Echo Tutorial

Intra-operative trans-esophageal echocardiography in congenital heart disease

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ABSTRACT

Intra-operative trans-esophageal echocardiography (TEE) is an important monitoring and diagnostic tool used during surgery for repair of congenital heart disease. In several studies,TEE has been shown to provide additional intra-cardiac anatomic information. Its ability to be used intra-operatively before and after cardiac repair makes it a unique tool. Before TEE was available for intra-operative use, significant residual abnormalities were frequently not detected. The result was often substantial post-operative morbidity and mortality and sometimes the need for re-operation. According to practice guidelines established by the Society of Cardiovascular Anesthesiologists and the American Society of Anesthesiologists, there is strong evidence for the usefulness of TEE in surgery for congenital heart disease because it significantly improves the clinical outcome of these patients. Before surgical correction, TEE helps confirm diagnosis and spot any additional lesion, while after the surgical correction, it provides baseline parameters for comparison after the surgical correction.

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Intra-operative trans-esophageal echocardiography (TEE) is an important monitoring and diagnostic tool used during surgery for repair of congenital heart disease. In several studies,[1,2] TEE has been shown to provide additional intra-cardiac anatomic information. Its ability to be used intra-operatively before and after cardiac repair makes it a unique tool. Before TEE was available for intra-operative use, significant residual abnormalities were frequently not detected. The result was often substantial post-operative morbidity and mortality and sometimes the need for re-operation. According to practice guidelines established by the Society of Cardiovascular Anesthesiologists and the American Society of Anesthesiologists, there is strong evidence for the usefulness of TEE in surgery for congenital heart disease because it significantly improves the clinical outcome of these patients.[3] Before surgical correction, TEE helps confirm diagnosis and spot any additional lesion, while after the surgical correction, it provides baseline parameters for comparison after the surgical correction.

TEE is performed either as a routine institutional protocol or when the patient has hemodynamic instability manifesting as hypotension, high filling pressures, and de-saturation. After surgical repair, a TEE is performed to see residual shunts, residual valve regurgitation, residual gradients across ventricular inflows and outflows, proper placement of a patch, ventricular function, and assessment of surgical repair. Various studies have shown the impact of TEE on patients undergoing surgery for congenital heart disease.[4-13] Gallivan, *et al*.[14] classified patients into three categories depending on surgical risk as an indication for performing intra-operative TEE:

1) Low risk; e.g., atrial septal defect (ASD), ventricular septal defect (VSD), valve replacement, and extracardiac procedures.
2) Moderate risk; e.g., atrioventricular (AV)

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canal, combined ASD and VSD or combined VSD and pulmonary stenosis, valve reconstruction, subaortic stenosis (SAS) resection.

3) High risk; e.g., reoperation and neo-natal surgery, Fontan procedure, Fallot's tetralogy, Ebstein anomaly.

GENERAL CONSIDERATIONS

After the routine anesthetic induction, all patients who have to undergo a TEE examination should be ruled out for any absolute contra-indication for TEE, such as esophageal obstruction or bleeding. A pediatric TEE probe should be inserted after ensuring an empty stomach by inserting a naso-gastric tube and aspirating the stomach contents. The naso-gastric tube is then removed and a well-lubricated pediatric TEE probe inserted. In our practice, we use a multi-plane pediatric probe (9.1 × 8.8 mm; 7 MHz) for patients weighing over 3.5 kg. For children weighing less than 3.5 kg, we try inserting the same probe for any complex defect or where surgical indication outweighs the risk.

A complete examination should be performed before surgical correction to confirm the diagnosis. Baseline images should be stored in the echocardiography machine for comparison after surgical correction. After surgical repair, TEE is done to see residual shunts, valve regurgitation, gradients across ventricular inflows and outflows, proper placement of the patch, and assessment of surgical repair. In this tutorial, the specific congenital lesions and key points to be assessed in those specific lesions after the surgical repair will be discussed.

