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REVIEW ARTICLE

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Transesophageal ultrasonography during orthotopic liver transplantation: Show me more

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The first perioperative transesophageal echocardiography (TEE) guidelines published 21 years ago were mainly addressed to cardiac anesthesiologists. TEE has since expanded its role outside this setting and currently represents an invaluable tool to assess chamber sizes, ventricular hypertrophy, and systolic, diastolic, and valvular function in patients undergoing orthotopic liver transplantation (OLT). Right-sided microemboli, right ventricular dysfunction, and patent foramen ovale (PFO) are the most common intra-operative findings described during OLT. However, left ventricular outflow tract obstruction and left ventricular ballooning syndrome are more difficult to recognize and less frequent. Transesophageal ultrasonography (TEU) during OLT is also underused. Its applications are as follows: (1) assistance in the difficult placement of pulmonary arterial catheters; (2) help with catheterization of great vessels for external veno-venous bypass placement; (3) intra-operative evaluation of surgical liver anastomosis patency, if feasible, through the liver window; and (4) intra-operative investigation of "acute hypoxemia" due to pulmonary and cardiac issues using trans-esophageal lung ultrasound (TELU). The aims of this review are as follows: (1) to summarize the uses of TEE and TEU throughout all phases of OLT, and (2) to describe other new feasible applications.

KEYWORDS
anesthesia, hypovolemia, intra-operative transesophageal echocardiography, right ventricular function, transesophageal echocardiography

1 | INTRODUCTION

Transesophageal ultrasonography (TEU), and in particular transesophageal echocardiography (TEE), is currently the most useful and less invasive cardiovascular monitoring tools in orthotopic liver transplantation (OLT) procedures.[1] The hemodynamic status of these patients may include cirrhotic cardiomyopathy, vascular tone abnormalities, microvascular dysfunction, acute cardiovascular failure, and sudden changes of preload during the most turbulent phases of the transplant, all of which require rapid identification and management.[2,3] This has led the American Association for the Study of Liver Diseases (AASLD) to state that TEE should be used in all liver transplant candidates.[4] In a 2014 survey, the overall rate of TEE used during OLT was very high (over 94%), with approximately 70% of transplant anesthesiologists supposedly proficient in echocardiography.[5] Nonetheless, despite the fact that TEE is becoming an increasingly popular tool, few reports exist about the use of TEU (understood as extra-cardiac ultrasonography) of the liver, lungs, and kidneys during the different transplant phases.

The aims of this review are as follows: (1) to summarize the use of TEE and TEU throughout the phases of OLT; and (2) to describe all others new feasible applications in this context.

2 | TEU SAFETY OF USE

2.1 | Probe insertion tips and tricks

Prepare the TEU probe with an endocavitary cover. After the induction of anesthesia and orotracheal intubation, insert the lubrificate probe through a bite block into the mouth. Push the probe with your right hand while your left hand raises the jaw. Difficulty can be encountered after a few inches of insertion if the probe is lodged into one of the pyriform sinuses.[6] If so, pull out the probe and try again. The probe tip can occasionally become distorted and unable to be advanced or retracted without extreme force, which brings the risk of pharyngeal, laryngeal, esophageal, or gastric trauma. You should hence ensure that the probe remains in line with the esophagus during insertion. After TEU positioning, bear in mind that extreme flexion of the probe during TEE for deep transgastric probe manipulation could lead to gastric injury (deep transgastric view). Remember that the gastroesophageal junction is a vulnerable zone and that probe manipulation may place the relatively fixed tissues under considerable tension.[6,7]

Depending on the center and the operator skills, esophageal varices may be considered a relative contraindication to TEU.[8] However, in OLT candidates, TEE has been shown to be both safe and feasible. In a recent study, the major complication rate was 0.86%—slightly higher than the 0.2% reported in cardiac literature.[9]

3 | PULMONARY ARTERIAL CATHETER AND TEU

Pulmonary artery catheterization (PAC) is used less frequently in OLT candidates than previously. Some anesthesiologists consider the Model for End-State Liver Disease (MELD) score in determining whether or not to employ it, with higher MELD scores being associated with increased risk of bleeding and decreased survival rates.[10] However, PAC and TEE appear to be the most widely used combination in contemporary clinical practice for these high-risk patients.

3.1 | TEU-guided PAC insertion

The PAC is usually inserted following anesthesia induction using the pressure waveform transduction technique. However, multiple attempts at PAC insertion may be required, increasing the risk of complications such as arrhythmias, PAC kinking, tricuspid valve, and pulmonary artery injury.[11] Proficient anesthesiologists should consider using TEE for accurate, quick PAC positioning. A step-by-step procedure follows the catheter from the superior vena cava, through the right atrium and ventricle, and up to the pulmonary artery (Figure 1).

3.2 | Portopulmonary hypertension

Portopulmonary hypertension (PPH) in patients undergoing OLT is a strong indication for PAC insertion. PPH is thought to be secondary to vascular obstruction, with smooth muscle proliferation and in situ thrombosis. A mean pulmonary artery pressure (mPAP) > 25 mm Hg at rest, and pulmonary vascular resistance (PVR) > 240 dynes/s/cm^5 after PAC placement in the presence of known portal hypertension confirm this pathology.[12] Studies have demonstrated that preoperative mPAP < 35 mm Hg is associated with no significant increased mortality, while a preoperative mPAP between 35 and 50 mm Hg is associated with 50% mortality, and mPAP > 50 mm Hg is associated with mortality approaching 100% after OLT.[13] Many case series and retrospective analyses have shown that successful OLT can be performed in patients following the reduction in pulmonary pressures with pharmacotherapy.[13,14] Fukazawa et al[15] described a case of severe PPH diagnosed at the time of OLT. In similar cases, PPH should be managed intraoperatively to avoid the risk of acute right ventricular failure during

