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TEE image quality improvement with our devised probe cover

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Abstract

Objective(s): Our hypothesis was that our devised transesophageal echocardiography probe cover with the capacity for pinpoint suction would improve image quality.

Design: Prospective cohort study.

Setting: Single tertiary medical center.

Participants: Patients undergoing surgery requiring intraoperative transesophageal echocardiography.

Interventions: Suctioning with inserted orogastric tube.

Measurements and main results: Changes in image quality with suctioning were assessed by 2 methods. In method #1, investigators categorized the quality of all acquired images on a numeric scale based on each investigator's impression (1: very poor, 2: poor, 3: acceptable, 4: good, and 5: very good). In method #2, the reproducibility of the left ventricular fraction area change (LV FAC) was assessed, assuming that improved transgastric midpapillary short-axis view image quality would yield better LV FAC reproducibility.

With method #1, for midesophageal views, 26.5%, 70.5%, and 3.0% of images showed improved, the same, and worsened image quality, respectively. For transgastric views, 55.3%, 43.3%, and 1.4% showed improved, the same, and worsened image quality, respectively. For deep transgastric views, 60.0%, 38.0%, and 2.0% showed improved, the same, and worsened image quality, respectively.

With method #2, the presuction group had an ICC of 0.942 (95% CI: 0.91, 0.965). The postsuction group had an ICC of 0.988 (95% CI: 0.981, 0.993).

Conclusions: Our investigation validates the potential image quality improvement withour devised TEE probe cover. However, its clinical validity needs to be confirmed by further studies.

KEYWORDS
probe cover image quality, Transesophageal echocardiography

1 | INTRODUCTION

Transesophageal echocardiography (TEE) has been in clinical use for decades,[1] and it has become a standard intraoperative diagnostic technique for cardiac and noncardiac surgeries.[2–6] As TEE plays a major role in quantitative and qualitative cardiac evaluations, high accuracy of these assessments is in demand.[7,8] Even with recent remarkable progress in spatial resolution and postprocessing,[9–14] image quality still has room for improvement with the assistance of ultrasound (US).[15–18] On the other hand, we frequently experience suboptimal image quality due to a number of factors; one of which is considered to be stomach distension secondary to gas formation and/or fluid secretion.[18,19] Clinically, an orogastric tube (OG tube) is often inserted at the beginning of the procedure and left there for intermittent suction as needed or removed before the TEE exam to prevent echoic artifacts. Bainbridge et al. reported the negative effect of this practice on image quality in cardiac surgery.[15] However, the challenges are that the effect of suction might be limited due to the unreliable position of the OG tube tip if the tube is left indwelling. On the other hand, the stomach will become distended again once the OG tube is removed. Recently, we reported the potential use of an OG tube attached to a TEE probe to improve image quality with real-time pinpoint suctioning.[18] In this prospective study, we devised a double-lumen TEE probe cover that allows the OG tube to pass through as needed and assessed the suction effect on the image quality in surgeries requiring intraoperative TEE monitoring. Our hypothesis was that this devised TEE probe cover with the capacity for pinpoint suction would yield improved image quality without causing device-related complications.

2 | METHODS

2.1 | Study design

This study was designed as a two-point evaluation at a single tertiary care medical center. This study was approved by the Henry Ford Health System Institutional Review Board (IRB #11958), and written consent was obtained from patients before enrollment. Additionally, this study was registered at ClinicalTrial.gov (NCT 03812185). This was a prospective, observational study of a cohort of adult patients who underwent surgeries requiring intraoperative TEE between January 2019 and December 2019 at Henry Ford Hospital in Detroit, MI. TEE data were collected from intraoperative TEE images as part of a prospective echocardiographic protocol using 2-dimensional (2D) TEE views. The demographics, perioperative clinical information, and postoperative outcomes of these patients were collected from our computerized patient database.