Trans-esophageal echocardiography in specific congenital lesions

Atrial septal defect

(A) *Ostium secundum*: After surgical closure of ASD, TEE is performed to confirm that:

- ASD patch is intact and there is no residual shunt.
- Superior vena cava (SVC) and inferior vena cava (IVC) are draining into the right atrium (RA) because, very rarely, in patients with a deficient inferior rim, the IVC may get routed to the left atrium (LA).

(B) *Sinus venosus*:

(a) SVC type: In the SVC type of sinus venosus ASD, there is associated partial anomalous pulmonary venous connection (PAPVC) of the right upper pulmonary veins. In these cases, a TEE is performed to verify that:

- The ASD patch is intact and there is no turbulence to the SVC flow which should be confirmed by pressure measurements in the SVC and RA.
- Pulmonary veins are re-routed to the LA, which should be confirmed with a pulsed wave Doppler of the pulmonary venous flow showing characteristic S and D waves.

(b) IVC type: In the IVC type of sinus venosus ASD, there is associated PAPVC of the right lower pulmonary veins. A TEE is performed to assess the following:

- The ASD patch is intact [Figure 1a] and the IVC is draining into the RA.

Pulmonary veins are re-routed to the LA and confirmed with a pulsed wave Doppler [Figure 1b].

Double outlet right ventricle

In double outlet right ventricle (DORV) there is a VSD and an aortic override is more than 50%. So the aorta lies far away [Figure 2a] from the left ventricle (LV). In DORV after the closure of VSD, a TEE is performed to assess the following:

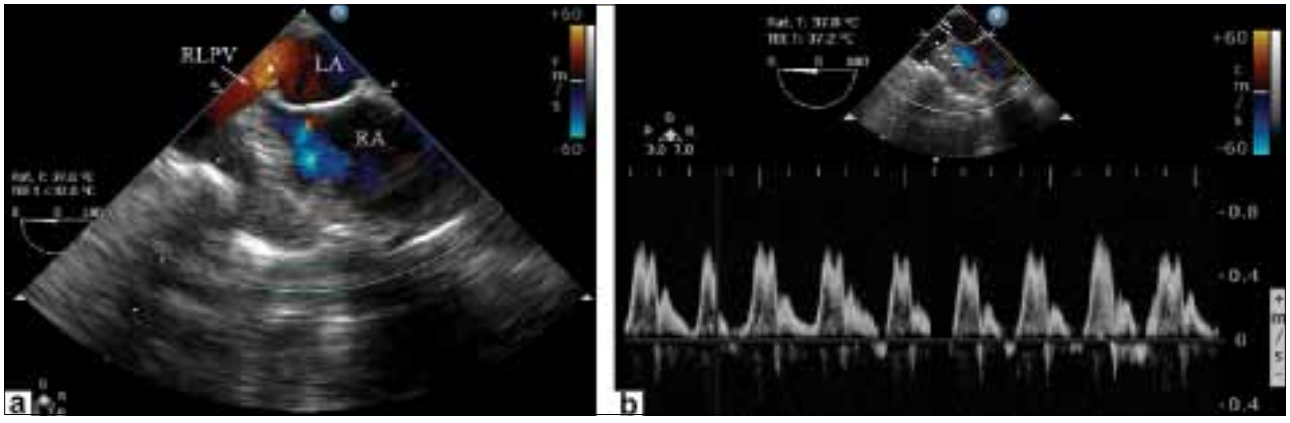

Figure 1: Mid-esophageal view in a patient operated for IVC type of sinus venosus ASD with PAPVC of RLPV showing (a) intact patch and re-routed RLPV (arrow) to LA (b) pulsed wave Doppler to confirm RLPV

- The VSD patch is intact and there is no residual shunt.
- There is no obstruction in the left ventricular outflow tract (LVOT) as the LVOT in patients with DORV is curved and if the patch is small it may project [Figure 2b] in the LVOT and cause significant obstruction which will need a second run bypass and enlargement of either the patch or enlarging the VSD and re-doing the VSD patch.
- There is no obstruction in the right ventricular outflow tract (RVOT).

