Complications Associated With Transesophageal Echocardiography in Transcatheter Structural Cardiac Interventions

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Background: Transesophageal echocardiograms (TEEs) performed during transcatheter structural cardiac interventions may result in greater complications than those performed in the nonoperative setting or even those performed during cardiac surgery. However, there are limited data on complications associated with TEE during these procedures. We evaluated the prevalence of major complications among these patients in the United States.

Methods: A retrospective cohort study was conducted using an electronic health record database (TriNetX Research Network) from large academic medical centers across the United States for patients undergoing TEE during transcatheter structural interventions from January 2012 to January 2022. Using the American Society of Echocardiography–endorsed International Statistical Classification of Diseases and Related Health Problems Clinical Modifications (10th edition) codes, patients undergoing TEE during a transcatheter structural cardiac intervention, including transaortic, mitral or tricuspid valve repair, left atrial appendage occlusion, atrial septal defect closure, patent foramen ovale closure, and paravalvular leak repair, were identified. The primary outcome was major complications within 72 hours of the procedure (composite of bleeding and esophageal and upper respiratory tract injury). The secondary aim was the frequency of major complications, death, or cardiac arrest within 72 hours in patients who completed intraoperative TEE during surgical valve replacement.

Results: Among 12,043 adult patients (mean age, 74 years old; 42% female) undergoing TEE for transcatheter structural cardiac interventions, 429 (3.6%) patients had a major complication. Complication frequency was higher in patients on anticoagulation or antiplatelet therapy compared with those not on therapy (3.9% vs 0.5%; risk ratio [RR] = 8.09, $P < .001$). Compared with those patients <65 years of age, patients ≥65 years of age had a higher frequency of major complications (3.9% vs 2.2%; RR = 1.75, $P < .001$). Complication frequency was similar among male and female patients (3.5% vs 3.7%; RR = 0.96, $P = .67$). Among 28,848 patients who completed surgical valve replacement with TEE guidance, 728 (2.5%) experienced a major complication.

Conclusions: This study found that more than 3% of patients undergoing TEE during transcatheter structural cardiac interventions have a major complication, which is more common among those on anticoagulant or antiplatelet therapy or who are elderly. With a shift of poor surgical candidates to less invasive percutaneous procedures, the future of TEE-guided procedures relies on comprehensive risk discussion and updating practices beyond conventional methods to minimize risk for TEE-related complications. (J Am Soc Echocardiogr 2023;36:381-90.)

Keywords: Transesophageal echocardiogram, Transcatheter structural cardiac interventions, Outcomes, Transesophageal echocardiogram related complications

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Abbreviations

ASD = Atrial septal defect

BMI = Body mass index

CPT = Current Procedural Terminology

EGD = Esophagogastroduodenoscopy

HIPAA = Health Insurance Portability and Accountability Act

ICD-10-CM = International Statistical Classification of Diseases and Related Health Problems Clinical Modifications, 10th edition

ICE = Intracardiac echocardiography

LAAO = Left atrial appendage occlusion

MVR = Mitral valve repair

PFO = Patent foramen ovale

PVLR = Paravalvular leak repair

RR = Risk ratio

TAVR = Transcatheter aortic valve replacement

TEE = Transesophageal echocardiogram

TVR = Tricuspid valve repair

VSD = Ventricular septal defect

INTRODUCTION

Transesophageal echocardiograms (TEEs) allow for higher-resolution images of posterior cardiac structures compared with transthoracic echocardiograms, and their diagnostic capabilities have expanded to improved visualization of valvular pathology, workup of recurrent strokes, and evaluation for thromboembolic risk prior to cardioversion in atrial fibrillation.[1-3] More recently, the role of TEE has evolved beyond simple image acquisition to real-time intraoperative visualization utilized to guide percutaneous structural interventions such as transcatheter aortic valve replacement (TAVR), transcatheter mitral valve repair (MVR), transcatheter tricuspid valve repair (TVR), left atrial appendage occlusion (LAAO), atrial septal defect (ASD) repair, ventricular septal defect (VSD) repair, patent foramen ovale (PFO) repair, and paravalvular leak repair (PVLR).[3-6] Transesophageal echocardiography has been considered a generally safe procedure, with the frequency of major complications ranging from 0.2% to 1.4% in both operative and nonoperative situations; however, it does carry an inherent risk as an invasive imaging technique.[7,8] Historically, complications during TEE have been rare injuries to the gastrointestinal tract because of direct mechanical trauma.[9,10] With the growing role in structural cases, complications have been more frequently reported secondary to the constant probe manipulation needed during procedures.[11,12]