2.2 | Patient cohort

Adult patients undergoing surgeries requiring intraoperative TEE between January 2019 and December 2019 were included. The exclusion criteria were patient refusal to participate in the study, absolute contraindication to TEE, significant wall motion abnormality that hindered measurement of the left ventricular fraction area change (LV FAC), and inability to advance the OG tube through the TEE probe cover. All patients received general anesthesia with endotracheal intubation, standard American Society of Anesthesiologists monitoring, arterial blood pressure monitoring, central venous pressure monitoring, pulmonary artery pressure monitoring, and a comprehensive TEE examination with a designated protocol. Intraoperative management with anesthetics, mechanical ventilation, vasopressors, inotropic agents, and fluids/transfusions was performed based on department protocols, such as maintaining a mean arterial pressure > 65 mmHg, tidal volume 6–8 mL/ideal body weight (kg), and positive end-expiratory pressure 5–7 cmH_2O.

2.3 | Data collection

After general anesthesia induction, our newly designed TEE probe cover (Figure 1; Fuji Medical, Tokyo, Japan) was attached to the X7 TEE probe (Philips Medical Systems, Andover, MA) and inserted into the patient's esophagus, and an OG tube (Salem Sump nasogastric tube, 16 Fr., Covidien, Minneapolis, MN) was advanced through the second lumen of the TEE probe cover. The length of advanced OG tube was adjusted so that the tip of OG tube would be 2–3 cm out of the second lumen. TEE images were intraoperatively collected by National Board of Echocardiography (NBE)-certified advanced perioperative echocardiographers, who are blinded to this study design, using an iE33 echocardiographic machine (Philips Medical Systems, Andover, MA) and stored in Syngo Workflow (Siemens Medical Solution, Malvern, PA, USA). The designated views for TEE images were as follows: midesophageal 4-chamber view (ME4C), midesophageal 2-chamber view (ME2C), midesophageal aortic valve short-axis view (ME AV SAX), midesophageal long-axis view (ME LAX), midesophageal bicaval view (ME BIC), transgastric midpapillary short-axis view (TG Mid SAX), and deep transgastric long-axis view (DTG LAX). Image acquisition was performed twice, before and after OG tube suctioning, when the baseline TEE assessment was performed after general anesthesia induction. Suction was performed for 1 minute at > -110 cm H2O, and the amount and characteristics of the suctioned content were recorded. While acquiring these views, the TEE device setting was not changed, and the iSCAN button was pressed before video acquisition.[10–13]

2.4 | Image quality assessment

TEE image quality was assessed in 2 different ways based on the TEE images acquired before and after suctioning. In the first method (method #1), the investigators categorized the quality of all acquired images on a numeric scale based on each investigator's impression (1: very poor, 2: poor, 3: acceptable, 4: good, and 5: very good). In the second method (method #2), the reproducibility of the LV FAC and right ventricular fraction area change (RV FAC) was assessed, assuming that better TG Mid SAX and ME4C image quality would yield better LV FAC and RV FAC reproducibility, respectively.[18] LV FAC was calculated using TG Mid SAX, while RV FAC was calculated using ME4C.

Three investigators (A, B, and C), who were also NBE-certified advanced perioperative echocardiographers, assessed the quality of all TEE images post hoc. Thus, 50 × 3 sets of images for each were evaluated to determine the interobserver variability. Subsequently, following an interval of between 6 and 8 months, investigator C again analyzed all images to determine the intraobserver variability. To minimize selection bias, all investigators were blinded to the hypothesis of the study. Additionally, all investigators were blinded to which images were obtained before or after suctioning.

