

OPEN

# Influence of Intraoperative Transesophageal Echocardiography and Pulmonary Artery Catheter Monitoring on Outcomes in Liver Transplantation

Ryan E. Hofer, MD,<sup>1</sup> Matthew N.P. Vogt, MD,<sup>1</sup> Timucin Taner, MD, PhD,<sup>2</sup> and James Y. Findlay, MB<sup>1</sup>

**Background.** Anesthetic management of orthotopic liver transplantation (OLT) can be challenging. Management involves responding to sudden hemodynamic shifts, addressing instability, and performing ongoing volume assessment. To best prepare for these perturbations, various monitors are used intraoperatively. We sought to explore the impact of transesophageal echocardiography (TEE) and pulmonary artery catheter (PAC) use on outcomes of patients undergoing OLT. **Methods.** We retrospectively reviewed records of patients who underwent OLT at a single institution and included all who were monitored intraoperatively with TEE alone, PAC alone, or both methods concurrently (TEE + PAC). We determined whether these groups had differences in length of hospitalization (primary outcome), 30-day mortality rate, and other outcomes. **Results.** Three hundred eighteen liver transplant operations were included in the study. Patients in the TEE + PAC group had the shortest median length of hospitalization (TEE + PAC, 8.6 days; TEE, 10.3; PAC, 9.1;  $P = 0.04$ ). The TEE + PAC group also had the lowest 30-day mortality rate (TEE + PAC,  $n = 1$  [1.3%]; TEE,  $n = 5$  [12.8%]; PAC,  $n = 7$  [3.5%];  $P = 0.009$ ). However, the TEE + PAC group also had the highest rate of a new postoperative need for dialysis (TEE + PAC,  $n = 8$  [10.3%]; TEE,  $n = 2$  [5.1%]; PAC,  $n = 1$  [0.5%];  $P < 0.001$ ). **Conclusions.** Compared with either TEE alone or PAC alone, intraoperative monitoring with TEE + PAC during OLT was associated with the shortest length of hospitalization and lowest 30-day mortality rate. Transplant anesthesiologists should be aware of the potential benefit on patient mortality and hospital length of stay with concurrent intraoperative TEE + PAC monitoring and the increased need for new postoperative dialysis.

(*Transplantation Direct* 2020;6: e525; doi: 10.1097/TXD.0000000000000972. Published online 13 January, 2020.)

The anesthetic management of orthotopic liver transplantation (OLT) can be challenging because of the complex patient population, which includes patients with multiple cardiovascular abnormalities,<sup>1</sup> and because of surgical considerations for the procedure.<sup>2</sup> Management involves treating

sudden and clinically significant hemodynamic shifts, addressing cardiovascular instability, and performing ongoing volume assessment.<sup>2,3</sup>

Advanced cardiovascular monitoring has routinely been used in clinical practice to manage OLT. Pulmonary artery catheters (PACs) traditionally were considered the standard of care for intraoperative management, but more recently, transesophageal echocardiography (TEE) has been used in addition to or instead of a PAC.<sup>4</sup> Surveys show an increasing prevalence of TEE use during OLT.<sup>5</sup> Increased use of this cardiac monitor is possibly due in part to the increased awareness of abnormal intraoperative TEE findings during OLT. Shillcutt et al<sup>6</sup> reported that 88 of 100 patients (88%) who had TEE monitoring during OLT had at least 1 abnormal intraoperative TEE finding. Most of these findings would not be detected with a PAC.

Numerous national and international anesthesiology associations have recommended TEE monitoring during OLT,<sup>1</sup> because it can be used intraoperatively to dynamically assess cardiac function, volume status, and surrounding structures in real time. This information presumably facilitates the anesthesiologist's decision-making process when selecting various interventions.

A 2012 survey of 79 transplant centers (performing at least 12 OLT cases in 2011) assessed TEE practice patterns during

Received 12 November 2019.

Accepted 2 December 2019.

<sup>1</sup> Department of Anesthesiology and Perioperative Medicine, Mayo Clinic, Rochester, MN.

<sup>2</sup> Division of Transplantation Surgery, Mayo Clinic, Rochester, MN.

The authors declare no funding or conflicts of interest.

R.E.H., M.N.P.V., and J.Y.F. were involved in all aspects of article development, including design of the research plan, analysis, and interpretation of data, statistical analyses, and drafting and revising the article. T.T. was involved in article drafting and revising. All authors have reviewed and approved the final copy for submission.

Correspondence: Ryan E. Hofer, MD, Department of Anesthesiology and Perioperative Medicine, Mayo Clinic, 200 First St SW, Rochester, MN 55905. (hofer.ryan@mayo.edu).