There is limited contemporary literature detailing the frequency of complications associated with TEE in transcatheter structural cardiac interventions. The potentially increased risk for TEE-related complications is concerning as we continue to see a dynamic shift to completing percutaneous procedures on these previously poor surgical candidates.[13] Over 38,000 LAAOs were completed from January 2016 to December 2018, and over 11,000 transcatheter MVRs were completed in 2019 in the United States.[14,15] While smaller studies outside of the United States have reviewed this topic, the frequency of TEE-related complications for transcatheter structural cardiac interventions in the United States has not been previously described.[11,12] Additionally, no previous studies have contrasted the frequency of TEE-related complications from intraoperative TEE in cardiac surgery.

The current study aimed to evaluate the short-term complications for U.S. adult patients undergoing TEE for transcatheter interventions that include TAVR, MVR, TVR, LAAO, PVLR, ASD repair, VSD repair, and PFO closure. It also aimed to contrast the frequency of complications seen during cardiac surgery with intraoperative TEE guidance as well.

METHODS

Data Source

We used the TriNetX (Cambridge, MA) research network database for this study.[16-22] This federated health research network database uses a combination of natural language processing and standardized clinical data entries to integrate electronic health records from multiple institutions into a cloud-based aggregate of nearly 59 million patients. The health entities contributing to the database were composed of approximately 75% academic medical centers and 25% community practices. The data are deidentified at the patient and organization levels to ensure patient privacy and Health Insurance Portability and Accountability Act (HIPAA) compliance. This data set includes lab values, medications, and procedures for analysis.[23] The data set undergoes a rigorous quality assessment to ensure adequate data representation and remove incomplete records.[22] The TriNetX software monitors the temporal trend of data volume to ensure data validity. Additionally, The TriNetX database allows for the comparison of data across several databases to ensure that referential integrity is maintained.[16-20,24] The TriNetX database uses the International Statistical Classification of Diseases and Related Health Problems Clinical Modifications, 10th edition (ICD-10-CM), to identify patient's diagnoses. The database uses Current Procedural Terminology (CPT) codes to record procedures. Finally, the data set uses the standard Logical Observation Identifiers Names and Codes to capture lab values.[16-20,22] Group-level data are available to researchers at participating health care organizations at www.trinetx.com. The ethical oversight for this study was provided by the University of Alabama at Birmingham Institutional Review Board.

Patient Population

Our analysis included patients undergoing TEE for transcatheter interventions (TAVR, MVR, TVR, LAAO, PVLR, ASD repair, VSD repair, and PFO closure) and traditional valve surgery (MVR, TVR, pulmonary valve repair, and surgical aortic valve replacement) between January 2012 and January 2022 at medical centers in the United States. The TriNetX Research Network includes large academic medical centers including the University of Alabama at Birmingham.[24] Using the American Society of Echocardiography–approved ICD-10-CM and CPT codes (93,355; Table 1), an aggregated population of patients undergoing a TEE-guided transcatheter intracardiac or great vessel structural intervention was identified for this analysis.[25,26] As a secondary analysis, a separate aggregated cohort of patients who completed an intraoperative TEE on the same day of cardiac surgery was identified. First, a group of patients who completed an intraoperative TEE using approved American Society of Echocardiography CPT codes (93,312-5; 93,317-8; 93,320-1; 93,325) was identified. Then we matched the date of the TEE to the date of the cardiac surgery by using CPT codes corresponding to aortic valve (33,400-1; 33,403; 33,405-6; 33,410-7), mitral valve (33,420; 33,422; 33,425-7; 33,430), pulmonic valve (33,463-4), and tricuspid valve (33,475) surgical procedures.[27] The TEE was considered intraoperative if the date of the TEE claim was

HIGHLIGHTS

- The risk of a TEE-related complication was 3.6% over the past decade.
- Gastrointestinal hemorrhage is the most frequently reported complication.
- Intraoperative TEE during cardiac valve surgery had a lower risk of complications.

performed on the same calendar day as the cardiothoracic surgical procedure.