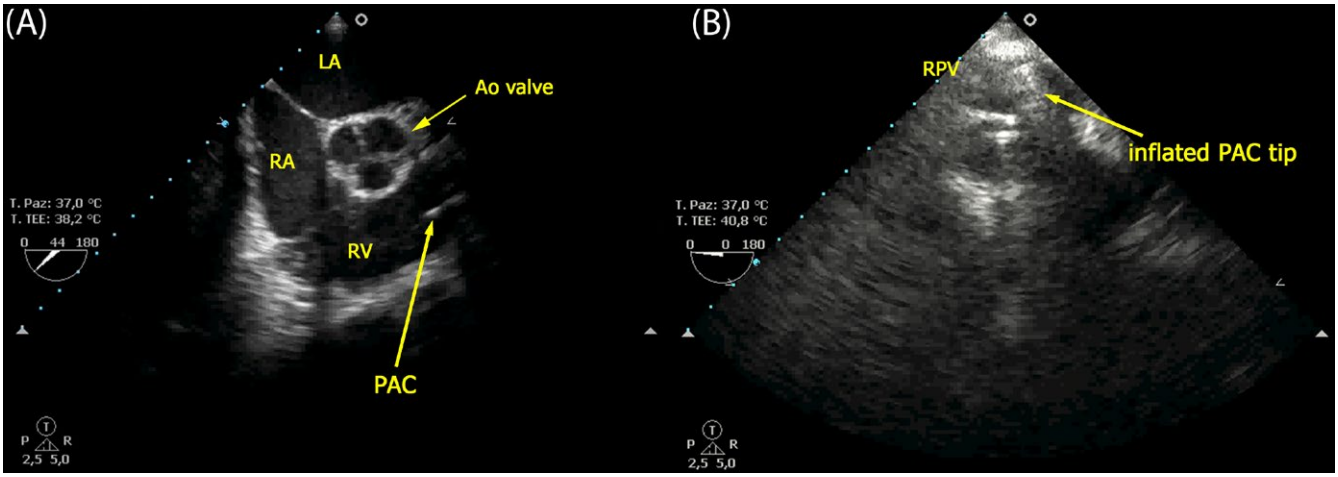

FIGURE 1 Transesophageal ultrasonography (TEU) guided PAC insertion through mid-esophageal right ventricle inflow–outflow view (A) and mid-esophageal ascending aorta short-axis view (see Movie S1); Ao valve = aortic valve; LA = left atrium; PAC = pulmonary arterial catheter; RA = right atrium; RPV = right pulmonary vein; RV = right ventricle

the reperfusion phase after de-clamp, including the use of pulmonary vasoactive drugs (prostaglandin, inodilator, and nitric oxide).[16] While echocardiography is used as a preoperative screening tool for the detection of pulmonary arterial hypertension, TEE also can be a valuable tool to monitor heart function in complex intraoperative scenarios.

4 | PLACEMENT OF TRANSCUTANEOUS VENO-VENOUS BYPASS

The OLT technique was first described as a complete resection of the recipient's inferior vena cava (IVC) involving the inter-position of the donor intra-hepatic vena cava with two end-to-end anastomoses. Due to hemodynamic instability, a veno-venous bypass was included from the left femoral to the left axillary vein. This approach remains the gold standard technique in many centers.[17] In this context, a TEU probe may be used to assist in the placement of a guidewire for transcutaneous veno-venous bypass placement, as described by Planinsic et al,[18,19] because the insertion of large bore catheters is not without risk and exposes the patient to life-threatening complications (ie, bleeding and vessel rupture) (Figure 2).

In our centers,[20] a modified "piggyback" technique is preferred over the classic approach. Introduced at the end of the 1990s by Tzakis et al,[18] this technique consists of preserving the full length of the recipient's vena cava but with anastomoses of the donor's suprahepatic veins to the ostium of the recipient's left and middle suprahepatic veins, without the need for a veno-venous bypass. TEU may be used to evaluate the degree of IVC clamping and subsequent residual blood flow during the anepathic phase.

5 | HEPATHOPULMONARY SYNDROME

Hepatopulmonary syndrome (HPS) has been reported in 4%–32% of patients referred for OLT.[21,22] It is characterized by an elevated ventilation/perfusion mismatch. The European Respiratory Society Task Force on Pulmonary-Hepatic Vascular Disorders has defined this syndrome as: *the presence of (1) liver disease (usually chronic); (2) abnormal arterial oxygenation (variably defined as alveolar-arterial [A-a] oxygen gradient > 15 mm Hg [or >20 mm Hg in those >65 years of age] or an arterial partial pressure of oxygen [PaO_2], 80 mm Hg while breathing room air) in the absence of an alternate cause; and (3) evidence of intra-pulmonary vascular dilatations (IPVDs), most commonly diagnosed using contrast transthoracic echocardiography (4).*[23] However, TEE showing bubbles in the pulmonary veins and the left cavity is more sensitive than transthoracic echocardiography with microbubbles.[12] Furthermore, Iyer et al[24] suggested that survival after OLT was not associated with PaO_2 levels at the time of HPS diagnosis. These findings indicate that most severe cases of HPS should not be a basis for transplant refusal, and that OLT remains the only effective treatment for HPS at present.

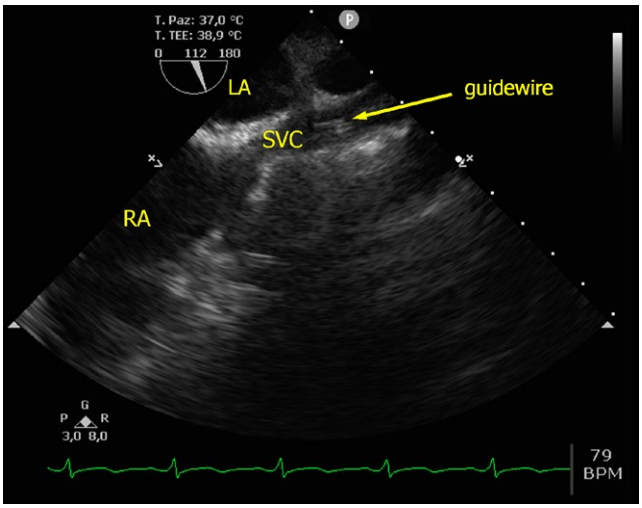

FIGURE 2 Superior vena cava through the mid-esophageal bicaval window. The white arrow indicated the guidewire for transcutaneous veno-venous bypass placement; LA = left atrium; RA = right atrium; SVC = superior vena cava

6 | TEE EXAM FOLLOWING ANESTHESIA INDUCTION

A standard comprehensive TEE examination for the baseline assessment of volume status and ventricular function following anesthesia induction is mandatory (in the authors' opinion, all the images should be stored in a standard manner). While prior guidelines have described the technical skills needed to acquire 20 views,[25] the new version of the American Society of Echocardiography/Society of Cardiovascular Anaesthesiologists recommends 28 views.[26] Most of these are specific to cardiac surgery. Nevertheless, the images of the IVC and hepatic veins must form part of a comprehensive perioperative examination during liver transplantation, as recommended by The American Society of Echocardiography/Society of Cardiovascular Anesthesiologists.[26]