Copyright © 2020 The Author(s). *Transplantation Direct*. Published by Wolters Kluwer Health, Inc. This is an open-access article distributed under the terms of the Creative Commons Attribution-Non Commercial-No Derivatives License 4.0 (CCBY-NC-ND), where it is permissible to download and share the work provided it is properly cited. The work cannot be changed in any way or used commercially without permission from the journal.

ISSN: 2373-8731

DOI: 10.1097/TXD.0000000000000972

adult liver transplant.<sup>7</sup> In that survey, the overall intraoperative TEE use was 94.9%; 38% used TEE routinely, and 57% used TEE for special circumstances or rescue conditions.

With the reported variations in monitor selection, we were unaware of any study examining the relationship between monitor selection and patient outcomes in OLT. We reviewed our institutional experience to evaluate how intraoperative monitoring with TEE, with or without a PAC, affected patient outcomes. We hypothesized that outcomes would not differ among these approaches, suggesting that the choice of either monitor could depend on availability and provider expertise.

## MATERIALS AND METHODS

The Mayo Clinic Institutional Review Board approved this retrospective review as a minimal risk study (protocol #18-006509). Protocol design was completed before dataset assembly. Patients who did not consent to authorize research use of their medical records were excluded from the study, in accordance with Minnesota Statute 144.295. Strengthening the Reporting of Observational Studies in Epidemiology guidelines were used as applicable.<sup>8</sup>

All liver transplant operations were performed at Mayo Clinic (Rochester, MN) from January 1, 2015, to April 30, 2018. For this study, we included adult patients (aged  $\geq 18$  y) who were monitored intraoperatively with TEE alone, PAC alone, or both (TEE + PAC). We excluded patients who had a combined heart–liver transplant and those who had OLT without TEE or PAC (uncommon in our practice).

All patients received care from a dedicated liver transplant anesthesia team. OLT patients underwent general anesthesia with a volatile agent. Invasive monitoring included an arterial catheter (usually brachial) and central venous access. Additional monitoring with TEE or a continuous cardiac output PAC (or both) was selected at the discretion of the attending anesthesiologist. Monitors were placed after induction and remained in use throughout the procedure. Goals for hemodynamic parameters, volume resuscitation, and transfusion management for each patient were at the discretion of the attending anesthesiologist, in consultation with the surgical team. The surgical approach was a “piggyback technique” with partial inferior vena cava clamping. If this approach was not feasible, the inferior vena cava was completely clamped. In our practice, the use of venovenous bypass is rare, and temporary portocaval shunts are not used.

We used an institutional data warehouse, the Perioperative Data Mart, to identify patients and abstract their demographic, surgical, transfusion, and laboratory characteristics.<sup>9</sup> A second institutional database, the Advanced Cohort Explorer, was used to obtain additional information.<sup>10</sup> Both databases are periodically validated, and data mining accuracy is reported to exceed that of manual extraction.<sup>11,12</sup>

Perioperative variables extracted from the databases included demographic characteristics (sex, age, weight) and severity of illness (Charlson comorbidity index score, American Society of Anesthesiologists [ASA] physical status score). Preoperative laboratory data included the model for end-stage liver disease (MELD) score (calculated at the time of transplant) and hemoglobin and creatinine levels. Operative characteristics included the type of monitoring (TEE, PAC, TEE + PAC), donor type (scheduled living donor versus deceased donor), and fluid administration

(intraoperative crystalloid, colloid, and blood transfusion volumes). Postoperative characteristics included total hospital length of stay (LOS; the primary outcome of interest), intensive care unit (ICU) LOS, need for postoperative mechanical ventilation, new postoperative need for dialysis, postoperative myocardial ischemia, cerebrovascular complication, return to the operating room within 7 days of transplant, and death within 30 days of transplant.

## Statistical Analysis

Patients were stratified by intraoperative monitoring approach into 3 groups (TEE alone, PAC alone, and TEE + PAC). Categorical variables are summarized with frequency and proportion, and continuous variables are summarized with median and interquartile range. Point estimates with 95% confidence intervals (CIs) were used to assess the frequency of outcomes. Univariable methods used to assess outcomes between these groups were the Pearson  $\chi^2$  test for categorical variables and analysis of variance for continuous variables. *P* values  $< 0.05$  were considered statistically significant.

Multivariable regression analysis was used to assess the relationship between monitoring approach and hospital LOS while adjusting for MELD, Charlson comorbidity score, and age. Further multivariable analyses were not pursued because of the lack of statistical power and predicted low frequency of outcomes.

