Echocardiographic Monitoring During Induction of General Anesthesia with a Miniaturized Esophageal Probe

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Standard transesophageal echocardiography (TEE) does not allow cardiac monitoring during the induction of anesthesia because standard probes would limit the oropharyngeal space and impair mask ventilation and tracheal intubation. We hypothesized that a prototype, miniaturized TEE probe could be safely introduced transnasally in awake patients and that mask ventilation and orotracheal intubation could be performed while continuously monitoring left ventricular (LV) function during the induction of anesthesia. Forty-five patients were studied prospectively. The transnasal TEE probe was introduced through one of the nares and advanced until a transverse plane image of the LV at the level of the papillary muscles was seen. Anesthesia was induced, and the patients were ventilated with a mask that had previously been threaded over the TEE probe via a central perforation. Probe insertion was successful in 12 patients under local anesthesia alone and in an additional 31 patients with a combination of local anesthesia and mild sedation. In two cases, probe placement was unsuccessful. Overall, hemodynamic variables did not change significantly during insertion. No case of significant mucosal bleeding was seen. In one patient, regurgitation of gastric contents occurred without affecting the perioperative outcome. The two-dimensional echocardiogram image quality of the LV during the induction of anesthesia was good or acceptable in 95% of patients. We conclude that transnasal TEE can effectively be used for cardiac monitoring during the induction of general anesthesia.

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Adverse cardiac events are a major cause of morbidity and mortality after noncardiac surgery in patients with coronary artery disease (1). Because intraoperative myocardial ischemia may be associated with negative cardiac outcomes in this patient population (1), monitoring should aim at early detection of ischemia to possibly prevent further myocardial damage.

Transesophageal echocardiography (TEE) is a sensitive monitor for the detection of intraoperative myocardial ischemia (2). Echocardiographic signs of ischemia can precede electrocardiographic (ECG) abnormalities (3–5). In patients at increased risk of ischemia or infarction, perioperative TEE monitoring may be useful in improving clinical outcomes (3). Diagnosis of new regional wall motion abnormalities (RWMAs), indicative of myocardial ischemia, could allow the clinician to initiate treatment before an adverse outcome occurs—even in the absence of ECG changes (2,6).

In clinical practice, the TEE probe is usually placed after the induction of anesthesia and tracheal intubation (7). Probe insertion before the induction is thought to produce additional stress in the patient and to complicate airway management (8). This means, however, that one of the highest-risk intervals during anesthesia and surgery escapes echocardiographic monitoring (8–11).

We hypothesized that a miniaturized TEE probe (Hewlett-Packard, Andover, MA) (12–14) could be introduced transnasally in awake patients immediately before anesthesia induction and that continuous monitoring of left ventricular (LV) function with TEE could be performed during mask ventilation and endotracheal intubation.

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Methods

After IRB approval and informed, written consent, 45 patients were studied prospectively. The study was

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performed in two phases. In phase 1, 25 patients without known cardiac risk factors or cardiac disease, classified as ASA physical status I or II, were studied. Phase 2 was conducted after the results of phase 1 had been reviewed and consisted of 20 patients with peripheral arterial vasculopathy who showed at least two of the following cardiac risk factors: arterial hypertension, diabetes mellitus, cerebrovascular disease, history of cigarette smoking, or documented coronary artery disease (previous myocardial infarction, typical angina, and positive exercise ECG or stress echocardiography). These patients were scheduled for peripheral vascular surgery and were classified as ASA physical status III. Patients with nasal septum deviation, anatomical variations of the nasopharyngeal area, known hiatus hernia, unstable angina, and bundle branch block in the resting ECG were excluded from the study. Obesity was not included in the exclusion criteria, but all patients were within 20% of their ideal body weight.

The transnasal use of a miniaturized prototype TEE probe has been described previously (12,13,15,16). The probe consists of a 32-element, monoplane imaging head that is 7.3 mm wide, 6.0 mm thick, and 21 mm long. It has a bevel on the imaging surface to aid nasal passage and is connected to a shaft that is 6 mm wide and 90 cm long. The probe allows a choice between 5.0- and 3.7-MHz frequency in two-dimensional mode and has pulse-wave and color Doppler imaging capabilities.