The TriNetX database was queried for applicable patients within the past decade as HIPAA-covered entities had largely transitioned to ICD-10-CM coding by January 2012.[28] Additionally, devices utilized in transcatheter structural cardiac interventions became approved by the Food and Drug Administration in 2012 as well, with TAVR for symptomatic aortic stenosis becoming approved in late 2011.[29] The patient population who completed a TEE-guided percutaneous intervention was further stratified based on age (ages ≤64 years old or above the age of 65 years old), sex (male or female), and whether they were taking either anticoagulation or an antiplatelet within a week of their procedure. Temporal trends of major complications were identified by comparing the frequency of major complications for the first 5 years of the decade versus the second half (January 1, 2012, to January 1, 2022).

Measures and Outcomes

After developing our patient population for analysis, we identified their baseline characteristics, including medical history, medications, and laboratory values on the day of the procedure. We defined a major complication as the presence of one of the following: (1) intraoperative hemorrhage and hematoma of a respiratory system organ or structure complicating a procedure (ICD-10-CM: J95.6), (2) postprocedural hemorrhage of a respiratory system organ or structure following a procedure (J95.83), (3) postprocedural hemorrhage of a digestive system organ or structure following a procedure (K91.84), (4) gastrointestinal hemorrhage, unspecified (K92.2), (5) other specified diseases of the esophagus (K22.8), (6) hemorrhage from throat (R04.1), (7) hemorrhage from other sites in respiratory passages (R04.89), (8) unspecified injury of esophagus (thoracic part) (S27.819), (9) unspecified open wound of the pharynx and cervical esophagus (S11.20), or (10) perforation of the esophagus (K22.3). The day of the procedure was defined as the index event. The primary study outcome was any major complication within 72 hours of the procedure. We also identified the frequency of deaths and cardiac arrest within 72 hours of the procedure. A secondary analysis assessed during this study compared the frequency of major complications (as previously defined) from intraoperative TEE during surgical valvular procedures. An additional secondary analysis involved assessing temporal trends regarding the frequency of major complications. Each procedure was counted as 1 separate event so patients who completed multiple procedures between the first half of the decade and the second half were included multiple times in the denominator of total cases. We also evaluated the frequency of major complications between all geographic regions. The individual codes used in the study for the definition of a major complication are listed in Table 1.

Statistical Analysis

This is a retrospective cross-sectional analysis of patients who completed a TEE-guided transcatheter structural cardiac intervention. The baseline characteristics for the patient population were reported as mean ± SD for continuous data and as numbers and percentages for categorical data. The study outcomes were reported as comparisons between age, sex, and patients on anticoagulation or antiplatelets. Additional comparisons were reported between the patient population who completed a TEE-guided percutaneous intervention

Table 1 Periprocedural transesophageal echocardiography–related outcomes in the study cohort (*N* = 12,043)

Clinical outcome	ICD-10-CM code	% (*n*)
Death		0.58 (70)
Cardiac arrest	I46	1.74 (210)
Major complications as defined below:		3.6 (429)*
Respiratory system:		
Intraoperative hemorrhage and hematoma of a respiratory system organ or structure complicating a procedure	J95.6	0.3 (41)
Postprocedural hemorrhage of a respiratory system organ or structure following a procedure	J95.83	0.4 (51)
Gastrointestinal system:		
Other specified disease of the esophagus	K22.8	0.1 (13)
Postprocedural hemorrhage of a digestive system organ or structure following a procedure	K91.84	0.4 (50)
Gastrointestinal hemorrhage, unspecified	K92.2	2.8 (338)
Hemorrhage from throat	R04.1	0.03 (4)
Hemorrhage from other sites in respiratory passages	R04.89	0.1 (13)
Unspecified injury of esophagus (thoracic part)	S27.819	0 (0)
Unspecified open wound of pharynx and cervical esophagus	S11.20	0 (0)
Perforation of esophagus	K22.3	0.02 (2)

*Due to individual patients with multiple complications from TEE, the sum of the major complications is not equal to the number of major complications seen in our patient population.