A separate secondary analysis compared 2 groups, those who had intraoperative TEE (with or without PAC) and those who had only PAC monitoring. Fisher exact tests were used to compare categorical variables, and Wilcoxon signed rank sum tests were used to compare continuous variables. Statistical analyses were completed with JMP software (SAS Institute Inc.).

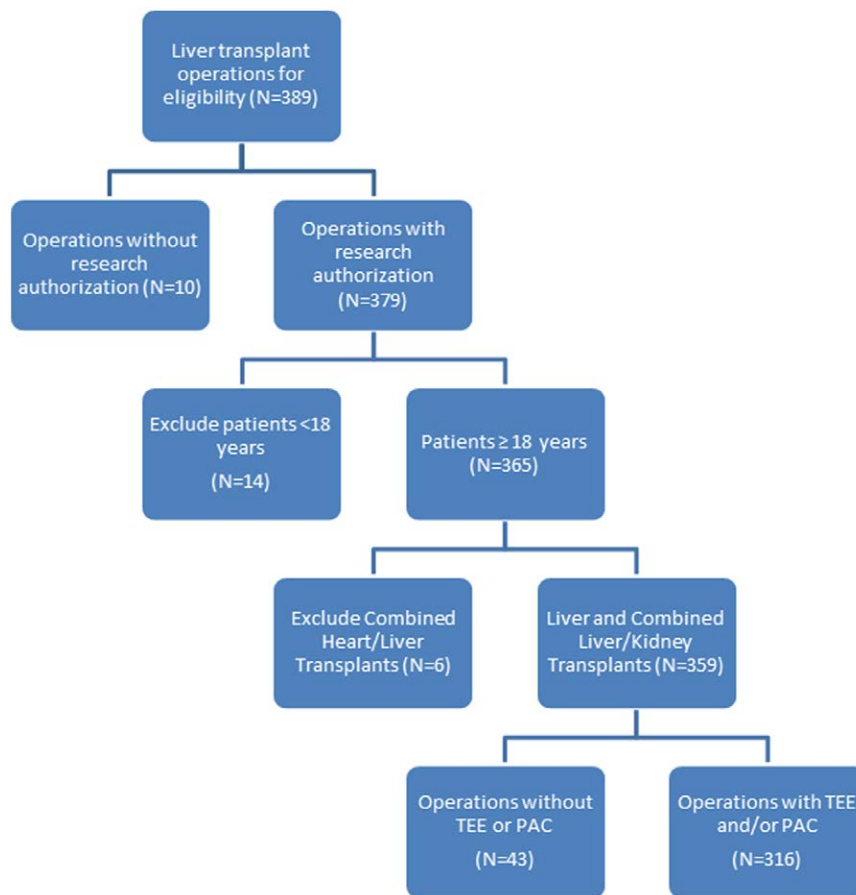
A post hoc analysis was performed examining intraoperative vasoactive medication use and total cumulative hypotension, defined as mean arterial pressure (MAP)  $< 60$  mm Hg.

## RESULTS

In total, 316 patients undergoing liver transplant were included in the study (Figure 1). Of these operations, 38 (12.0%) were managed with TEE alone, 200 (63.3%) were managed with PAC alone, and 78 (24.7%) were managed with TEE + PAC.

Patient demographics, comorbid conditions, cause and sequelae of liver disease, and preoperative laboratory values are shown in Table 1. The groups generally were similar; however, patients in the TEE + PAC group had the highest rate of prior myocardial infarctions (6/78 [7.7%]; *P* = 0.004). The groups were not different in terms of preoperative creatinine level, MELD score, Charlson comorbidity index, ASA physical score, age, warm ischemia time, or cold ischemia time.

Intraoperative data are shown in Table 2. Patients in the TEE + PAC group received the lowest volume of crystalloid (4123 mL; *P* = 0.01) and also had the lowest total volume of intraoperative infusion (crystalloid, colloid, blood products; 8330 mL; *P* = 0.02). The incidence and volume of blood products transfused did not significantly differ between groups with 1 exception. Patients in the PAC + TEE group were less likely to be transfused fresh frozen plasma although the amounts transfused did not significantly vary. The TEE group had the lowest cumulative time with MAP  $< 60$  mm Hg (72



**FIGURE 1.** Study patient flowchart. PAC, pulmonary artery catheter; TEE, transesophageal echocardiography.

minutes;  $P < 0.0001$ ). The TEE group also had the highest rate of any vasopressor infusion ( $P = 0.02$ ) with vasopressin infusion being the only infusion with a significant difference of use between the 3 groups ( $P = 0.03$ ).

