosis of traumatic aortic injury or dissection in recent years. However, atherosclerotic plaques, injury and aortic dissections located at the proximal part of the aortic arch are often missed or inaccessible by TEE. In order to improve visualization of these areas, preoperative trans-thoracic echocardiography or intraoperative epiaortic ultrasound has been utilized. Schwammenthal and colleagues studied aortic arch atheromas by both suprasternal harmonic imaging (harmonic imaging from suprasternal windows) and TEE. Although suprasternal harmonic imaging provided complementary views for TEE, adequate quality images for evaluating the aortic arch transcutaneously could not be obtained in 16% of the patients. Wilson and colleagues studied 22 consecutive patients undergoing open heart surgeries with both TEE and epiaortic ultrasound imaging to identify atherosclerotic lesions in the ascending aorta. The results suggested that epiaortic ultrasound was superior to TEE as it detected more atheromatous lesions, particularly in the middle and distal segments of the ascending aorta. Vignon and colleagues and Bergman and colleagues showed that epiaortic ultrasound has a sensitivity which was higher than or equal to that of computed tomography in diagnosing atherosclerosis of the ascending aorta. Patal and colleagues showed that intravascular ultrasonography was more sensitive and specific than TEE in blunt trauma patients with abnormal thoracic aortogram. Yamada and colleagues found that intravascular ultrasonography had higher sensitivity in detecting the intimal flap than angiography or computed tomography in patients with aortic dissection.

TEE offers a number of advantages over the other aortic imaging techniques mentioned above. First, acute dissection or trauma of the aorta requires prompt and reliable diagnosis to reduce mortality. Compared with aortic computed tomography or angiography, TEE can be performed by anaesthesiologists at the operating room without transportation to radiology sites, without contrast and in hemodynamically unstable patients. Second, epiaortic ultrasound can only be used for patients with a sternotomy and may interrupt the conduct of surgery. TEE can be performed simultaneously with the ongoing surgical procedure. Third, TEE provides multi-planar images of vessels and offers a relatively broader view of the aorta compared with intravascular ultrasonography. Fourth, TEE provides real time imaging of the aorta throughout the surgical procedure as compared with all the other techniques.

Conventionally, innominate artery pathologies such as atheroma and injury are only diagnosed by angiography or computed tomography. Visualization of innominate artery using TEE is often difficult or impossible because of the interposition of the tracheal air column. Krinsky and colleagues showed that in 10 innominate artery atheromas demonstrated by magnetic resonance angiography, none of them was visualized on TEE. Our study shows that ‘TEE trans-tracheal acoustic window’ provides adequate images of the innominate artery. Innominate artery imaging may be helpful in the operating room as the vessel may be involved by intraoperative processes such as
iatrogenic dissection, trauma or selective innominate artery cannulation. Orihashi and colleagues studied the ability of TEE in detecting the main branches of the aortic arch in patients undergoing aortic surgery. Proximal innominate artery was seen in 36% of patients. However, the image qualities were not graded. With ‘TEE trans-tracheal acoustic window’, the proximal innominate artery was well visualized in 94% of the patients. In fact, as the innominate artery is located almost directly anterior to the trachea, the trachea can be used as a guiding landmark to locate the innominate artery. TEE imaging of the innominate artery may be helpful in diagnosing its pathology.

The potential usage of this acoustic window are as follows: (i) to improve visualization of the aortic arch and innominate artery anterior to the trachea; (ii) to detect pathology of the proximal aortic arch and the innominate artery during CPB, such as dissection, trauma, embolism or atheroma; and (iii) to monitor blood flow in innominate artery when aortic cannula is inserted in the right subclavian artery or when selective brain perfusion through the innominate artery is performed.

There are several limitations in this study. First, the ‘TEE trans-tracheal acoustic window’ technique can only be performed when the ventilator is disconnected or during CPB. Unfortunately during the period just before aortic cannulation when visualization of aortic atheroma is most crucial, TEE trans-tracheal acoustic window could not be utilized as the patient is not yet on CPB and routine TEE has to be used. Second, the tracheal balloon is made by the investigator and is not commercially available. Finally, TEE image acquisition is operator dependent and requires experience. The TEE images in the present study were all acquired by a single experienced operator.

Conclusion
A new ‘TEE trans-tracheal acoustic window’ is established by usage of a saline-filled endotracheal balloon during CPB. This window partially eliminates the TEE blind zone and provides improved visualization of the proximal aortic arch and innominate artery. However, a major limitation to applying this technique currently is the requirement of CPB and apnoea.

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