6.1 | Left ventricular function

For the assessment of left ventricle function, mid-esophageal TEE positioning provides a four-chambers view (0°), a two-chambers view (80–100°), and a long-axis view of the left ventricle (120–140°) (Figure 3).[26] The most common qualitative approach to left ventricular (LV) systolic function in anesthesiology hands is the so-called eyeball method in which global function is usually described as normal, hyperdynamic or depressed. A more sophisticated cardiological approach involves using the modified Simpson's method to calculate the left ventricle ejection fraction (EF) and categorize it according to performance as normal (>55%), mild (45%–54%), moderate (30%–44%), or severely depressed (<30%) (Figure 4).[27,28] The transgastric short-axis view at the mid-papillary level (0–20°)[26] is an easy way to assess ventricular function. Using fractional area change (FAC), its normal value is ≥45%, calculated as follows: left ventricular

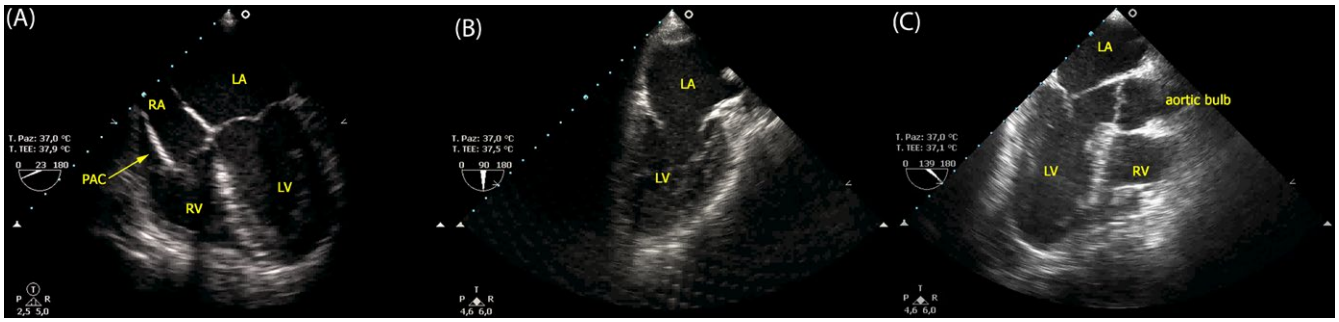

FIGURE 3 Assessment of left ventricle function through the mid-esophageal transesophageal echocardiography positioning: A, four-chambers view (0°), B, two-chambers view (80–100°), and C, a long-axis view of the left ventricle (120–140°); LA = left atrium; LV = left ventricle; PAC = pulmonary arterial catheter; RA = right atrium; RV = right ventricle

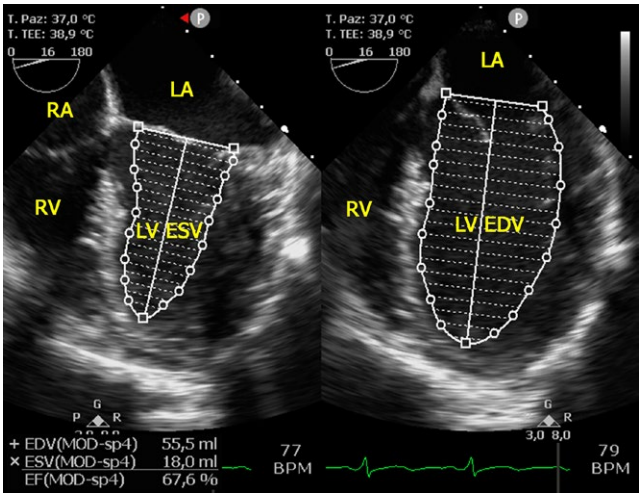

FIGURE 4 Semi-automatic left ventricle ejection fraction (EF) evaluation with the modified Simpson's method; LA = left atrium; LV EDV = left ventricular end diastolic volume; LV ESV = left ventricular end systolic volume; RA = right atrium; RV = right ventricle

short-axis diastolic area (ASxd) minus left ventricular systolic short-axis area (ASxs) divided by ASxd (ASxd–ASxs/ASxd).[7]

Left-ventricular dysfunction is rarely seen after anesthesia induction, although 23% of transplanted patients exhibit abnormal cardiac response.[29] This is due to the fact that the peripheral vasodilatation associated with an impaired cardiac ventricular response is the result of end-stage liver disease known as "cirrhotic cardiomyopathy" in which the combination of decreased systemic vascular resistance and central hypovolemia leads to a hyperdynamic circulatory state. Carey et al demonstrated that 32% of patients over the age of 50 display severe coronary artery disease at coronary angiography.[30,31] TEE is thus able to detect new areas of regional wall dysfunction that would otherwise remain undiagnosed throughout all surgical phases.

6.2 | Right ventricular function evaluation

Transesophageal echocardiography is the only instrument able to identify the acute failure of the right ventricle "in real time," as well as showing the effects of the treatment during the different OLT phases. However, as stated in the guideline for right ventricular evaluation, a qualitative assessment alone is insufficient.[32] We suggest using the following two simple methods: right–left area ratio (RV:LV ratio)[33] and tricuspid annular plane systolic excursion (TAPSE). RV:LV ratio is normally lower than 0.6. A ratio ranging from 0.6 to 1 indicates mild right ventricular dilatation, while a ratio between 1 and 2 denotes severe right ventricular dilatation[32] (Figure 5). TAPSE is obtained by positioning the M-mode scan line at the lateral tricuspid annulus in the inflow-outflow view, and by measuring the distance from the lowest point to the highest point of the excursion curve (Figure 6). A value <16 mm is considered abnormal.[32] Both of these measurements could be easily obtained in the mild esophageal four-chamber view. A third, slightly more complex method is to calculate the velocity time integral (VTI) obtained by placing a PW Doppler sample volume through the transgastric right ventricular inflow-outflow view (Figure 7 and Movie S3). A value <12 cm predicts a RV stroke volume of <2.2 L/min/m^2 (we believe this method to be confirmative).[34] Although other methods are available for RV functional evaluation (myocardial systolic velocity, tissue Doppler image, speckletracking deformation imaging, and three-dimensional echocardiography), these measurements are performed by software that is not implemented in all echocardiography machines.

6.3 | Patent foramen ovale

For the assessment of patent foramen ovale (PFO), a mid esophageal modified bicaval view should be carried out with the transducer angle rotated between 90 and 110° and the probe turned to the right (clockwise).[26] The inter-atrial septum should be observed in its entirety, with and without color flow, as atrial septal aneurysms may be associated with inter-atrial shunts. PFO should be thought of as a dynamic condition that may appear over the various stages of OLT surgery as a consequence of hypotension and/or severe reperfusion syndromes, changes in intra-abdominal pressure, or changes in mechanical ventilation.[35] Particular care should be taken to prevent thrombus formation and air entering the venous system via the left atrium, crossing the PFO, as well as systemic circulation leading to cerebro-vascular accident.