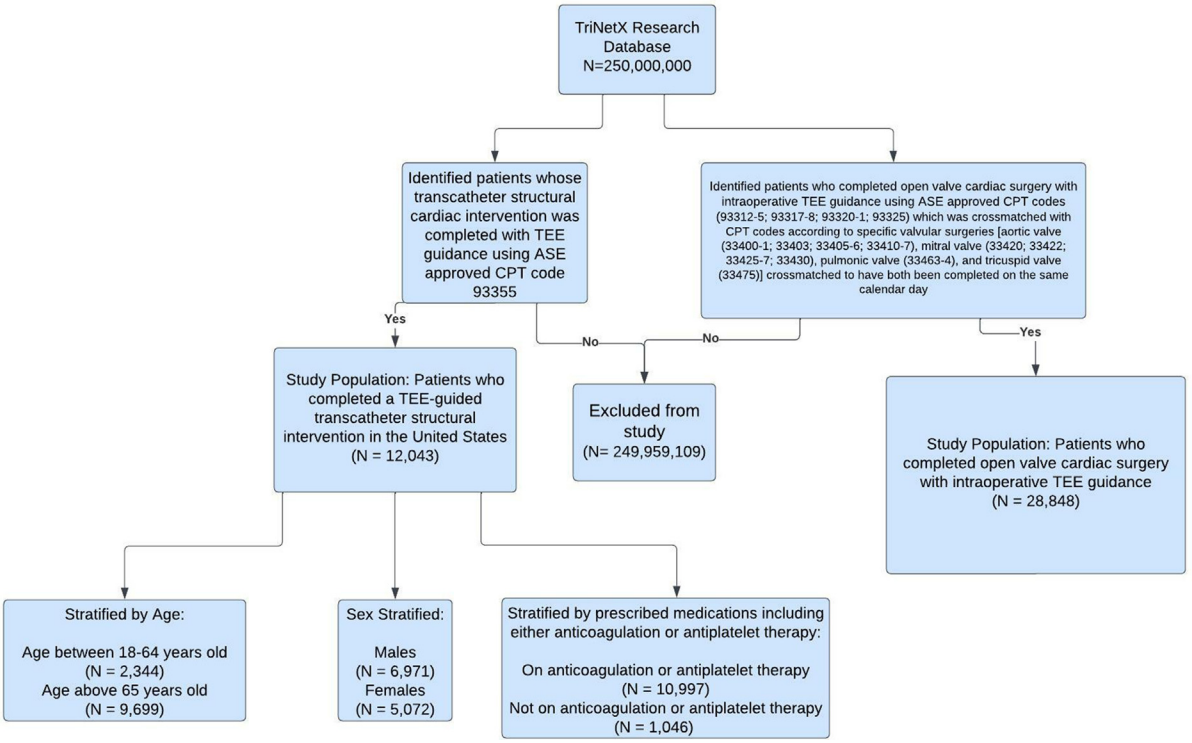

Figure 1 Derivation of the study population. The TriNetX database was queried for applicable patients by using the American Society of Echocardiography (ASE) approved ICD-10-CM and CPT codes. After a study population was developed from the database, the patients were further substratified by age, sex, and prescribed medications. A separate cohort of patients who completed cardiac valve surgery with TEE guidance was also identified.

versus a TEE-guided surgical intervention. Characteristics of continuous data were compared using an independent-sample *t*-test. Categorical variables, such as age or ethnicity, were compared using a Pearson chi-square test. All primary and secondary outcomes were reported in both the overall patient population and within each subset. Logistic regression was performed to assess the odds of TEE-related complications for the subgroup stratification by sex, age (<65 vs ≥65 years), and medication (antiplatelet and anticoagulant use). The TriNetX analytic program utilizes a combination of JAVA, R, and Python for statistical analyses.[16-20,22-24] The study outcomes are reported as estimates (odds ratios and risk ratios [RRs]) with 95% CIs. For all analyses, a 2-sided type I error of 0.05 was considered statistically significant.[30]