Tetralogy of fallot

The various components to be assessed on TEE in Tetralogy of Fallot (TOF) patients are as follows:

- VSD: Look for intact VSD patch, no residual shunt, no LVOT obstruction
- The RVOT should be assessed in both midesophageal RV inflow-outflow view as well as trans-gastric views

In the midesophageal RV inflow-outflow view [Figure 3a] look for obstructive muscle bundles in the RVOT and compare with the pre-correction baseline values. Anatomic resection and relief of obstruction in the RVOT should be assessed.

The trans-gastric view [Figure 3b] shows both the anatomic view of the RVOT and we can also compare the gradients in the RVOT with the pre-correction values as this gives the correct gradients across the RVOT since the Doppler signal and blood flows are parallel to each other.

Atrio-ventricular canal defect

In an atrio-ventricular canal defect (AVCD) there is a primum ASD, VSD, and a common atrio-ventricular (AV) valve [Figure 4a] with a cleft in the AV valve causing left-sided valve regurgitation. The key points to be assessed, after the surgical repair, on TEE [Figure 4b] are as follows:

- ASD and VSD patches are intact with no residual shunting
- LVOT has to be assessed for any obstruction because the VSD patch may cause LVOT obstruction in the AVCD
- Leaflets of the mitral and tricuspid components of the common AV valve are moving normally because the VSD patch can sometimes hinder the movement of the leaflets
- There is no inflow gradient across the tricuspid and

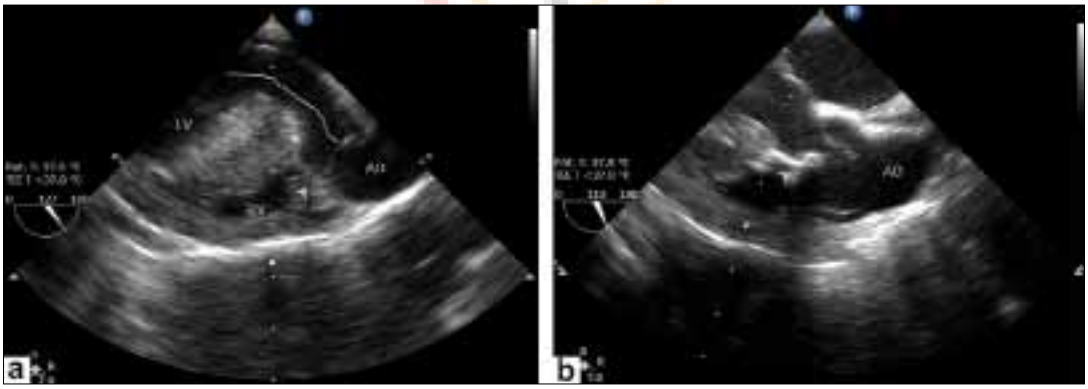

Figure 2: Mid-esophageal long axis view demonstrating (a) curved course of LVOT in DORV and (b) improper patch (arrow) projecting into LVOT