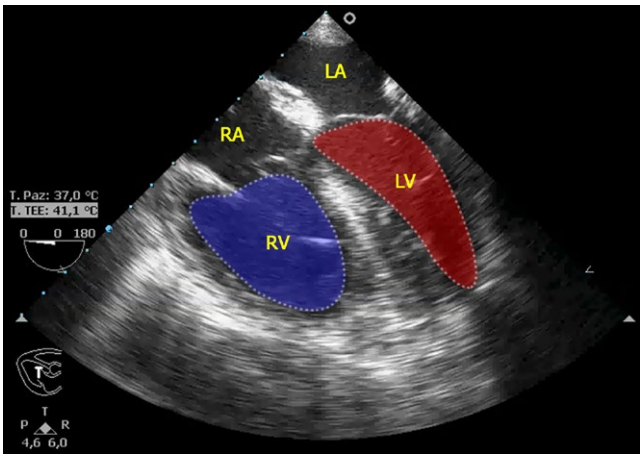

FIGURE 5 Right ventricle (blue shape) and left ventricle (red shape). The ratio between the two color is >1 and denotes severe right ventricular dilatation (see Movie S2); LA = left atrium; LV = left ventricle; RA = right atrium; RV = right ventricle

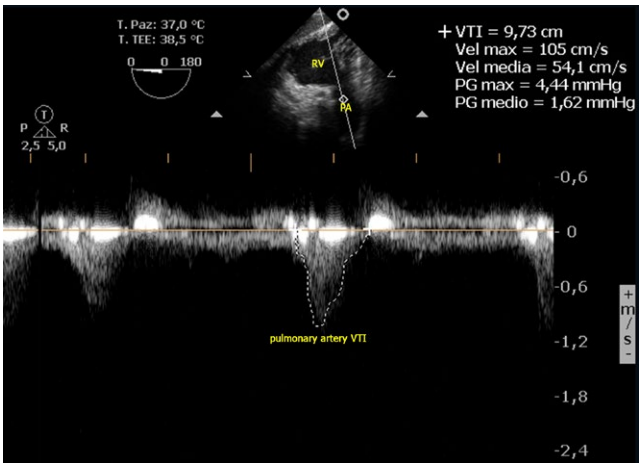

FIGURE 7 The VTI obtained by placing a pattern flow (PW) Doppler sample volume through the transgastric right ventricular inflow–outflow view. PA = pulmonary artery; RV = right ventricle; VTI = velocity time integral

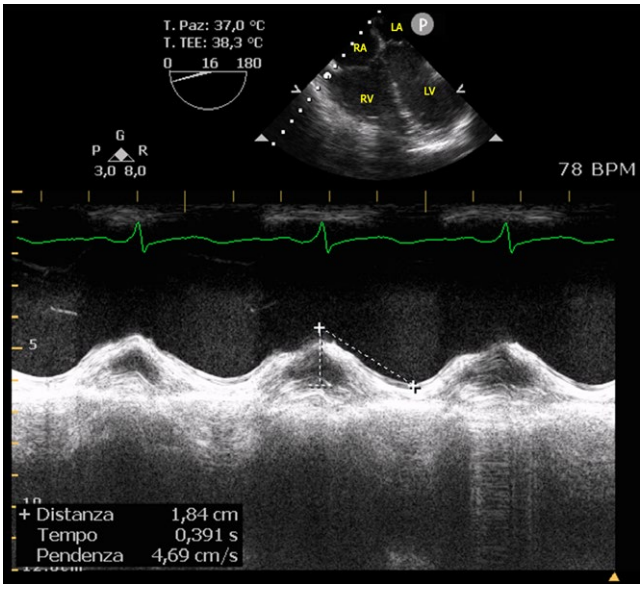

FIGURE 6 Tricuspid annular plane systolic excursion is obtained by positioning the M-mode scan line at the lateral tricuspid annulus in the inflow–outflow view, and by measuring the distance from the lowest point to the highest point of the excursion curve; LA = left atrium; LV = left ventricle; RA = right atrium; RV = right ventricle

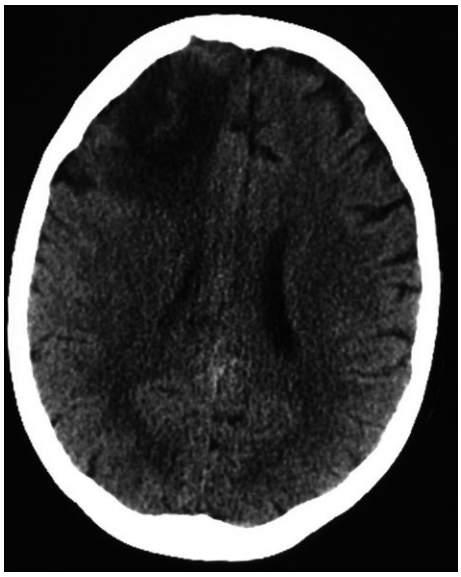

FIGURE 8 Right frontal ischemia after liver transplantation

If the presence of PFO is in doubt, a saline injection should be performed to test for right-to-left intra-cardiac shunt (Figure 8, Movies S4,S5,S6). The appearance within three beats of more than three saline bubbles in the left heart soon after opacification of the right heart is considered diagnostic.[36] There are currently no studies published that include large populations addressing the importance of PFO in patients undergoing OLT. Alba et al[37] concluded that a PFO does not appear to affect patient outcomes during the perioperative phase of liver transplantation. However, others have stated that the combination of a PFO and an atrial septal aneurysm leads to a three- to fivefold increased risk of stroke.[36,37] Nevertheless, due to the high mortality rate that occurs once the cerebrovascular complication is identified, PFO screening appears useful for the preoperative evaluation of liver transplant candidates.[38]

6.4 | Diastolic dysfunction

Diastolic dysfunction (DD) in liver transplantation candidates is mainly due to the increased stiffness of the myocardial wall due to the presence of myocardial edema secondary to cirrhotic cardiomyopaty.[39] In previous studies, diastolic dysfunction has ranged

between 40% and 50% in liver transplantation candidates. This was based on criteria involving trans-mitral pattern flow (PW) with E/A ratio (corrected for age), prolonged deceleration time (>200 ms), and prolonged isovolumetric relaxation time (>80 ms) (Figure 9A).[40] A significant statistical correlation was found between DD and mortality after transplantation. However, its prevalence was found to be <30% in the new recommendations from the European Association of Cardiovascular Imaging on the introduction of tissue Doppler image (TDI).[41,42] In practice, TDI is easily obtained via a mild esophageal four-chambers view where the motion of mitral annulus can be recorded by placing the sample volume approximately 1 cm from the insertion of the mitral valve leaflets. Two waves appear after TDI activation: the first of these is termed e′ (e prime), and the second a′ (a prime) (Figure 9B). The relationship between the conventional PW Doppler E wave and e′ is widely used in practice. The E/e′ ratio in normal individuals is <8, and an E/e′ ratio >15 is highly suggestive of elevated filling pressures. However, further studies are needed to clarify the role of DD in the context of liver transplantation.[41]