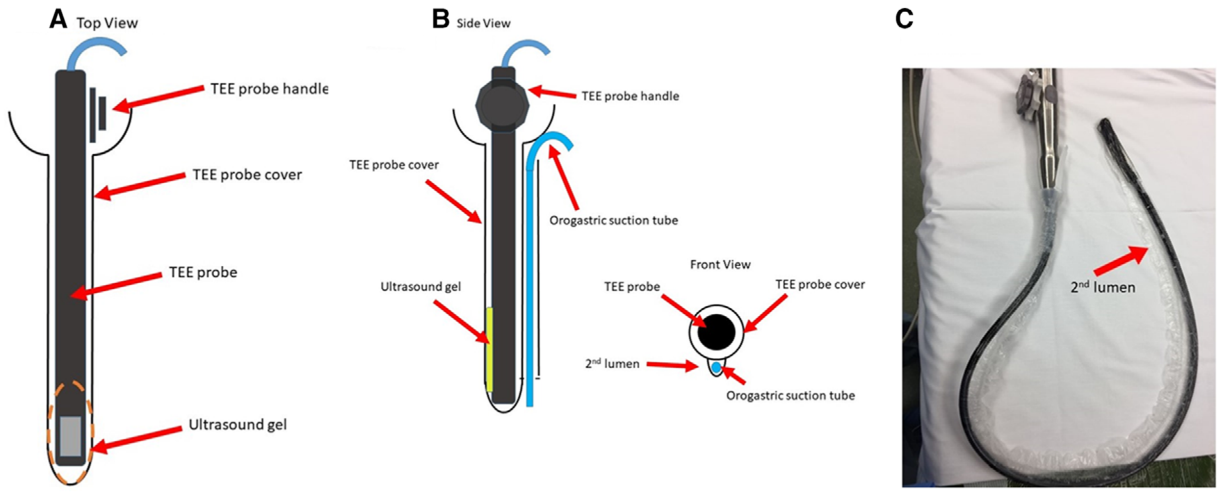

FIGURE 1 Our newly designed TEE probe cover (made by Fuji Medical, Tokyo, Japan). Abbreviation: TEE, transesophageal echocardiography

2.5 | Outcomes

The quality of images obtained before and after pinpoint suctioning with our newly designed TEE probe cover was assessed using the following views: ME4C, ME2C, ME AV SAX, ME LAX, ME BIC, TG Mid SAX, and DTG LAX. As described in method #1, post hoc assessments were performed using image quality categorized as discrete numbers based on each investigator's impression (1: very poor, 2: poor, 3: acceptable, 4: good, and 5: very good) before and after suctioning. Image quality improvement was defined as an increase in this number. Additionally, as described in method #2, the LV FAC was also assessed post hoc for intraclass correlation coefficient (ICC) analysis. Furthermore, we assessed the occurrence of TEE probe-related complications (postoperative severe sore throat, dysphagia, bloody aspirate from the OG tube) and the suctioned volume.

2.6 | Statistical analysis

Continuous variables with a normal distribution are displayed as the mean ± standard deviation, while those variables with a nonnormal distribution are displayed as the median and interquartile range. Categorical variables are presented as proportions and absolute numbers. For continuous variables, normality was tested using the Kolmogorov-Smirnov test.

The differences between 2 groups were investigated using the chi-square test or Fisher's exact test if any of the expected frequencies were < 5 for categorical variables and unpaired and paired Student's t-tests or the Mann-Whitney U test for continuous variables. Differences among 3 groups were investigated using Fisher's exact test for categorical variables and one-way ANOVA or the Kruskal-Wallis test for continuous variables.

Intraobserver and interobserver reliability analyses of the LV FAC and RV FAC were performed using the ICC.[20–22] We obtained consistency ICCs for interobserver variability using all three investigators and absolute-agreement ICCs for intraobserver variability using investigator C, who measured all images twice at an interval between 6 and 8 months. The proportion of cases showing improvement using the numeric scale and the occurrence of TEE probe-related complications (severe sore throat, dysphagia, and bloody aspirate from the OG tube) are also reported for descriptive assessment. The change in image quality according to the numeric scale (method #1) was averaged for the same case, and its association with the suctioned volume was assessed using Pearson's or Spearman's rank correlation test. All statistical analyses were performed with R (version 4.0.2). A p-value of less than 0.05 was considered statistically significant.