Table 2 also shows ICU LOS, duration of postoperative mechanical ventilation, return to the operating room within 7 days of transplant, new organ failure, and 30-day mortality rate. Patients in the TEE + PAC group had the shortest median hospital LOS (8.6 days;  $P = 0.03$ ) and the lowest 30-day mortality rate (1/78 [1.3%];  $P = 0.047$ ). However, the TEE + PAC group also had the highest incidence of a new postoperative need for dialysis (8/78 [10.3%];  $P < 0.001$ ). No differences were noted for total ICU LOS, total duration of mechanical ventilation, return to the operating room within 7 days, or organ rejection. There was no significant difference in hospital LOS ( $P = 0.48$ ) or 30-day mortality ( $P = 0.29$ ) between the 4 surgeons who performed all included cases.

In a multivariable regression analysis adjusting for MELD, Charlson comorbidity index, and age, monitor selection remained significantly associated with hospital LOS ( $P = 0.04$ ). Specifically, after adjustment, TEE was associated with a longer hospital LOS than PAC (estimate, 8.2 days [95% CI, 1.8-14.5 days];  $P = 0.01$ ) or TEE + PAC (estimate, 8.8 days [95% CI, 1.7-15.8 days];  $P = 0.02$ ). No pairwise difference was observed in adjusted hospital LOS estimates between PAC and TEE + PAC (estimate, 0.62 days [95% CI, -4.2 to 5.4 days];  $P = 0.80$ ). Other outcomes were rare, and their incidence rates were insufficient for adequate linear or logistic regression modeling.

Table 3 shows intraoperative and outcome data from the TEE versus no-TEE secondary analysis. With this stratification approach, we observed no difference in hospital LOS, ICU LOS, duration of postoperative mechanical ventilation, need to return to the operating room within 7 days of transplant, or 30-day mortality rate. However, the TEE group received less crystalloid (4561 mL;  $P = 0.006$ ) and had a lower total volume of infusions (crystalloid, colloid, blood products; 9219 mL;  $P = 0.01$ ). The TEE group also had a higher incidence of a new postoperative need for dialysis (10/116 [8.6%];  $P < 0.001$ ). Furthermore, we observed no difference in preoperative creatinine levels between the 2 groups ( $P = 0.22$ ).

## DISCUSSION

To our knowledge, this is the first study comparing the effect of intraoperative use of TEE alone, PAC alone, or TEE + PAC on patient outcomes after OLT. Patients in the TEE + PAC group received the lowest volume of fluid intraoperatively, had the shortest hospital LOS, and had the lowest 30-day mortality rate, but it also had the highest incidence of a new postoperative need for dialysis. In the secondary analysis of TEE versus no-TEE, we did not observe any significant differences in survival rates or hospital LOS; however, the TEE group again had a higher rate of postoperative dialysis initiation.

OLTs are complex cases with challenging anesthetic management. Hemodynamic lability that requires frequent assessment and intervention is common. Our study suggests that

**TABLE 1.**  
**Demographic, surgical, clinical, and laboratory characteristics**

Characteristic <sup>a</sup>	TEE only (n = 38)	PAC only (n = 200)	TEE + PAC (n = 78)	P <sup>b</sup>
<b>Demographic</b>				
Age, y	55.6 (41.6-60.1)	59.0 (51.0-64.2)	59.3 (47.5-64.1)	0.08
Male sex	26 (68.4)	125 (62.5)	55 (70.5)	0.41
Weight, kg	76.9 (65.8-101.6)	82.8 (69.4-97.9)	88.0 (72.6-100.3)	0.42
ASA physical status	4 (3-4)	4 (4-4)	4 (3-4)	0.40
<b>Surgical data</b>				
Living donor	6 (15.8)	30 (15.0)	12 (15.4)	0.96
Combined liver and kidney transplant	2 (5.3)	19 (9.5)	5 (6.4)	0.55
Warm ischemia time, min	39 (34.8-45.5)	41 (36-49)	44.5 (38-50.8)	0.63
Cold ischemic time, h	5.7 (4.7-6.8)	5.3 (4.6-6.3)	5.5 (4.4-6.1)	0.49
<b>Comorbidity</b>				
Charlson comorbidity index	3 (1.8-6.3)	4.5 (3-6)	4 (2-6)	0.07
Myocardial infarction	0 (0)	2 (1.0)	6 (7.7)	0.004
<b>Liver disease<sup>c</sup></b>				
Alcoholic liver disease	3 (7.9)	34 (17.0)	11 (14.1)	0.34
Hepatobiliary malignancy	14 (36.7)	51 (25.5)	29 (37.2)	0.10
Nonalcoholic fatty liver	7 (18.4)	45 (22.5)	21 (26.9)	0.56
Primary sclerosing cholangitis	17 (44.7)	53 (26.5)	23 (29.5)	0.08
Primary biliary cirrhosis	2 (5.3)	11 (5.5)	2 (2.6)	0.58
Viral hepatitis	6 (15.8)	22 (11.0)	7 (9.0)	0.55
Drug- or toxin-induced disease	2 (5.3)	2 (1.0)	0 (0)	0.051
α-1 antitrypsin	1 (2.6)	0 (0)	0 (0)	0.03
Hemochromatosis	1 (2.6)	5 (2.5)	2 (2.6)	>0.99
Autoimmune hepatitis	1 (2.6)	16 (8.0)	7 (9.0)	0.45
<b>Liver disease sequelae<sup>c</sup></b>				
Esophageal varices	20 (52.6)	112 (56.0)	43 (55.1)	0.93
Portal hypertension	27 (71.5)	153 (76.5)	64 (82.1)	0.38
Thrombocytopenia	13 (34.2)	94 (47.0)	27 (34.6)	0.09
Hepatopulmonary syndrome	1 (2.6)	9 (4.5)	5 (6.4)	0.64
Hepatic encephalopathy	18 (47.4)	81 (40.5)	23 (29.5)	0.12
Hepatorenal syndrome	4 (10.5)	57 (28.5)	22 (28.2)	0.06
Portal vein thrombosis	4 (10.5)	19 (9.5)	4 (5.1)	0.45
<b>Preoperative laboratory values</b>				
MELD score	20.7 (13.7-27.8)	21.4 (13.3-31.0)	20.9 (13.9-29.2)	0.72
Hemoglobin, g/dL	9.6 (8.6-11.3)	9.8 (8.3-11.7)	9.6 (8.3-11.8)	0.95
Creatinine, mg/dL	1 (1.0-1.4)	1.2 (1.0-2.2)	1.2 (1.0-1.8)	0.12