7 | TRANSESOPHAGEAL LUNG ULTRASOUND (TELU)

Cavayas et al have recently introduced a systematic approach for the intra-operative study of hypoxia known as transesophageal lung ultrasound (TELU).[43,44] In TELU, the craniocaudal axis of each lung is divided into apical, middle, and basal regions; the left subclavian artery is used as a landmark to identify the apical regions; the superior pulmonary veins are used to mark the middle regions; and finally, the inferior vena cava and the right atrial junction are used to identify the basal segments. The lungs are scanned along the longitudinal axis from each of these landmarks by rotating the ultrasound plane at 0 and 90°. If we consider that moderate dyspnea is a common finding in patients with liver cirrhosis due to the compression of lung parenchyma by ascites and/or pleural effusion (eg, hydrothorax), and that hypoxia is relatively common following anesthesia induction, a quick examination of the lung is merited (Figure 10A,B).[8]

The use of TELU in liver transplantation is justified by the fact that TEU is already in place. Furthermore, the sensitivity and specificity of this method for the detection of pleural effusion is high.[43,44] The detection of atelectasis and/or lung consolidation is also possible due to the easier acoustic windows provided via the esophagus, from where a larger portion of the dorsal respiratory system can be rapidly examined. In cases of unexpected intra-operative hypoxia during OLT, the main advantage of TELU lies in its ability to examine both pulmonary and cardiac regions.[43]

8 | MONITORING RENAL PERFUSION WITH TEU

Transesophageal renal ultrasonography (TERU) may be the only way to study renal perfusion during liver transplant. Indeed, ultrasound assessment of renal artery flow has been shown to be highly sensitive and specific in the early detection of acute kidney injury (AKI). The feasibility of using TEU for the assessment of the abdominal aorta and its branches was first described by Chouinard et al[45] more than 20 years ago, in a patient following abdominal aortic aneurysm resection. In that case, the renal vessels, as well as a portion of the infrarenal aorta, were clearly visualized. Recently, a technique to locate the left kidney involving calculations for artery velocities, resistive index (RI), and pulsatility index (PI) has been well described by Bandyopadhyay et al.[46] Normal values here are approximately 0.64–0.70 for RI and 0.93–1.25 for PI in healthy subjects. Higher values indicate increased resistance to the flow distal to the point of measurement. For better visualization, vascular preset should be selected to allow for automated measurements (Figure 11). However, TERU data are still lacking in liver transplantation literature—an omission that is probably due to the risk of varices bleeding during the gastric manipulation of the probe.[47]

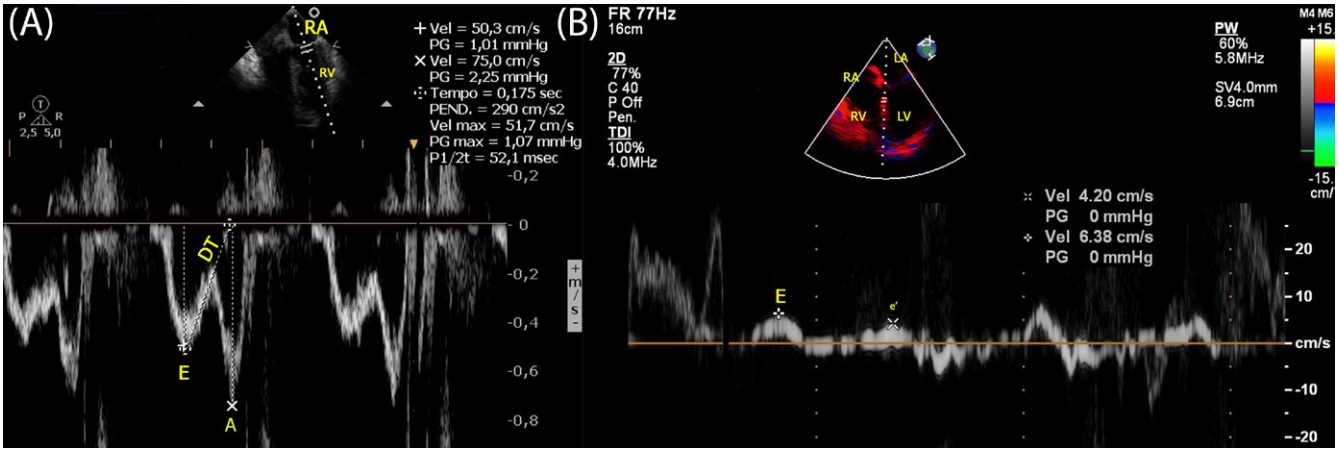

FIGURE 9 Trans-mitral pattern flow (PW) showed E/A ratio and deceleration time (A) and tissue Doppler imaging (TDI) (B) e/e′; A = atrial wave; DT = deceleration time; E = early wave; LA = left atrium; LV = left ventricle; RA = right atrium; RV = right ventricle

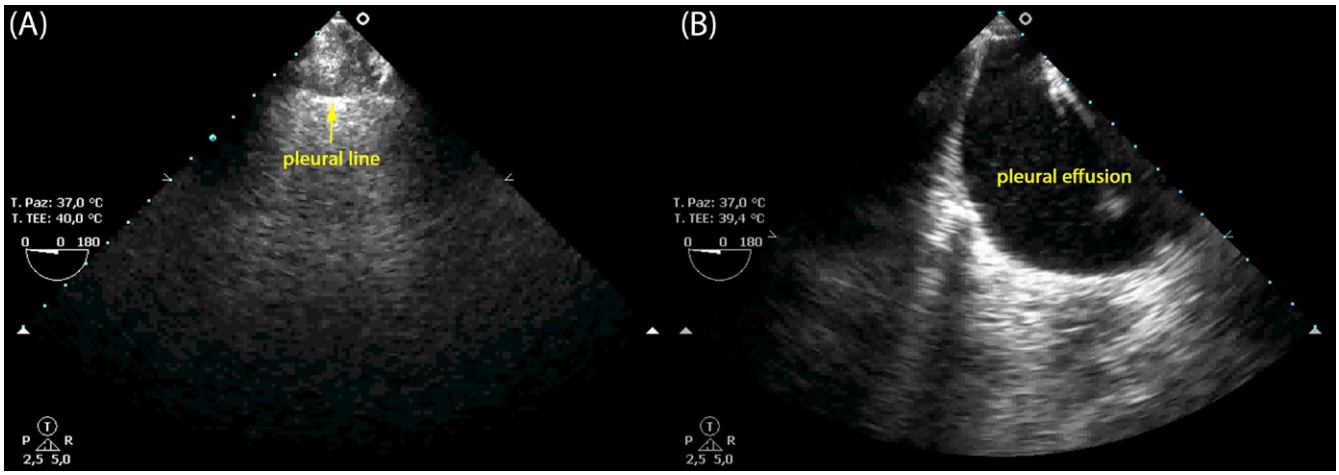

FIGURE 10 Transesophageal lung ultrasound (TELU) showed normal lung sliding (A) and right hydrothorax (B)