2.7 | Sample size calculation

According to our preliminary results,[18] enrolling 42 patients was determined to provide at least 90% power to detect a difference of 0.12 between the pre- and postsuction interobserver ICC and intraobserver ICC, respectively, with a significance level (alpha) of 0.05.[20–22] Therefore, the power analysis indicated that we needed at least 42 patients.

3 | RESULTS

Fifty-three patients (35 undergoing open heart surgery and 18 undergoing orthotopic liver transplantation (OLT)) consented to participate in this study. Three patients were excluded due to resistance to OG tube advancement. The remaining 50 patients (33 undergoing open heart surgery and 17 undergoing OLT) were enrolled, and appropriate images were stored (Figure 2). Transesophageal echocardiography image quality improvement with suctioning orogastric tube is shown in Figure 3.

Table 1 shows patient demographics and characteristics regarding open heart surgery and OLT. Table 2 lists changes in image quality with OG tube suctioning recorded by the 3 investigators. Table 3 lists the ICCs for the LV FAC and RV FAC measured by the 3 investigators.

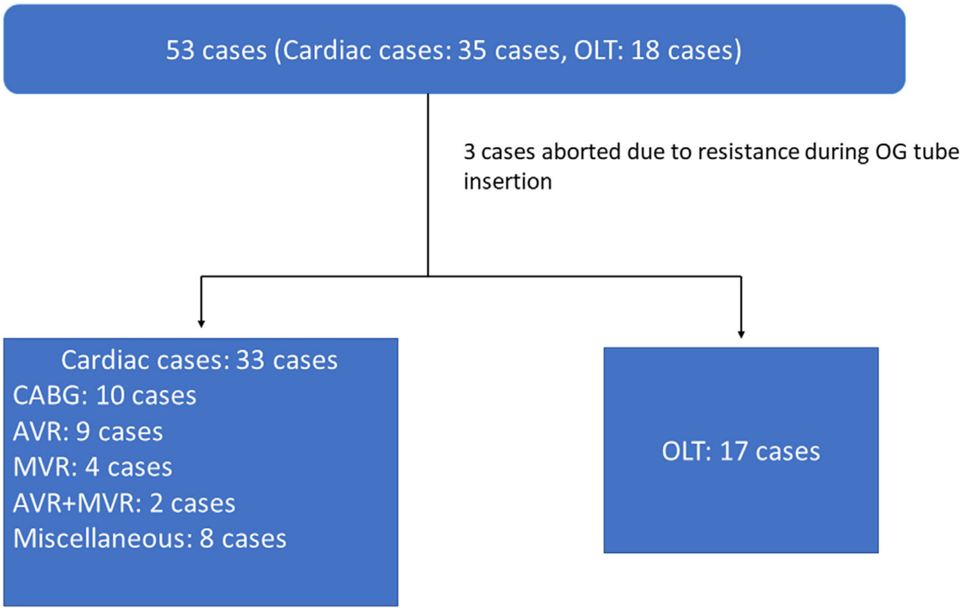

FIGURE 2 Flow of patients enrolled in this study. Abbreviations: AVR, aortic valve replacement; CABG, coronary artery bypass graft; MVR, mitral valve repair; OLT, orthotopic liver transplantation