<sup>a</sup>Continuous variables are presented as median (interquartile range) and categorical variables as No. (%).

<sup>b</sup>Univariable comparisons between continuous variables were assessed with ANOVA, and comparisons between categorical or nominal were assessed with the Pearson  $\chi^2$  test.

<sup>c</sup>No patients had shock liver (ischemic hepatitis), Wilson disease, or portopulmonary hypertension.

ASA, American Society of Anesthesiologists; MELD, model for end-stage liver disease; PAC, pulmonary artery catheter; TEE, transesophageal echocardiography.

the complexity of these cases is best met by using TEE + PAC. A possible explanation for the superior outcomes is that the combination of right heart pressure data (from the PAC) and cardiac volume/function data (from the TEE) provides a unique combination of data that are otherwise not available but nonetheless still pertinent for the successful management of a high complexity case such as an OLT. This additional information may allow for an improved interpretation of the patient's status, thus improving management.

Baseline demographic assessment of these groups showed no differences in MELD scores, Charlson comorbidity scores, ASA physical scores, or age (Table 1). Therefore, monitor selection in our practice appeared to be guided more by provider preference than by the patient's overall clinical status, although other confounding variables cannot be excluded. Unfortunately, our study was underpowered for measuring the effects of individual anesthesiologists on monitor

selection. Furthermore, we lacked detailed data about management goals or how certain decisions were made, especially data regarding decisions on the type of monitors selected.

Our multivariable regression analysis showed a significant association between hospital LOS and monitor selection. Although the evidence suggested a longer hospital LOS when TEE was used, we note that these results are likely skewed by a small number of extended hospitalizations. For example, 1 patient in the TEE group underwent 2 liver transplant operations during a 147-day hospitalization.

Although patients in the TEE + PAC group had the shortest hospital LOS and lowest 30-day mortality rate, the higher proportion of patients with a new postoperative need for dialysis is a discordant result. This finding could have several underlying mechanisms. First, the choice of monitoring approach for patients with presumed marginal renal function may have been subject to selection bias. Second, the TEE +