RESULTS

We identified 12,043 adult patients who underwent a TEE-guided structural intervention (TAVR, MVR, TVR, LAAO, PVLR, ASD repair, or PFO closure) between January 2012 and January 2022. Figure 1 describes the derivation of the study population and the separate cohort of patients who completed TEE-guided valvular cardiac surgeries. Overall, the geographic distribution of the study population, determined by the location of the health care organization headquarters, was composed of 43.9% ($n = 5,284$) of patients from the South, 39.5% ($n = 4,756$) from the Northeast, 8.3% ($n = 995$) from the Midwest, and 2.8% ($n = 336$) from the West; 5.6% ($n = 672$) of patients were unable to be identified as being from a specific geographic region. The baseline clinical demographics of the study population are summarized in Table 2. The study population had a mean age of 74 ± 14 years, 57.8% ($n = 6,971$) were male, and 83.6% ($n = 10,062$) were White. At baseline, there was a relatively high prevalence of comorbidities such as hypertension (73.7%), ischemic heart disease (65%), heart failure (53.4%), mitral valve disease (48%), aortic valve disease (47%), and tricuspid valve disease (25%). The baseline lab parameters for the study population are described in Table 3.

In the overall cohort, 3.6% ($n = 429$) experienced a major complication as defined above within 72 hours of their procedure. Table 1 shows the number of events stratified by each major individual complication. Additionally, 0.6% ($n = 70$) of patients died and 1.7% ($n = 210$) experienced a cardiac arrest within 72 hours after their TEE-guided transcatheter structural cardiac intervention. The most frequent major complication reported following the procedure was gastrointestinal hemorrhage, with 338 (78.7%) documented with this complication. Within this group, 6.5% ($n = 22$) had a clinically significant bleed requiring transfusion within 24 hours of their procedure; the rest of the group experienced a minor bleed not requiring transfusion. Within our cohort of 429 patients with a major complication; 0.9% ($n = 3$) died and 6.1% ($n = 26$) had a cardiac arrest within 72 hours of their procedure. Compared with the cohort with no major complications, only 0.6% ($n = 67$) died and 1.6% ($n = 184$) experienced a cardiac arrest within 72 hours of their procedure. Thus, patients with a TEE complication had a statistically significant increased risk of cardiac arrest (RR = 3.98 [95% CI, 2.57 – 5.70], $P < .001$) but not death (RR = 1.26 [95% CI, 0.40-3.98], $P = .37$).

In the sex-stratified comparison of the study population, 6,971 male and 5,072 female patients were identified. The frequency of

Table 2 Baseline characteristics of the study cohort

Clinical characteristic	Value
Age at index, years	70.2 ± 14.5
Gender:	
Male	6,971 (57.8)
Female	5,072 (42.2)
Ethnicity:	
Not Hispanic or Latino	9,960 (82.7)
Unknown	1,585 (13.2)
Hispanic/Latino	498 (4.1)
Race:	
White	10,062 (83.6)
Black or African American	1,100 (9.1)
Unknown	742 (6.2)
Asian	110 (0.9)
American Indian or Alaska Native	22 (0)
Native Hawaiian or Other Pacific Islander	10 (0)
Diagnosis:	
Essential (primary) hypertension	8,870 (73.7)
Coronary artery disease	7,472 (62.0)
Heart failure	6,436 (53.4)
Cerebrovascular diseases	4,767 (39.6)
Neoplasms	4,412 (36.6)
Medications:	
Anticoagulants	9,239 (76.7)
Beta-blockers	8,603 (71.4)
Antiplatelets	8,337 (69.2)
Angiotensin-converting enzyme inhibitors/ angiotensin II inhibitor	8,327 (69.1)
Antilipemic drugs	8,069 (67.0)
Vitals:	
Heart rate	75 ± 15.7
BMI	29.4 ± 6.7
Systolic blood pressure	129 ± 20.6
Diastolic blood pressure	71.7 ± 12.1

Continuous data are presented as a median with interquartile range, and categorical data are presented as counts with percentage.