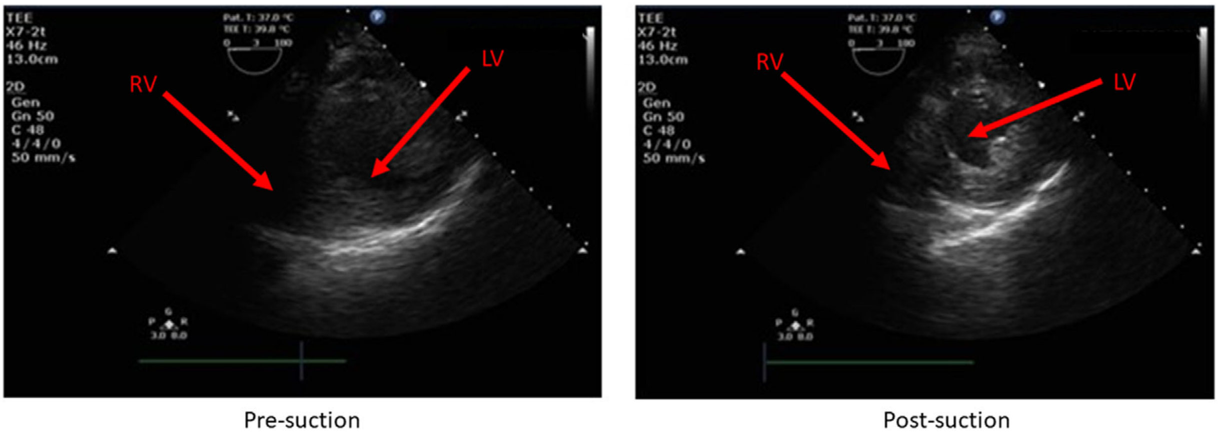

FIGURE 3 Transesophageal echocardiography image quality improvement with suctioning orogastric tube. Note that echocardiography setting stayed the same before and after suctioning

3.1 | Image quality change with suctioning

Method #1

For all five ME views, on average, 26.5% of images showed improved image quality, 70.5% showed the same image quality, and 3.0% showed worsened image quality. For TG views, 55.3% showed improved image quality, 43.3% showed the same image quality, and 1.4% showed worsened image quality. For DTG LAX views, 60.0% showed improved image quality, 38.0% showed the same image quality, and 2.0% showed worsened image quality (Table 1).

Method #2

LV FAC

The interobserver and intraobserver variance assessments are summarized in Table 3-A.

RV FAC

The interobserver and intraobserver variance assessments are summarized in Table 3-B.

3.2 | Image quality change with suctioning and suction volume

For the ME, TG, and DTG views, there was no correlation between the change in image quality and the suction volume ($p = 0.30$, 0.31, and 0.91, respectively).

TABLE 1 Patient demographics

	Open heart surgery (n = 33)	OLT (n = 17)	*p*-value
Age (years)	61 [48, 68]	59 [48, 67]	0.73
Male	21 (63.6%)	12 (70.6%)	0.76
BMI	27.8 [24.3, 32.3)	29.4 [28.0, 33.8)	0.14
Noncompliance with NPO guideline	0 (0%)	3 (17.6%)	0.01
DM	14 (42.4%)	4 (23.5%)	0.23
HTN	25 (75.8%)	9 (52.9%)	0.12
GERD	14 (42.4%)	4 (23.5%)	0.23
CKD (> stage III)	3 (9.1%)	0 (0%)	0.54
CVA	4 (12.1%)	0 (0%)	0.29
Abdominal surgery history	3 (9.1%)	1 (5.9%)	1.0
Preoperative opioid use	18 (54.5%)	4 (23.5%)	0.070
Stomach distension	Could not be determined	10 (58.9%)	NA
Blood in aspirate	2 (6.1%)	3 (17.6%)	0.32
Postoperative dysphagia	1 (3.0%)	0 (0%)	1.0
Postoperative severe sore throat	2 (6.1%)	0 (0%)	0.54
Suction volume (mL)	0 [0, 30]	100 [80, 170]	<0.01

Demographic data and characteristics of patients. Values are shown as the mean +/- SD, interquartile range, or number (%) of patients.
Note that DM, a history of abdominal surgery, and opioid use are risk factors for a delayed gastric emptying time.[19.]
Abbreviations: BMI, body mass index; CKD, chronic kidney disease; CVA, cerebrovascular accident; DM, diabetes mellitus; GERD, gastroesophageal reflux disease; HTN, hypertension; OLT, orthotopic liver transplantation.