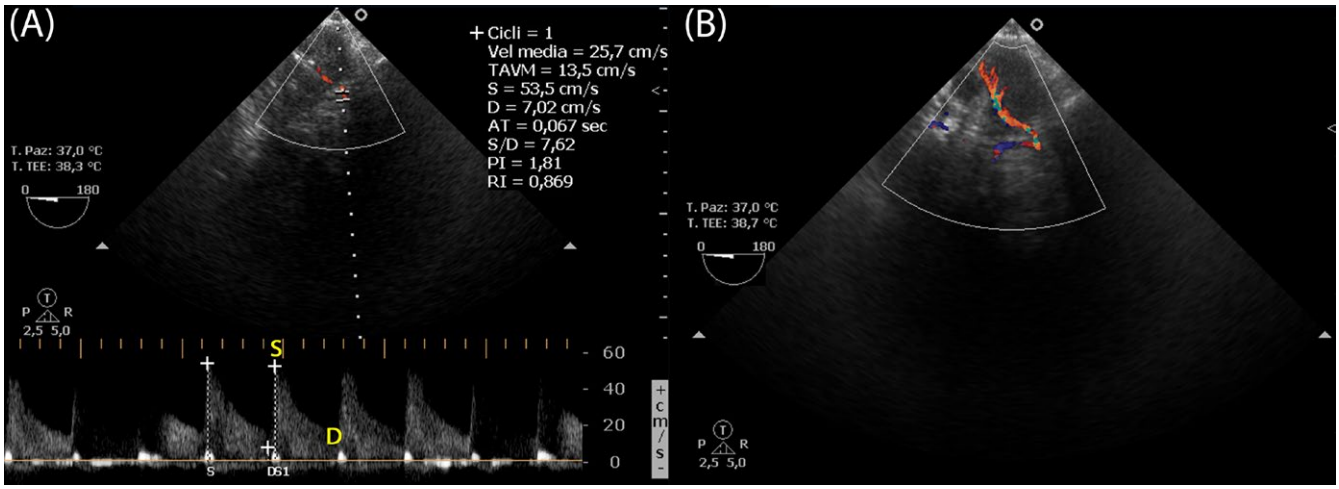

FIGURE 11 Transesophageal renal ultrasonography showing renal perfusion during liver transplant and PW Doppler; D = minimum diastolic flow velocity; S = peak systolic flow velocity

9 | PREANHEPATIC AND ANHEPATIC PHASE

In the preanhepatic phase, hypotension may result from the temporary obstruction of venous return as a consequence of surgical manipulation of the liver, or from bleeding due to visceral adherence in patients who have undergone previous surgery. During the anhepatic phase, an important decrease in preload occurs meanwhile portal vein clamping and IVC reconstruction. An external veno-venous bypass facilitates hemodynamic stability for the passage of the preload from the lower body to the upper body.[19] However, in a center such as ours where the modified "piggyback" technique is used and partial inferior vena cava clamping performed, fluid should be given to replace the transit of unavailable preload prior to the application of the IVC tangential clamp.[7,18–51] Of course, the increased obstacle to IVC vein drainage can precipitate renal function during this phase.[52]

9.1 | Fluid replacement

Fluid therapy is significantly influenced by TEE findings in up to 50% of these two phases, with the use of static (LVEDA, CO, VTI) and dynamic preload indices (SVC collapsibility, VTI respiratory variation).[53] However, we prefer a more sophisticated approach that uses the respiratory variation of the superior vena cava (ΔSVC) (Figure 12) or VTI respiratory variation. Furthermore, CO (if not monitored with PAC) can be calculated as the product of the aortic cross-sectional area (CSA) and the velocity time integral (VTI). To obtain CSA, the diameter of the left ventricular out-flow tract (LVOT) from the transgastric long-axis view is used, while VTI can be obtained via the deep trans-gastric view (Figure 13A,B).

Although it falls outside the scope of this study, it is noteworthy that fluid administration during liver transplant may be divided into fluid maintenance (blue line) and fluid replacement (red line). A major change in the last 10 years in our clinical practice has been

the management of this "blue line." Indeed, insensible perspiration during the perioperative period has been re-evaluated following the study by Lamke et al[54] in which baseline evaporation during large-scale abdominal surgery (and also transplantation) was shown to be approximately 0.5–1 mL/kg/h. We have thus changed from 10 mL/Kg/h (in the past) to 1–3 mL/Kg/h (our present protocol).[55] Furthermore, evidence has come to light indicating that the "third space" does not exist, and therefore (ascites) does not need to be totally replaced.[56] Notably, permissive oliguria (<0.5 mL/kg/h) is a new concept that is accepted as a normal neuro-hormonal response to surgery (and not a the reason to administer fluid bolus).[57–60]

Although normal saline solution is used worldwide as a maintenance fluid, its excessive use can lead to hyperchloremic acidosis. There is currently a debate regarding the morbidity associated with this condition in the postoperative phase.[61] Regarding fluid replacement (red line), patients with acute blood loss and unstable hemodynamics should receive faster replacement with a 1:1 ratio. This is best achieved using a rapid infusion device.[62] Given the uncertainty regarding the safety of artificial colloids (gelatin and hydroxyethyl starch) in liver transplantation patients, we routinely use albumin 4% bolus of 3 mL/Kg as a fluid challenge, as well as blood products.[63] Last but not least, liver transplantation is associated with increased bleeding, mostly as a result of bad fluid therapy.[64] However, it should be recalled that although LT is associated with increased bleeding, altered coagulation with a prothrombotic state may also occur. Intra-vascular thrombus formation and subsequent embolization is a potentially fatal complication that can occur after reperfusion.[65]