All patients received standard oral premedication with 7.5 mg of midazolam. Routine monitoring, including pulse oximetry, noninvasive blood pressure (NIBP) measurements (unless direct arterial pressure monitoring was clinically indicated), and ECG, was initiated. Continuous multi-lead ST segment analysis was performed by using an integrated anesthesia care monitoring system (Philips Medical Systems, Andover, MA). After the application of vasoconstrictive drops (0.4 mL of 1% xylometazoline) to both nares, topical anesthesia of the naso- and oropharyngeal spaces was achieved with 10% lidocaine spray and 2% lidocaine jelly to lubricate the nasal passage. In phase 1, transnasal probe insertion was initially attempted without further sedation. Only when patients were uncomfortable was additional sedation administered i.v. (2 mg of midazolam and 0.1 mg of fentanyl, incrementally). In phase 2, all patients received further sedation, consisting of 1 or 2 mg of midazolam and 0.05 or 0.1 mg of fentanyl. This was done to minimize hemodynamic reactions, because 44% of the phase 1 patients had experienced some pain or discomfort with topical anesthesia only.

The probe was inserted transnasally, with the imaging head longitudinally, to better fit through the nares. Nasal trumpets were not used. Once the back of the nasal passage was reached, the probe was rotated 90° to a transverse position, and anteflexion was applied (12). When the probe reached the oropharynx, patients were asked to swallow to facilitate its advancement into the esophagus. The transducer was eventually secured manually in a transgastric position to depict a short-axis view of the LV at the level of the papillary muscles. This imaging plane was kept in place by one investigator throughout the induction of general anesthesia to monitor for new RWMA or inadequate systolic wall thickening as signs of myocardial ischemia. The transgastric short-axis view is the single best cross section for ischemia monitoring because myocardium supplied by all three coronary arteries can be visualized (17). Echocardiographic images were analyzed in real time for RWMA and recorded on videotape for later off-line analysis of cardiac function and image quality.

With the transnasal echocardiographic probe in place, general anesthesia was induced with fentanyl 3 μg/kg, thiopental 3–5 mg/kg until loss of the eyelid reflex, and cisatracurium 0.15 mg/kg to facilitate tracheal intubation. After loss of consciousness, patients were ventilated before tracheal intubation for 4 min by using a mask (VBM endoscopy mask; Thomas Medical Inc., Alpharetta, GA) that had previously been threaded over the TEE probe via a removable silicone membrane with a central perforation. Mask ventilation and intubation conditions were rated by the resident performing the anesthesia. Intubation conditions were judged as good, moderate, or poor, on the basis of the scoring of ease of jaw opening and laryngoscopy, position of the vocal cords, and obstruction by the TEE probe. Pulse oximetry readings, heart rate, ST segment analysis, and invasive blood pressure (when available) were continuously monitored until 10 min postintubation. NIBP was measured in 2-min intervals. After probe withdrawal, the imaging head and shaft, as well as the nasal and oral cavity, were inspected for blood to exclude or confirm hemorrhage related to insertion of the TEE probe.

Systolic contraction was graded as normal when both the myocardium thickened and the endocardium moved inward. Abnormal contraction was documented as hypokinesis (diminished thickening), akinesis (absent thickening), or dyskinesis (paradoxical outward movement).

Echocardiographic image quality was assessed off-line from the taped video sequences by two investigators not involved in probe placement or on-line evaluation. The LV was divided into four quadrants (inferior, lateral, anterior, and septal). The image quality for each separate induction phase (preinduction, induction, mask ventilation, and intubation) was rated as good when the endocardial border could be visualized throughout the complete phase, as moderate when it could be visualized through the longest part

of the phase but short image dropouts of <15 s occurred, and as inadequate when the quadrant could not be assessed at all or the echocardiographic image dropped out of view for longer than 15 s.

On the day after surgery, patients were asked to rate their level of pain or discomfort during probe placement on a visual analog scale (VAS) (18) from 0 (no discomfort) to 100 (severe discomfort or pain). Patient assessment was performed by one investigator not involved in the clinical part of the study.