TABLE 2 Image quality change for each TEE view with OG tube suctioning (method #1)

	Views from the esophagus					Views from the stomach	
	ME4C	ME2C	ME AV SAX	ME LAX	ME BIC	TG MID SAX	DTG LAX
Improved	23 (15.3%)	48 (32.0%)	56 (37.3%)	35 (23.3%)	37 (24.7%)	83 (55.3%)	90 (60%)
Remained the same	121 (80.7%)	98 (65.3%)	89 (59.3%)	112 (74.7%)	109 (72.7%)	65 (43.3%)	*57 (38%)*
Worsened	6 (4.0%)	4 (2.7%)	5 (3.4%)	3 (2.0%)	4 (2.6%)	2 (1.4%)	3 (2.0%)

Abbreviations: DTG LAX, deep transgastric long-axis view; ME AV SAX, midesophageal aortic valve short-axis view; ME BIC, midesophageal bicaval view; ME LAX, midesophageal long-axis view; ME2C, midesophageal 2-chamber view; ME4C, midesophageal 4-chamber view; OG, orogastric; TEE, transesophageal echocardiography; TG Mid SAX, transgastric midpapillary short-axis view.

3.3 | Complications

Significant sore throat was noted in 2 patients (4.0%), dysphagia was noted in 1 patient (2.0%), and bloody aspirate from the OG tube was noted in 5 patients (10.0%). No other clinically major TEE-related complications, such as vocal cord palsy, significant oral bleeding, or tooth damage, were noted.[23–29]

In OLT, stomach distention was noted intraoperatively in 10 out of 17 patients (58.9%) by the surgeon, and the stomach shrank after suction in all 10 cases.

4 | DISCUSSION

Our study shows the potential of this newly devised TEE probe cover with the capacity for pinpoint suction to contribute to improving image quality. Our study is novel because we performed an assessment using 2 methods to mitigate this subjectivity. In method #1, a numeric scale was used by 3 investigators to categorize the quality of each image. In method #2, the inter- and intraobserver variance of LV FAC and RV FAC measurements were assessed using ICCs based on the assumption that better image quality would yield less inter- and intraobserver variance. Our rationale for choosing the RV FAC and LV FAC for assessment was to compare the effect of suction on midesophageal (ME) and transgastric (TG) views. Our results show that the image quality of TG views was significantly better with suction, while the image quality of ME views was not (method #1). This difference can be explained as follows: for TG views, the OG tube was in stomach, and the suction allowed the stomach to shrink if it was distended, reducing the media present between the TEE transducer and the heart; for ME views, the OG tube was in the esophagus, and the suction did not greatly affect the distance between the TEE transducer and the heart. Modern

TABLE 3A Intraclass correlation coefficients (ICCs) of LV FAC before and after suction

	Group	ICC	95% CI
Interobserver	Presuction	0.94	(0.91, 0.96)
	Postsuction	0.99	(0.98, 0.99)
Intraobserver	Presuction	0.95	(0.91, 0.97)
	Postsuction	1.00	(0.99, 1.00)

Note that the relationship between the reliability and the ICC is as shown below[7];

ICC	Reliability
> 0.90	Excellent
0.75 - 0.90	Good
0.50 - 0.75	Moderate
< 0.50	Poor

Note that the 95% confidence interval (CI) of ICC for post suction does not overlap with presuction, indicating the significant improvement of image quality after suction.
Abbreviations: CI,. confidence interval; LV FAC, left ventricular fraction area change.

TABLE 3B Intraclass correlation coefficient (ICC) of RV FAC before and after suction

	Group	ICC	95% CI
Interobserver	Presuction	0.89	(0.84, 0.92)
	Postsuction	0.90	(0.86, 0.94)
Intraobserver	Presuction	0.88	(0.81, 0.92)
	Postsuction	0.85	(0.84, 0.90)

Note that the 95% confidence interval (CI) of ICC for post suction overlaps with presuction, indicating no significant improvement of image quality after suction.
Abbreviations: CI, confidence interval; RV FAC, right ventricular fraction area change.