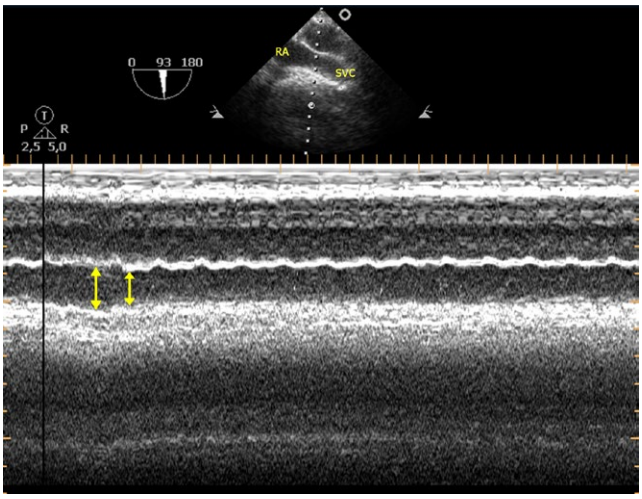

FIGURE 12 Respiratory variation of the superior vena cava (ΔSVC); RA = right atrium, SVC = superior vena cava

10 | REPERFUSION

This is the phase of surgery associated with the greatest cardiovascular hemodynamic instability.[66] The reperfusion phase is mainly a feature of the "piggyback" technique, with the de-clamp of the portal vein and sopra-hepatic vein cuff anastomosis leading to graft reperfusion.[18] This may induce a characteristic pattern named post-reperfusion syndrome (PRS), the mechanisms and pathophysiology of which are complex and not yet fully understood.[67] The literature has reported that PRS occurs in 12%–77% of cases—a very wide range.[68] Different explanations have been previously associated with this syndrome, including donor-related factors (age, cold ischemia time); the presence of macrovesicular steatosis; and factors related to the host (a high MELD score and mismatches in size between the recipient and the grafted organ).[67,68] The first to describe this phenomenon were Aggarwal et al,[69] who defined PRS as a decrease in mean arterial pressure (mAP) >30% below baseline, for at least 1 minute, occurring during the first 5 minutes after reperfusion of the liver graft. Later, Hilmi et al[70] introduced two different degrees of severity: mild and severe PRS. In mild PRS, mAP and/

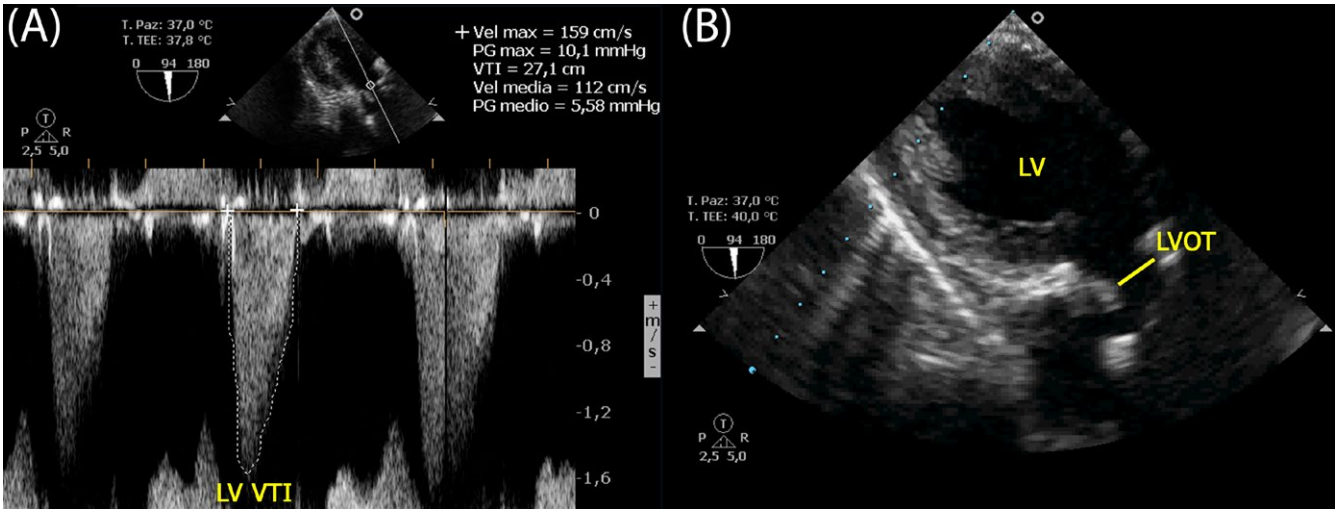

FIGURE 13 Velocity Time Integram (VTI) of the left ventricle (A), measured in long-axis transgastric view (B). LV VTI = left ventricle velocity time integral; LV = left ventricle; LVOT = left ventricle outflow tract

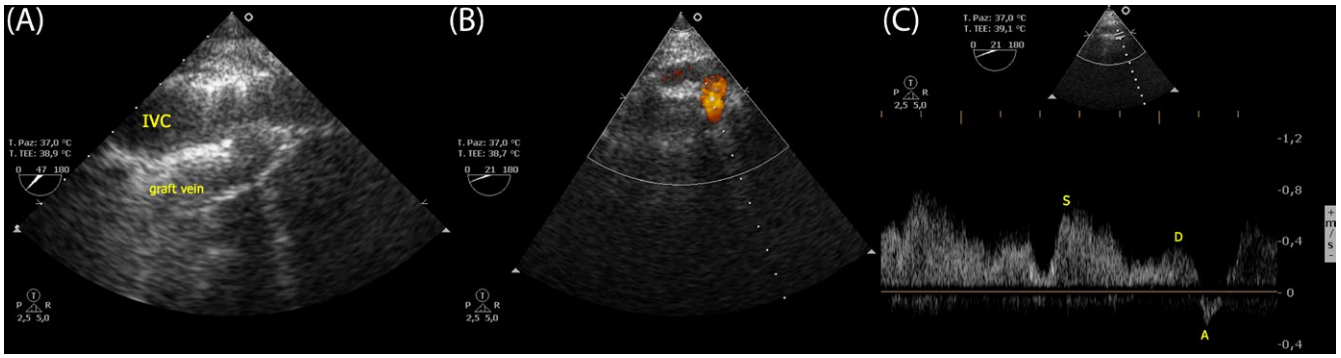

FIGURE 14 Hepatic view of the "piggyback" anastomosis (A); color Doppler demonstrating normal flow through the anastomosis (B); and Doppler waveform through the anastomosis with systolic (S), diastolic (D) anterograde wave blood flow toward the right atrium and A wave retrograde flow. IVC = inferior vena cava

or heart rate (HR) decrease without reaching 30% of baseline, for <5 minutes, and are responsive to an intra-venous bolus of calcium chloride (1 g) and/or epinephrine (≤100 mcg), without the need to start a continuous infusion of vasopressors. Severe PRS is defined by greater hemodynamic instability, with a drop in mAP/HR exceeding 30% of baseline, asystole, or hemodynamically significant arrhythmias, and the need to start the infusion of vasopressors during the intra-operative period that continues throughout the postoperative period.