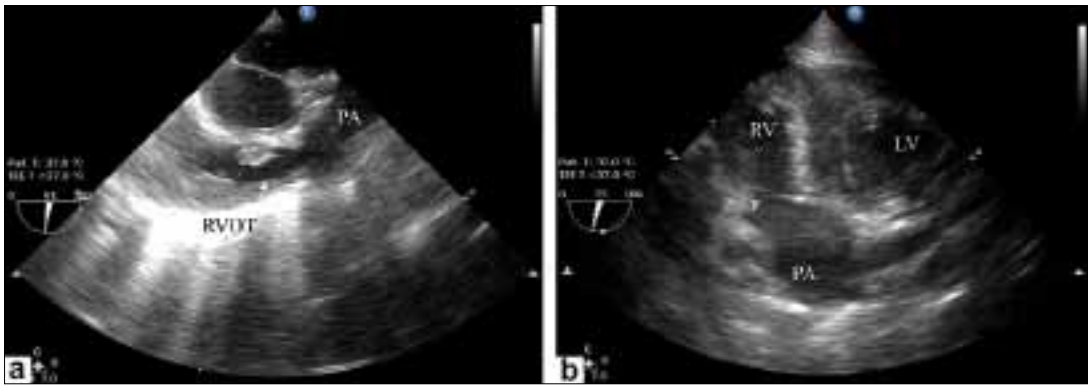

Figure 3: Post-operative TOF showing RVOT in (a) mid-esophageal RV inflow-outflow view and (b) deep trans-gastric view

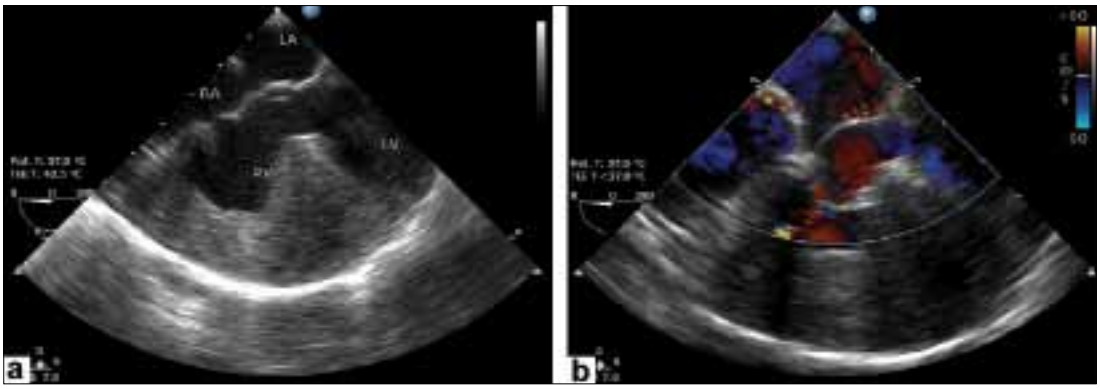

Figure 4: (a) Pre-operative mid-esophageal view of complete AVCD (b) Post-operative AVCD showing intact ASD and VSD patches with trivial MR

mitral valve because if the common AV valve is smaller then by dividing it into two components, one of the components may be smaller which will produce inflow turbulence. If this inflow gradient is high, especially on the mitral component, it is not acceptable.

- The cleft on the common AV valve is repaired and there is either no left-sided (mitral) valve regurgitation or mild regurgitation, which is acceptable. Moderate to severe valvular regurgitation is not acceptable and it requires a second run bypass. Similarly right-sided (tricuspid) valve regurgitation has to be assessed.

Ventricular septal defect with aortic regurgitation

Ventricular septal defect (VSD) with aortic regurgitation (AR) is yet another common condition where TEE plays an important role in surgical repair assessment. The AR is associated with VSD when the right coronary cusp (RCC) of the aortic valve prolapses [Figure 5] into the VSD causing different degrees of AR. Sometimes the VSD is small in size but the prolapse of the RCC is an indication of surgery so that aortic valve can be preserved alleviating the need for an aortic valve replacement and managing it with an aortic valve repair. After surgery for VSD closure with aortic valve repair, TEE helps in assessment of the following:

- VSD patch assessment, which should be intact, with no residual shunting
- AR should to be compared with pre-operative values and morphology and coaptatation of the RCC with other cusps has to be assessed

Right ventricle to pulmonary artery conduit

A valved conduit is placed between the right ventricle and pulmonary artery in cases of Rastelli procedure (for VSD with pulmonary atresia) and truncus repair. After surgical repair, the main point to assess the TEE is to see the gradient at the take-off point of the conduit from the right ventricle, which can be seen in the RV inflow-outflow view or the trans-gastric view [Figure 6]. In both these conditions, the VSD patch should also be assessed for any residual shunt.