echocardiographic machines have automatic adjustment systems that optimize the spatial resolution and postprocessing by time-gain compensation, receiver gain, and system compression maps.[8–14] However, even with these technologies, intermediating gas between the ultrasound transducer and objects will significantly negatively affect image quality because of ultrasound velocity differences in different media.[11–13]

With method #2, relatively poor reproducibility was found for the RV FAC compared with the LV FAC. This can be explained not only by the greater effect of suction on image quality for TG Mid SAX (for the LV FAC) than ME4C (for the RV FAC) but also by the difficulty in tracing the RV endocardial border by planimetry due to the complex geometry and the heavy trabeculation of the right ventricle.[11–13] Comparing the pre- and post-suctioning ICCs, in terms of both the interobserver and intraobserver reliability (Table 2), the 95% CI of the ICCs of the LV FAC but not the RV FAC improved without range overlapping after OG tube suctioning. This suggests that significant improvement in image quality in TG views (for LV FAC) resulted in improvement in the interobserver and intraobserver variability of the LV FAC.

In our study, we were unable to measure the volume of air suctioned, but our results show that there was no correlation between the volume of liquid suctioned and the change in image quality. This was not surprising given the similar ultrasound velocity in tissue and liquid.[11–13] On the other hand, our findings of TG image improvement with suction support that we were effectively able to remove air between the TEE transducer and stomach wall with our devised TEE probe cover and the OG tube. The utility of our devised TEE probe cover and the OG tube for shrinking the stomach intraoperatively was confirmed by surgeons in 58.9% of OLT cases. Bainbridge et al. previously reported that intraoperative OG tube suction did not significantly change TEE image quality.[15] Although their image quality assessment strategy was different from ours, we propose that our devised TEE probe cover with the OG tube had the capacity to achieve a more practical effect with pinpoint suction. Our study shows similar results as our preliminary study with an OG tube attached to a TEE probe,[18] but our devised TEE probe cover with the OG tube has an advantage in terms of patient safety because the OG tube was guided toward the tip of the probe through the double lumen with the TEE probe serving as a “guide rail” to avoid traumatic complications affecting the surrounding tissue.

Our pinpoint suction strategy has additional potential benefits. With better image quality, echocardiographers will be able to avoid excessive probe manipulation, which would lead to less trauma to surrounding tissue. Trauma to surrounding tissue caused by a TEE probe is, albeit rarely critical, especially concerning in cardiac patients requiring full heparinization, in aortic stenosis patients who commonly have acquired von Willebrand disease and angiodysplasia,[30,31] and in end-stage liver disease patients who commonly have esophageal or gastric varices as well as coagulopathy.[32,33] Especially in aortic stenosis patients, TG or DTG TEE views are useful for assessment of the aortic valve pressure gradient and valve integrity, and it is very important to minimize unnecessary manipulation of the TEE probe.

Our investigation has several limitations. This study is limited by the single-center data set. Furthermore, image quality assessment can be subjective, although we incorporated the intra- and interobserver variability for specific measurement of the RV FAC and LV FAC in addition to numeric categorization of the image quality based on each investigator’s impression. Additionally, our investigation does not include an assessment of how these image quality improvements would benefit patient care, including any effects on surgical decision making. These points need to be investigated for further studies. This is going to be very important given that TEE will play an increasingly critical role in the future with an increasing number of less invasive procedures being performed.

In conclusion, our investigation validates the potential image quality improvement achieved using our devised TEE probe cover with an OG tube, which enables pinpoint suctioning around the TEE probe transducer. This image quality improvement might improve patient safety by avoiding unnecessary TEE probe manipulation. However, its clinical validity needs to be confirmed by further studies.

AUTHOR CONTRIBUTIONS

Yoshihisa Morita contributed the study for designing the study, data gathering, and manuscript writing. Taro Kariya for statistical analysis and manuscript writing. Jaber El-Bashir, Dragos Galusca, Jayakar Guruswamy, and Ken Tanaka for data gathering, and helping with manuscript writing.

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