Hemodynamic data were tested for normal distribution by the Kolmogorov-Smirnov test. Mean values were tested for significant differences by using a one-way analysis of variance.

Results

Biometric data of the 45 patients, coexisting diseases, and medications are shown in Tables 1–3. In phase I, 25 ASA status II patients were studied. Transnasal insertion of the TEE probe was successful with topical anesthesia of the nasal and oropharyngeal spaces alone in 12 patients (48%). Eleven patients (44%) required additional IV analgesia or sedation because of discomfort or anxiety. Fentanyl (up to 100 μg) and midazolam (up to 5 mg) were titrated IV until a level of sedation was reached at which patients were somnolent but able to respond to verbal commands. In one patient, probe placement was abandoned because of pain not responsive to fentanyl and in another patient because of anatomical obstructions.

Echocardiographic probe insertion was possible in all 20 phase 2 patients (100%), all of whom received additional sedation. In this group, probe insertion was not attempted without conscious sedation because of the possible negative effects of additional stress or discomfort in patients at risk of myocardial ischemia. For both phases combined, the success rate of probe insertion was 96% (43 of 45 patients).

Hemodynamic variables before, during, and after TEE probe insertion are shown in Table 4. Results for both phases were combined because they did not differ significantly. Mean values of heart rate, systolic blood pressure, diastolic blood pressure, and oxygen saturation did not change significantly during probe insertion. In one patient, however, systolic blood pressure increased from 120 to 150 mm Hg. In addition, four patients (8.9%) had an increase of heart rate of >20% from baseline and >100 bpm. Patient 1 was the subject who had probe placement stopped because of pain on insertion; patient 2 was from phase 1, receiving no additional sedation; patients 3 and 4 were from phase 2, and their medication did not include β-blockers. No ST segment changes were noted in any of these patients.

The mean VAS score rating (pain or discomfort) on the day after surgery showed a mean value of 11.0 ± 7.2. This includes 6 of 20 patients who could not remember probe insertion at all and who were given a VAS score of 0. Exclusion of these patients would result in a VAS of 13.4 ± 5.4. No patient rated introduction of the echocardiography probe worse than 30, which is equivalent to mild to moderate pain (18).

Although no nasal trumpet was used and the probe position had to be adjusted occasionally to optimize imaging of the LV view, no case of nasal mucosal bleeding was noted with transnasal intubation. The quality of mask ventilation and intubation conditions with the nasal probe in place was assessed by the residents who performed the anesthesia (Table 5). The face mask had an inflatable rim for a better fit and provided an excellent seal. All patients could be tracheally intubated on the first or second attempt by the resident, and in no patient was the probe assessed to complicate ventilation or intubation.

In one patient, a pool of gastric secretions was noted on the base of the pharynx during laryngoscopy. A test of tracheal secretions after intubation revealed an acidic pH suggestive of tracheal aspiration of gastric fluids. No bronchospasm was detected on auscultation, however. Surgery proceeded as planned, and the patient was tracheally extubated at the end of the procedure and had an uneventful postoperative

Table 1. Biometric Data of all Patients

Variable	Phase 1	Phase 2
Patients (*n*)	25	20
Age (yr)	53 ± 14	67 ± 11
Weight (kg)	72 ± 11	73 ± 12
Male/female	11/14	14/6

Values are mean ± SEM unless otherwise indicated.

Table 2. Coexisting Diseases

Variable	Phase 1	Phase 2
Coronary artery disease	0	8
Arterial hypertension	7	13
Diabetes mellitus	0	3
Congestive heart failure	0	4
Cerebrovascular disease	0	16
Obstructive pulmonary disease	1	3

Table 3. Patient Medications

Medication	Phase 1	Phase 2
Anticoagulants	0	6
β-Blockers	0	10
Calcium channel antagonists	0	3
Vasodilators	0	5
ACE inhibitors	3	4
Diuretics	2	9

ACE = angiotensin-converting enzyme.