Table 3 Laboratory measures in the study cohort

Characteristics	Mean ± SD	Reference
Hematologic parameters:		
Leukocytes, cells × $10^3/\mu L$	7.54 ± 3.35	4.3-10.8
Hemoglobin, g/dL	12.3 ± 2.12	12-17
Platelets, cells × $10^3/\mu L$	212 ± 78.9	150-400
Liver function:		
Alanine aminotransferase, IU/L	28.5 ± 89.8	10-40
Albumin, g/dL	3.91 ± 0.91	3.5-5.5
Alkaline phosphatase, IU/L	90.2 ± 49.9	30-120
Aspartate aminotransferase, IU/L	35.8 ± 259	10-40
Bilirubin total, mg/dL	0.77 ± 0.867	0.3-1.0
Protein, g/dL	6.86 ± 0.76	5.5-9.0
Renal function:		
Creatinine, mg/dL	1.42 ± 2.78	0.8-1.2
Blood urea nitrogen, mg/dL	24.5 ± 14.7	6-20
Electrolytes:		
Calcium, mg/dL	9.26 ± 0.592	8.5-10.2
Potassium, mEq/L	4.25 ± 0.471	3.7-5.2
Sodium, mEq/L	139 ± 3.33	136-144
Bicarbonate, mEq/L	26.6 ± 3.5	23-29
Coagulation function:		
Activated partial thromboplastin time, seconds	36.7 ± 16.8	30-50
Prothrombin time, seconds	15.2 ± 5.77	12-13
INR	1.36 ± 1.26	0.8-1.2
Endocrine:		
A1c, %	6.29 ± 1.51	4-5.6

Laboratory values are presented as an average mean with 1 SD.

major complications was 3.5% (244/6,971) in male and 3.7% (185/5,072) in female patients (RR = 0.96 [95% CI, 0.80-1.16], $P = .67$). The risk of cardiac arrest within 72 hours of their intervention was not statistically significant (RR = 0.90 [95% CI, 0.69-1.18], $P = .43$) between male (1.7%, 116/6,971) and female patients (1.9%, 94/5,072). The risk of death within 72 hours of their intervention was lower between male (0.5%, 33/6,971) and female patients (0.8%, 37/5,072), although not statistically significant (RR = 0.65 [95% CI, 0.41-1.04], $P = .07$).

In the age-stratified analysis, there was a higher risk for major complications in patients older than 65 years old. Our study population identified 9,699 patients older than 65 years old and 2,344 patients between the ages of 18 and 64 years. In the older age group, the frequency of major complications was 3.9% (377/9,699) compared with the middle-aged and younger patient group, where the frequency was 2.2% (52/2,344; RR = 1.75 [95% CI, 1.32-2.33], $P < .001$). The risk of death within 72 hours of intervention was higher in the older age group (0.7%, 65/9,669) versus the younger age

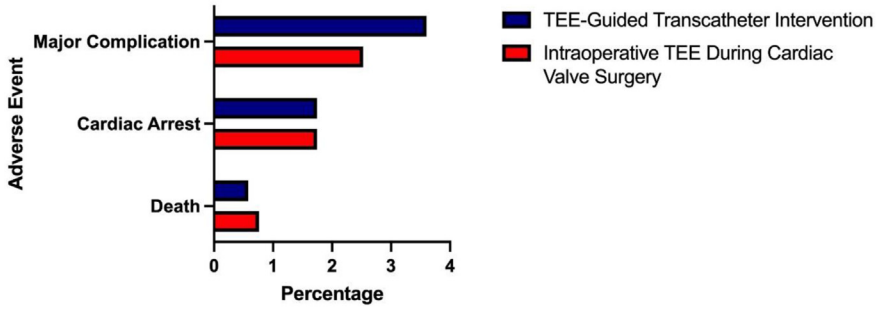

Figure 2 Comparison of the frequency of major complications, cardiac arrest, and death within 72 hours of intervention between TEE used during transcatheter interventions and intraoperative TEE during cardiac valve surgeries.

group (0.2%, 5/2,344), and the relative risk was statistically significant (RR = 3.14 [95% CI, 1.27-7.80], $P = .01$). The risk of cardiac arrest within 72 hours of intervention was not statistically significantly different between the younger (2.0%, 47/2,344) and the older (1.7%, 163/9,699; RR = 0.84 [95% CI, 0.60-1.60], $P = .28$) group.