Total anomalous pulmonary venous connection

In a supra-cardiac type of total anomalous pulmonary venous connection (TAPVC), all the four pulmonary veins form a common chamber which drains into the SVC via the vertical vein. During surgery, this common chamber is anastomosed to the left atrium. On TEE (midesophageall four-chamber view) this anastomosis has to be assessed for any gradient.

Senning procedure

The Senning procedure is performed on a patient with transposition of great arteries (TGA) where the aorta arises from the RV and the pulmonary artery arises from the LV. Senning is performed in patients not fit for an arterial switch operation (ASO) because either the LV has regressed or there is a coronary anomaly making it unsuitable for ASO. While the Senning procedure is performed, the SVC and IVC are routed through the mitral valve and pulmonary veins are routed through the tricuspid valve with the help of a baffle. This procedure is a physiological correction whereby SVC and IVC blood is directed towards the LV, which ejects de-oxygenated blood into the pulmonary arteries and the pulmonary veins are routed to the RV, which supplies oxygenated blood to the aorta. The various points to be assessed on the TEE after Senning procedure are as follows:

a) Assessment of the pulmonary venous pathway

The pulmonary venous pathway is to be assessed for any obstruction. The pulmonary venous atrium (PVA) should be checked for any turbulence, the most common site being where it curves anteriorly towards the tricuspid valve [arrow in Figure 7b]. A continuous wave Doppler should be used to quantify the gradient. Individual pulmonary veins should be assessed for turbulence, the most common pulmonary vein to show turbulence

Figure 5: Pre-operative mid-esophageal long axis view showing prolapsed RCC (arrow) in the VSD

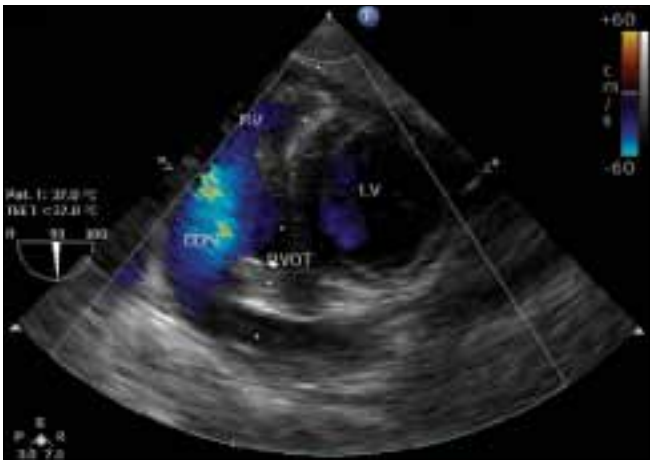

Figure 6: Deep trans-gastric view of post-operative Rastelli showing native blind ended RVOT and homograft conduit (CON) arising from RV