Table 4. Hemodynamic Variables

Variable	Baseline	Probe insertion	Induction	Mask ventilation	Intubation
HR (bpm)	85 ± 13	87 ± 15	85 ± 16	81 ± 11	79 ± 13
SAP (mm Hg)	141 ± 19	144 ± 18	136 ± 17	123 ± 17*	120 ± 16*
DAP (mm Hg)	75 ± 15	76 ± 15	73 ± 11	71 ± 15	70 ± 10
Spo_2 (%)	96 ± 1.7	95 ± 1.9	98 ± 2.7	99 ± 2.9	99 ± 1.9

Values are mean ± SEM.
HR = heart rate; SAP = systolic arterial blood pressure; DAP = diastolic arterial blood pressure; Spo_2 = pulse-oxymetric oxygen saturation.
* $P < 0.01$ versus baseline.

Table 5. Quality of Mask Ventilation and Intubation Conditions with Transnasal TEE Probe in Place

Quality	Mask	Intubation
Good	40	37
Moderate	2	5
Poor	0	0

Values represent numbers of patients.
TEE = transesophageal echocardiography.

course, without any clinical signs of aspiration pneumonitis.

The image quality of the transgastric short-axis view was assessed at four time points: 1) baseline, which was after probe insertion but before the induction of general anesthesia; 2) during IV induction of anesthesia; 3) during mask ventilation; 4) and during intubation until 2 minutes postintubation. During each interval, the echocardiographic image quality was judged separately for every quadrant (inferior, lateral, anterior, and septal). In summary, we assessed 4 × 4 quadrant phases in each patient for image quality. Table 6 shows the number of quadrants that were rated to be of good, moderate, or inadequate quality. Because 43 patients were studied echocardiographically, 688 quadrants were evaluated. Four-hundred-ninety-nine (73%) were graded as good image quality, 156 (23%) as moderate, and 33 (4.8%) as poor. In 14 (42%) of the 33 quadrants with poor image quality, it was the lateral endocardial border that could not be viewed adequately. Six of the 14 quadrant phases with inadequate image quality were recorded during intubation. The image was occasionally lost during laryngoscopy and was sometimes difficult to recover. In summary, overall echocardiographic image quality was adequate for evaluation of RWMA in 95% of all quadrants, with occasional inadequate images of the lateral border during intubation.

During the induction of general anesthesia, no significant ST segment changes or arrhythmias were seen on the ECG. One patient, with a prior myocardial infarction, had significant worsening of preexisting RWMA. During laryngoscopy, the mid-posterior and mid-inferior segments (segments 10 and 11) (19), which had previously been mildly hypokinetic, became akinetic. Arterial blood pressure remained unchanged, and the heart rate increased from 88 to 107 bpm. No ST segment changes were seen on the five-lead ECG monitor (leads II and V5). RWMAs were interpreted as early signs of myocardial ischemia, and the patient was treated with IV esmolol, which promptly resolved the akinesia. No increase in the severity of RWMA or impairment of systolic myocardial thickening was noted in the remaining patients during the induction of general anesthesia.

Discussion

In this study, we demonstrated that it is feasible to start TEE monitoring in awake patients and to monitor cardiac performance throughout the induction period. The miniaturized probe has been shown to have advantages over standard-sized probes in various circumstances. Spencer et al. (16) used a transnasal probe for long-term placement in the critical care setting and for graded treadmill exercise stress echocardiography, with excellent results (15). Because the probe is comparable in size to a 16F nasogastric tube, it is possible to insert it in awake patients without subjecting them to undue discomfort. During phase 1 in our study, probe placement was successful in 23 of 25 patients. This is consistent with previous reports (15). Topical anesthesia of the nasopharyngeal space alone was sufficient to allow insertion of the probe in 12 patients. Eleven patients, however, felt some pain or discomfort during insertion and therefore were given small amounts of fentanyl, midazolam, or both. Only one patient experienced a degree of pain that led us to abandon probe placement despite topical anesthesia and IV analgesia with 0.1 mg of fentanyl. A nasal trumpet acting as a conduit for the probe (12) might have been helpful in this patient, but this was not part of the study design and therefore was not used.