**TABLE 2.**  
**Primary analysis, intraoperative and postoperative characteristics**

Characteristic <sup>a</sup>	TEE only (n = 38)	PAC only (n = 200)	PAC + TEE (n = 78)	P <sup>b</sup>
Intraoperative volume infusion, mL				
Total	6732 (5500-8136)	6949 (5286-8596)	5741 (4362-7287)	0.012
Colloid	1505 (1003-2497)	1503 (1000-2010)	1004 (501-2000)	0.15
Crystalloid	5030 (3988-6579)	5474 (4024-6754)	4123 (3561-5786)	0.01
Blood product administration				
Any RBC transfusion	31 (81.6)	161 (80.5)	57 (73.0)	0.08
RBC, total, mL	1314 (640-2331)	1650 (963-2330)	1320 (661-1664)	0.25
Any FFP transfusion	32 (84.2)	151 (75.5)	49 (62.8)	0.03
FFP, total, mL	1179 (582-2704)	1661 (533-2729)	1213 (895-1958)	0.26
Any platelet transfusion	18 (47.3)	116 (58.0)	34 (43.6)	0.07
Platelet, total, mL	408 (204-686)	562 (289-899)	293 (205-564)	0.10
Any cryoprecipitate transfusion	21 (55.3)	92 (46.0)	32 (41.0)	0.35
Cryoprecipitate, total, mL	208 (166-388)	215 (190-401)	202 (179-351)	0.45
Any cell salvage transfusion	31 (81.6)	161 (80.5)	66 (84.6)	0.73
Cell salvage transfusion, total, mL	1083 (587-2154)	1167 (612-2265)	934 (418-1436)	0.13
Total infusion, mL	10886 (8245-14248)	10213 (7808-14465)	8330 (6339-11940)	0.02
Total cumulative OR time with MAP < 60 mm Hg, min	76 (44-127)	217 (168-287)	183 (132-239)	<0.0001
Vasoactive infusions				
Ephedrine bolus	16 (42)	98 (49)	44 (56.4)	0.32
Total ephedrine, mg	0 (0-31.3)	0 (0-20)	10 (0-31.3)	0.39
Total phenylephrine, µg	1300 (825-2375)	1000 (400-1688)	900 (300-1700)	0.04
Phenylephrine infusion	3 (7.9)	6 (3.0)	2 (2.6)	0.28
Total norepinephrine, µg	21.3 (0-1211)	0.75 (0-294)	0.5 (0-203)	0.38
Norepinephrine infusion	27 (71.1)	105 (52.5)	40 (51.3)	0.09
Total epinephrine, µg	20 (0-40)	20 (0-50)	20 (0-36.3)	0.07
Epinephrine infusion	3 (7.9)	11 (5.5)	3 (3.8)	0.66
Total vasopressin, units	0 (0-5.2)	0 (0-2.7)	0 (0-3.7)	0.68
Vasopressin infusion	10 (26.3)	21 (10.5)	13 (16.7)	0.03
Any vasopressor infusion	30 (78.9)	113 (56.5)	45 (57.7)	0.03
Hospital LOS, d	10.6 (6.3-19.0)	9.1 (6.9-15.7)	8.6 (6.9-18.9)	0.03
ICU LOS, d	1.8 (1.2-3.0)	1.5 (1.1-2.7)	1.4 (1.1-3.0)	0.63
Duration of postoperative mechanical ventilation, h	7.6 (3.5-45.5)	8.7 (4.1-18.6)	7.7 (4.0-14.1)	0.34
Return to operating room within 7 d of transplant	4 (10.5)	27 (13.5)	12 (15.4)	0.77
Organ rejection	13 (34.2)	58 (29.0)	22 (28.2)	0.78
New postoperative need for dialysis	2 (5.3)	1 (0.5)	8 (10.3)	<0.001
Myocardial infarction	0 (0)	3 (1.5)	2 (2.6)	0.58
Cerebrovascular complication	1 (2.6)	0 (0)	0 (0)	0.03
Hepatic artery thrombosis	1 (2.6)	4 (2.0)	3 (3.8)	0.68
Death within 30 d of transplant	5 (12.8)	7 (3.5)	1 (1.3)	0.047

<sup>a</sup>Continuous variables are presented as median (interquartile range) and categorical variables as No. (%).

<sup>b</sup>Univariable comparisons between continuous variables were assessed with ANOVA, and comparisons between categorical or nominal were assessed with the Pearson  $\chi^2$  test.

FFP, fresh frozen plasma; ICU, intensive care unit; LOS, length of stay; MAP, mean arterial pressure; OR, operating room; PAC, pulmonary artery catheter; RBC, red blood cells; TEE, transesophageal echocardiography.

PAC group received the lowest total volume of all infusions; conservative fluid management, more time with MAP < 60 mm Hg (compared to the TEE group), and a higher rate of vasoactive medication use (compared to the TEE group) may have contributed to a decline in postoperative kidney function. Further examination of acute kidney injury and its postoperative management were not pursued as this was outside the scope of design of the present study.

In our secondary analysis (TEE versus no-TEE), hospital LOS and 30-day mortality rate were not significantly different between the 2 groups, suggesting that the combination of TEE and PAC provides a synergistic benefit. We also noted that the TEE group had a lower total volume of infusions and that patients in this group more commonly had a new postoperative need for dialysis. A possible explanation is that these

patients were managed more conservatively regarding volume administration. Nevertheless, the other outcomes were similar for TEE versus no-TEE patients, suggesting that the TEE interpretation was consistent and appropriate. Notably, none of the patients newly requiring dialysis had undergone a combined kidney–liver transplant; those patients already were receiving dialysis.