10.1 | Right ventricular function in practice

Echocardiography features of the reperfusion phase may include acute right ventricular failure (see Movie S2). TEE should thus be positioned in the mild esophageal four-chambers view, and/or in the right inflow-outflow view (50–70°) to allow for real time monitoring of the right free wall and the detection of intra-cardiac air and thrombosis (see Movies S7,S8).[8,9,32] The right ventricle is extremely sensitive to changes in loading conditions such as those that occur in the reperfusion phase, where three times more cardiac output crosses the cavity. Fluid administration during this phase should be discouraged. High tidal volume (>8 mL/Kg) and a PEEP of 5–8 cm H_2O should always be decreased, as the drainage of the dilated vascular pulmonary bed onto the left ventricle is reduced. Before de-clamping the anastomoses, it is thus advisable to: (1) limit tidal volume and turn the PEEP to ZEEP for a few minutes; (2) increase the oxygen inspired fraction to 60%–80%; (3) avoid hypercapnia increasing the respiratory rate to 14–16/minute. In challenging cases, right ventricular systolic contractility should be sustained with the use of catecholamines (epinephrine, dobutamine) or phosphodiesterase 3 inhibitors (enoximone or milrinone), and afterload managed through the use of pulmonary vasodilators drugs (inhaled nitric oxide, inhaled prostacyclin, inhaled milrinone).[71]

10.2 | Left ventricular tract obstruction

Transesophageal echocardiography views can be an invaluable tool to detect new mitral valve regurgitation. If the patient has left ventricular hypertrophy and long anterior mitral leaflet, left ventricular outflow tract obstruction (LVOTO) may occur (see Movies S9,S10). In LVOTO, the anterior leaflet of the mitral valve can occlude left ventricle outflow, causing severe posterolateral mitral regurgitation flow.[8,72] A retrospective review of 106 transplant recipients found inducible LVOTO on preoperative dobutamine stress echocardiography (DSE) in 40% of patients.[73] In this study, an outflow gradient equal to or greater than 36 mm Hg was significantly associated with intra-operative hypotension. LVOTO necessitates a prompt treatment with fluid loading, vasoconstriction drugs, and avoidance of inotropic agents.[74]

10.3 | Left ventricular ballooning syndrome

We previously described a case of ballooning syndrome with left ventricular acute failure associated with profound hypotension after liver reperfusion that fortunately restored after adrenalin bolus infusion, with the restoration of preload due to inferior vena cava reconstruction.[8] This last scenario, known as Takotsubo cardiomyopathy, with transient left ventricular apical ballooning syndrome, is a reversible condition triggered by stressful events, such as the reperfusion of a transplanted liver or the exogenous administration of vasoactive medications. Lee et al[75] reported a similar finding for the postoperative period.

10.4 | Vena cava reconstruction

If hemodynamic instability persists in the late phase of reperfusion, a quick look with TEU allows the visualization of the large vessels, indicating whether inferior vena cava reconstruction should be performed.[8] The use of TEU to assess inferior vena cava patency in liver transplant patients was first described in 1992. Here, the authors suspected a stricture of the suprahepatic inferior vena cava (IVC) anastomosis and used TEE to evaluate its patency. The authors described how the liver appeared swollen following separation from the venous–venous bypass, while Doppler color flow imaging demonstrated marked turbulence in the suprahepatic IVC, with a narrow jet streaming into the right atrium. This revealed that the cause of

the obstruction was due to kinking of the vessel, and the anastomosis was subsequently revised. Unrecognized IVC stenosis, thrombosis, and kinking can lead to devastating consequences, requiring the patient to undergo further operations such as surgical repair or re-transplant.[8,48] Details of the hepatic and inferior vena cava views have been previously described by our group.[50] A normal hepatic view of the "piggyback" anastomosis is shown in Figure 14.

11 | CONCLUSION

Transesophageal ultrasonography (and TEE) offer a first-class instrument with which to understand in real time the life-threatening hemodynamic disturbances along the liver transplantation phases, and especially during reperfusion. In the literature, TEE has shown that more than 75% of patients exhibit some abnormal cardiac finding during OLT. The advantages of TEE are twofold, offering both immediate recognition and prompt management of complications.[76]

The most common abnormal intra-operative TEE findings during OLT are right-sided microemboli, right ventricular dysfunction, and patent foramen ovale (PFO) with a left-to-right shunt.[76] However, left ventricular outflow tract obstruction is more difficult to diagnose, and very few reports describe this dynamic problem.[8,72] The same may be true for the diagnosis of left ventricular ballooning syndrome following reperfusion.[8,75]

Since its introduction in 1976, TEE has progressively expanded its role outside the cardiac surgery setting. Currently, it is a rational instrument that may lead to changes in fluid administration and hemodynamic management during liver transplantation.[53] However, the use of TEE should not be focused exclusively on the heart; a role may be also envisaged for the liver, lungs, and kidneys.[8,43,45,48]

Where feasible, TEU of the liver offers an opportunity to evaluate the intra-operative patency of the surgical anastomosis through the liver window at the end of surgery.[8,48] Transesophageal lung ultrasonography is also an invaluable tool by which to investigate "acute hypoxemia" in the intra-operative setting where TEE is already in place.[43] To our knowledge, no studies have been carried out into intra-operative renal function with TEU. A major limitation in the development of TEU during OLT is a lack of proficiency outside the cardiothoracic setting. However, Basic Certification remains attainable by many anesthesiologists.

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CONFLICT OF INTEREST

The authors have no conflict of interests related to this publication.

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of the article.

Movie S1. Mid-esophageal ascending aorta short axis view showing inflated PAC tip.

Movie S2. Mid esophageal 4 chambers view, showing acute right ventricular failure.

Movie S3. Trans gastric right ventricular inflow-outflow view.

Movie S4. Bicaval view of patent foramen ovale.

Movie S5. Color Doppler of a patent foramen ovale.

Movie S6. Bubble test swoving bubbles passing through the patent foramen ovale.

Movie S7. Mid esophageal four chambers view showing air in the right cavities at the reperfusion phase.

Movie S8. Right inflow-outflow view during reperfusion phase showing air bubbles.

Movie S9. Long anterior mitral leaflet creating a left ventricular outflow tract obstruction.

Movie S10. Color Doppler of left ventricular outflow tract obstruction with mitral regurgitation.

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