Because two patients during phase 1 became mildly tachycardic, it was decided that all patients in phase 2 should receive IV analgesia and sedation to minimize hemodynamic reactions to probe insertion. Despite this, 2 patients in phase 2 also reacted with moderate tachycardia. Although no ECG changes were detectable, tachycardic episodes pose a risk in patients with

Table 6. TEE Image Quality of Transgastric Short-Axis Images of the Left Ventricle

Variable	Inferior			Lateral			Anterior			Septal		
	g	mod	in	g	mod	in	g	mod	in	g	mod	in
Preinduction	35	8	0	29	12	2	35	7	1	33	10	0
Induction	31	11	1	27	13	3	32	10	1	30	12	1
Mask	34	7	2	26	14	3	34	7	2	32	9	2
Intubation	32	9	2	27	10	6	32	7	4	30	10	3

TEE image quality in 43 patients: g = good; mod = moderate; in = inadequate.
TEE = transesophageal echocardiography.

cardiovascular pathology (1,20). The vast majority of patients (41 of 45), however, did not show any clinically important hemodynamic changes during insertion of the TEE probe. Also, no patient with IV sedation who was taking routine β-adrenergic blocking medication reacted hemodynamically. Thus, we believe that with adequate topical anesthesia, light sedation, and β-blocker medication to control heart rate, insertion of a transnasal probe in awake cardiovascular risk patients can be safely achieved without major hemodynamic reactions.

One of the reasons that current-generation TEE probes are introduced after the induction of general anesthesia is that their size makes it difficult to perform mask ventilation and might complicate laryngoscopy and tracheal intubation. In contrast, we found mask ventilation and intubation conditions to be excellent with the miniaturized probe in place. Use of a specially designed face mask is necessary, however, to achieve a tight seal (Fig. 1). Because it is no bigger than a standard nasogastric tube, the probe does not occupy much of the oropharyngeal space and did not complicate intubation in any case.

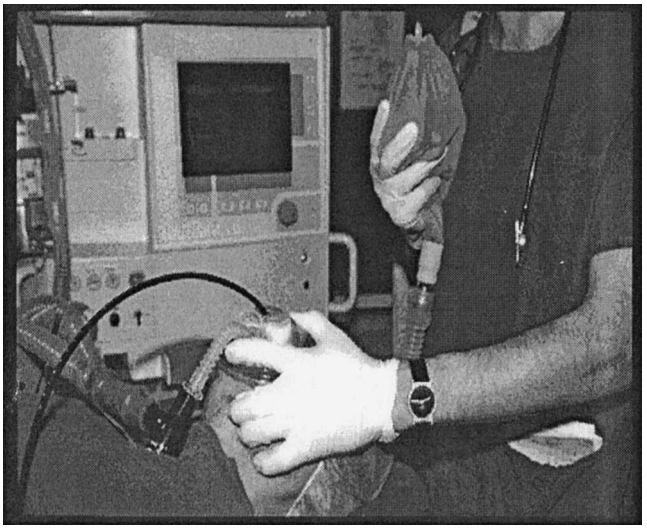

Figure 1. Mask ventilation after anesthesia induction with the transesophageal echocardiography probe in place.

In one patient, a pool of gastric secretions was noted at the base of the pharynx during laryngoscopy. Gastroesophageal reflux during general anesthesia is a well known phenomenon, and studies have indicated a 4%–26% incidence (21–23). We cannot eliminate that the presence of the TEE probe in the esophagus during anesthesia induction might have disrupted lower esophageal sphincter tone and acted as a wick for reflux (21). Regurgitation and tracheal aspiration of gastric contents are important factors of perioperative morbidity and mortality. We recommend that nothing-by-mouth guidelines be strictly followed and that the administration of aspiration prophylaxis and application of cricoid pressure be considered with TEE monitoring during the induction of general anesthesia.

This study has several limitations. The transnasal TEE probe used in our study is a monoplane probe with 32 ultrasound elements. Current standard probes feature 64 elements and offer multiplane imaging capabilities. Prior investigations using this transnasal TEE probe found that the general image quality was inferior compared with that of standard probes. However, the LV short-axis and four-chamber long-axis imaging are comparable (12,13).