Our practice is to remove the TEE probe at the conclusion of surgery, and the majority of PACs are removed at that time as well. Ongoing use of PAC during the immediate postoperative period, when patients are in a dedicated ICU, could influence outcome. However, PAC management in the ICU and its effects on outcomes, along with ICU management of these cases in general, were beyond the scope of the current study.

**TABLE 3.**  
**Secondary analysis, intraoperative and postoperative characteristics**

Characteristic <sup>a</sup>	TEE (n = 116)	No-TEE (n = 200)	P value <sup>b</sup>
Intraoperative volume infusion, mL			
Total	6070 (4936-7912)	6949 (5286-8596)	0.02
Colloid	1500 (989-2009)	1503 (1000-2010)	0.53
Crystalloid	4561 (3665-6039)	5474 (4024-6754)	0.006
Blood product administration			
Any RBC transfusion	91 (78.4)	164 (82.0)	0.44
RBC, total, mL	1319 (660-1840)	1650 (963-2330)	0.06
Any FFP transfusion	81 (69.8)	151 (75.5)	0.27
FFP, total, mL	1189 (791-2201)	1661 (928-2729)	0.16
Any platelet transfusion	52 (44.8)	116 (58.0)	0.03
Platelet, total, mL	338 (205-567)	562 (289-898)	0.004
Any cryoprecipitate transfusion	53 (45.7)	92 (46.0)	0.96
Cryoprecipitate, total, mL	206 (179-378)	215 (190-401)	0.38
Any cell salvage transfusion	97 (83.6)	161 (80.5)	0.49
Cell salvage transfusion, total, mL	1002 (459-1810)	1167 (612-2265)	0.17
Total infusion, mL	9219 (6589-12 350)	102 013 (7808-14 465)	0.01
Hospital LOS, d	9.1 (6.8-18.7)	9.1 (6.9-15.7)	0.73
ICU LOS, d	1.5 (1.1-3.0)	1.5 (1.1-2.7)	0.78
Duration of postoperative mechanical ventilation, h	7.7 (4-16.7)	8.7 (4.3-18.6)	0.61
Return to operating room within 7 d of transplant	16 (13.8)	27 (13.5)	0.94
Organ rejection	35 (30.2)	58 (29.0)	0.83
New postoperative need for dialysis	10 (8.6)	1 (0.5)	<0.001
Myocardial infarction	2 (1.7)	3 (1.5)	0.88
Cerebrovascular complication	1 (0.9)	0 (0)	0.19
Hepatic artery thrombosis	4 (3.4)	4 (2.0)	0.43
Death within 30 d of transplant	5 (4.3)	7 (3.5)	0.71

<sup>a</sup>Continuous variables are presented as median (interquartile range) and categorical variables as No. (%).

<sup>b</sup>Comparisons between continuous variables were assessed with the Wilcoxon signed rank sum test, and comparisons between categorical or nominal were assessed with the Fisher exact test. FFP, fresh frozen plasma; ICU, intensive care unit; LOS, length of stay; RBC, red blood cells; TEE, transesophageal echocardiography.

The anesthesiologists in our group have varying levels of TEE training and experience, ranging from no formal training to board certification in advanced perioperative TEE. This TEE experience mix is consistent with that of other transplant anesthesiologist groups.<sup>7</sup> The effects of differing levels of training, certification, and experience on the interpretation of TEE data are unclear in the liver transplant setting. Likewise, anesthesiologists are often assumed to be experts in interpreting PAC data, and this assumption may not always be true. With a general decrease in the use of PAC, such issues may become more prevalent, depending on training and experience.<sup>13-15</sup> Placement of TEE and PAC is not without risks and complications either. However, the incidence of complications is low, even when TEE and PAC are both used.<sup>16,17</sup>

This study has several limitations. First, this retrospective review had all the limitations inherent in such a design and available data were limited to what was in our databases. Second, no monitoring system by itself affects clinical outcomes. It is the provider interpreting the data and acting on the interpretation who influences outcomes. Our series contained a number of cases that were managed by more than 1 anesthesiologist, and it was not possible to determine the primary anesthesiologist whose management had the most pronounced effect on each case. The remaining cases managed with a sole anesthesiologist were too few for any meaningful analysis. Because of this, the anesthesiologist variable is likely an unmeasured cofounder although available evidence does not support or refute this claim. Third, our TEE system does not capture or store intraoperative video clips

or images for later review, and our practice does not document intraoperative TEE findings. Thus, we could not review cases to determine what could have affected clinical decision-making. However, most patients undergoing OLT have abnormal findings with TEE,<sup>6</sup> and these abnormalities commonly affect clinical decisions. Fourth, we had a relatively small sample size and a small number of events in some result categories and the study was underpowered to detect numerous outcomes. Thus, additional multivariable modeling was not pursued because of concerns with model overfitting. Finally, only limited donor characteristics were available and there was no difference in cold or warm ischemia times.