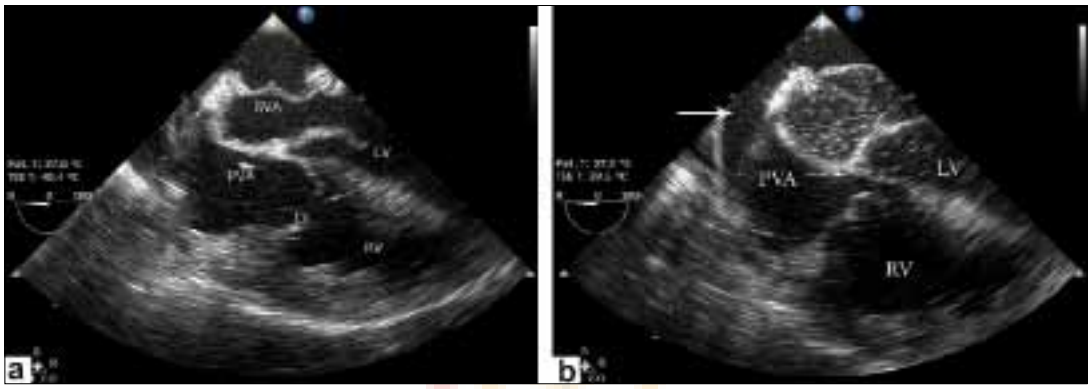

Figure 7: Mid-esophageal four chamber view of post-operative Senning showing (a) SVA and PVA (b) contrast in the SVA to check baffle leak

is the right upper pulmonary vein (RUPV). A pulsed wave Doppler should be used to quantify individual pulmonary veins especially RUPV. A gradient of more than 4-5 mmHg in the pulmonary venous pathway or individual pulmonary veins is not acceptable.

b) Assessment of systemic venous pathway

The systemic venous atrium (SVA) should be assessed for any obstruction, the common site being an obstruction in the SVC. A continuous wave Doppler should be used to quantify the gradient, which will show the gradient to be either continuous or phasic. The gradient in SVC is significant if it is more than six mmHg and it is continuous. A phasic gradient up to six mmHg is acceptable.

c) Assessment of baffle

The baffle used to make the systemic venous pathway should be assessed for any leak that may lead to de-saturation. The leak is checked by injecting a contrast through the cannula in the internal jugular vein and simultaneously examining the TEE and ensuring that it is not leaking into the pulmonary venous pathway. The baffle should also be examined for any redundant tissue that can project into the pulmonary venous pathway and it should not be too short that it causes high venous pressures.

Arterial switch operation

Arterial switch operation (ASO) is conducted in a patient with TGA where the aorta arises from the RV and the pulmonary artery arises from the LV. In ASO, the aorta and coronary buttons are transferred to the proximal pulmonary artery, which forms the neo-aorta and pulmonary artery and is anastomosed to the proximal aorta, which forms the neo-pulmonary artery. On TEE, the key point to be assessed is ventricular function, which determines the adequacy of coronary transfer. The ventricular outflows (trans-gastric view) should be assessed because these may show turbulence in the supra-valvular area because of a disparity in the size of the aorta and pulmonary artery. These outflow gradients, if present, should be quantified.

Sub-aortic membrane

In this condition, there is a circumferential membrane in the LVOT just before the aortic valve [arrow in Figure 8] causing a fixed sub-aortic obstruction. TEE

Figure 8: Mid-esophageal long axis view showing sub-aortic membrane (arrow)

is valuable to assess the severity of the obstruction. A TEE[15] helps to know the relation of this membrane to the aortic cusps as this membrane is adhered to the aortic cusps and may lead to varying degrees of aortic regurgitation (AR) as well. After surgery, TEE helps compare the gradient across LVOT, visualize the complete excision of the membrane by its absence and ensures that there is no significant AR.

Side effects and complications

In pediatric patients, TEE has certain adverse effects.[16,17] Compression of the airway leading to desaturation and hemo-dynamic instability are the most common side effects in younger patients. Complications of TEE are trauma during insertion, mild bleeding in the oropharynx in cyanotic patients, and extubation of the patient especially neonates. Perforation of the esophagus during insertion has also been reported.

Future

Firstly, three dimensional (3D) echocardiographies are gaining popularity in assessing the intra-cardiac anatomy. As 3D TEE has great impact in valve repairs in adult cardiac surgical patients, the introduction of a pediatric 3D TEE probe will help understand the complex intra-cardiac anatomy in a better way.

Secondly, the advent of micro multiplane TEE probes as small as 5 mm with good resolution will enable us perform TEEs in neonates weighing less than 2.5 kg.

To conclude, intra-operative TEE is a safe, reliable, and good diagnostic modality which provides a real-time assessment of surgical repair. It should be routinely used in all patients undergoing surgery for congenital heart disease.[18]

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