Compared with single-plane imaging, multiplane TEE provides a greater ability to obtain images of cross sections with improved anatomic orientation to the structures being examined (19). This is especially important in cardiac surgery postcardiopulmonary bypass and when valvular structures have to be evaluated (3,19). Typical indications for perioperative TEE in noncardiac cases, however, are serial evaluation of global or regional ventricular function and volume status (3). Studies have shown that for both indications, this monoplane transnasal probe can be used with results comparable to those with a multiplane probe (12,13). In patients for whom a comprehensive, diagnostic TEE examination is needed, a multiplane probe may be superior (13).

In this study, we used only the transgastric short-axis view at the level of the papillary muscles because this is the single most useful view to monitor for RWMA and volume status (17,24). Although the American Society of Echocardiography has suggested a 16-segment model of the LV, of which only 6 can be viewed in the mid-transgastric short axis plane (19),

the incremental value of additional intraoperative views has been questioned (25). By advancing and withdrawing the probe to the apical and basal planes, respectively, all 16 segments can theoretically be visualized, even with monoplane TEE (19). The true apex of the LV, however, is often missed by using transverse views alone (26).

From 688 echocardiography screen quadrants that were evaluated for image quality, 655 (95%) were rated as having good or moderate image quality. The most difficult quadrant to visualize was the lateral one. This is probably because of the relatively small size of the transducer tip resulting in a reduced contact area with the gastric mucosa and the inability to perform a forward axial rotation with a monoplane probe.

In a study of critical care patients, Spencer et al. (12) found the transgastric short-axis view of the LV to be of good or acceptable image quality in all 72 patients. The main reason for unacceptable quality in 5% of all images in our investigation was that during mask ventilation and intubation, images were sometimes lost and not recovered before completion of the phase. Overall echocardiographic image quality, however, was adequate for the evaluation of RWMA in 95% of all quadrants. One limiting factor in using transnasal TEE for the induction of anesthesia is that one separate echocardiographer has to constantly manipulate the probe to keep a steady image.

In our study, we detected worsening of preexisting RWMA from mild hypokinesia to akinesia in one patient during laryngoscopy. This was interpreted as an early sign of myocardial ischemia, and treatment with IV esmolol was initiated, which led to prompt resolution of the akinesia. The patients' heart rate had increased from 88 to 107 bpm during laryngoscopy. Tachycardia predisposes to myocardial ischemia in cardiac risk patients and therefore should be avoided; tachycardic episodes are often seen in this patient group perioperatively (27), and rates less than 110 bpm are not uniformly treated without signs of myocardial ischemia. No ST segment changes were present in our patient, so without TEE monitoring he would not have received treatment and might have had more serious consequences.

A weakness of this study is that no comparison with transthoracic echocardiography (TTE) was performed. However, the acoustic images of TTE are generally poorer than those of TEE (3), especially in circumstances in which the lungs are inflated with positive pressure, as during mask ventilation. It may also be harder to keep the image steady during the entire induction phase. Furthermore, if the medical condition of the patient or the type of surgical procedure warrants perioperative TEE, it seems logical to commence at the earliest possible moment with continuous monitoring rather than using TTE during induction and then changing to TEE during surgery. Complications of TEE probe insertion, such as massive gastrointestinal hemorrhage (28) or hypopharynx or esophageal perforation (29,30), which are a result of forcing the probe along the orogastric pathway in anesthetized patients, can probably be reduced by introducing TEE before anesthesia induction and by having the patient actively swallow the probe.

Finally, another weakness of this study is that it lacks the power to define a risk/benefit ratio. Such a study would require many more patients. One patient had myocardial ischemia detected during induction and could be treated, and, on the other hand, one patient had gastric regurgitation and two cardiac risk patients became mildly tachycardic during probe placement. Although these side effects had no negative consequences, they pose a potential safety concern.

This feasibility study demonstrates that it is possible to introduce a miniaturized TEE probe transnasally in awake patients and monitor cardiac performance during the induction of general anesthesia. Although the results of this study do not support the routine use of transnasal TEE, individual patients may benefit from early detection of RWMA or identification of reasons for hemodynamic instability. Further investigations are encouraged to determine which patients may profit most from continuous TEE monitoring during the induction of anesthesia.

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