In conclusion, patients managed with TEE + PAC had the shortest hospital LOS and the lowest 30-day mortality rate. Transplant anesthesiologists should be aware of the potential benefits of using these monitors concurrently during OLT. Additional studies are needed. Ideally, these would include a randomized controlled trial design incorporating multiple institutions to confirm our findings and to elucidate the mechanism underlying these effects. Further studies examining the need for new postoperative dialysis after OLT would also be beneficial.

## ACKNOWLEDGMENT

We thank Phillip J. Schulte, PhD, for his assistance with statistical analysis and Kimberly D. Evans, RRT, LRT, for her assistance with data acquisition.

## REFERENCES

1. Dalia AA, Flores A, Chitilian H, et al. A comprehensive review of transesophageal echocardiography during orthotopic liver transplantation. *J Cardiothorac Vasc Anesth.* 2018;32(4):1815–1824.
2. Isaak RS, Kumar PA, Arora H. PRO: transesophageal echocardiography should be routinely used for all liver transplant surgeries. *J Cardiothorac Vasc Anesth.* 2017;31(6):2282–2286.
3. Peiris P, Pai SL, Aniskevich S 3rd, et al. Intracardiac thrombosis during liver transplant: a 17-year single-institution study. *Liver Transpl.* 2015;21(10):1280–1285.
4. De Wolf AM. Pulmonary artery catheter: rest in peace? Not just quite yet. *Liver Transpl.* 2008;14(7):917–918.
5. Schumann R, Mandell MS, Mercaldo N, et al. Anesthesia for liver transplantation in united states academic centers: intraoperative practice. *J Clin Anesth.* 2013;25(7):542–550.
6. Shillcutt SK, Ringenberg KJ, Chacon MM, et al. Liver transplantation: intraoperative transesophageal echocardiography findings and relationship to major postoperative adverse cardiac events. *J Cardiothorac Vasc Anesth.* 2016;30(1):107–114.
7. Soong W, Sherwani SS, Ault ML, et al. United states practice patterns in the use of transesophageal echocardiography during adult liver transplantation. *J Cardiothorac Vasc Anesth.* 2014;28(3):635–639.
8. von Elm E, Altman DG, Egger M, et al.; STROBE Initiative. The strengthening the Reporting of Observational Studies in Epidemiology (STROBE) statement: guidelines for reporting observational studies. *Lancet.* 2007;370(9596):1453–1457.
9. Herasevich V, Kor DJ, Li M, et al. ICU data mart: a non-IT approach. A team of clinicians, researchers and informatics personnel at the Mayo Clinic have taken a homegrown approach to building an ICU data mart. *Healthc Inform.* 2011;28(11):42, 44–45.
10. Chute CG, Beck SA, Fisk TB, et al. The enterprise data trust at mayo clinic: a semantically integrated warehouse of biomedical data. *J Am Med Inform Assoc.* 2010;17(2):131–135.
11. Singh B, Singh A, Ahmed A, et al. Derivation and validation of automated electronic search strategies to extract Charlson comorbidities from electronic medical records. *Mayo Clin Proc.* 2012;87(9):817–824.
12. Alsara A, Warner DO, Li G, et al. Derivation and validation of automated electronic search strategies to identify pertinent risk factors for postoperative acute lung injury. *Mayo Clin Proc.* 2011;86(5):382–388.
13. Jacka MJ, Cohen MM, To T, et al. Pulmonary artery occlusion pressure estimation: how confident are anesthesiologists? *Crit Care Med.* 2002;30(6):1197–1203.
14. Marik P, Heard SO, Varon J. Interpretation of the pulmonary artery occlusion (wedge) pressure: physician's knowledge versus the experts' knowledge. *Crit Care Med.* 1998;26(10):1761–1764.
15. Komadina KH, Schenk DA, LaVeau P, et al. Interobserver variability in the interpretation of pulmonary artery catheter pressure tracings. *Chest.* 1991;100(6):1647–1654.
16. Evans DC, Doraiswamy VA, Prosciak MP, et al. Complications associated with pulmonary artery catheters: a comprehensive clinical review. *Scand J Surg.* 2009;98(4):199–208.
17. Mathur SK, Singh P. Transoesophageal echocardiography related complications. *Indian J Anaesth.* 2009;53(5):567–574.