There were 10,997 (91.3%) patients completing a TEE-guided transcatheter structural intervention who were on anticoagulation or an antiplatelet within 7 days of their procedure. In patients on anticoagulation or antiplatelet therapy, there was a higher frequency of major complications (3.9%) compared with those not on anticoagulation or antiplatelets (0.5%; RR = 8.09 [95%, CI: 3.36-19.5], $P < .001$). The risk of cardiac arrest within 72 hours of intervention was not statistically significant (RR = 1.44 [95% CI, 0.83-2.52], $P = .20$) between patients on anticoagulation or antiplatelet therapy (1.8%, 197/10,997) and patients who were not (1.2%, 13/1,046). The risk of death within 72 hours of intervention was similar (RR = 1.24 [95% CI, 0.50-3.07], $P = .13$).

There were 28,848 patients identified who completed cardiac surgeries with intraoperative TEE guidance. In this group, the frequency of a major complication was 2.5% ($n = 728$). Notably, the relative risk of a major complication related to TEE-guided percutaneous interventions was higher compared with intraoperative TEE guidance during cardiac surgery (RR = 1.41 [95% CI, 1.26-1.59], $P < .001$). In contrast, the relative risk of death within 72 hours was lower in the group who completed a TEE-guided percutaneous intervention versus the group who completed cardiac surgeries (RR = 0.76 [95% CI, 0.58 - 0.997], $P = .05$). The relative risk of cardiac arrest in the TEE-guided percutaneous intervention group was similar when compared with the cardiac surgery group (RR = 1.00 [95% CI, 0.85-1.17], $P = .99$; Figure 2).

When reviewing temporal trends of major complications over the past 10 years, there was a similar frequency of major complications from January 1, 2012, to December 31, 2016 (74/2,157), compared with January 1, 2017, to January 1, 2022 (355/9,936; RR = 0.96 [0.75-1.23], $P = .37$). The frequency of cardiac arrests from 2012 to 2017 was higher at 2.3% (50/2,157), whereas from 2017 to 2022 it was at 1.6% (160/9,936; RR = 1.44 [95% CI, 1.05-1.97], $P = .01$). The frequency of deaths from 2012 to 2017 was 0.7% (14/2,157) versus from 2017 to 2022, when it was 0.6% (56/9,936; RR = 1.15 [95% CI, 0.64-2.07], $P = .59$; Figure 3). Over the study period of a decade, 47 patients had multiple procedures completed.

When stratified by intervention type, 6,978 patients (57.9%) out of the entire cohort of 12,043 patients were able to be stratified by the type of intervention they completed. For patients who completed a TAVR procedure, the relative frequency of a major complication was 1.8% (32/1,761). In patients who completed an LAAO procedure, the frequency of a major complication was higher at 8.6% (262/3,042). The most reported type of complication was gastrointestinal hemorrhage at 95.4% (250/262). Patients who completed a transcatheter MVR also had a high frequency of major complications at 2.5% (42/1,711). The most frequent complication reported was again gastrointestinal hemorrhage at 81.0% (34/42). Patients undergoing transcatheter pulmonary valve repair, transcatheter TVR, and VSD repair also had higher rates of major complications, but the sample size from which this group of patients was taken was much smaller. The full breakdown regarding the frequency of major complications, cardiac arrest, and death within 72 hours by intervention type is shown in Table 4.

When reviewing geographic trends of major complications by region, the frequency of a major complication within 72 hours of the procedure was highest in the Midwest at 6.4% compared with other regions. The Northeast had the lowest frequency of major complications at 2.5%. The frequency of major complications in the South was 3.7%, and in the West it was 3.0%.

DISCUSSION

This study is the first to analyze the outcomes and complications associated with TEE guidance in transcatheter structural cardiac interventions in the United States. It is also the first to contrast the frequency of TEE-related complications between percutaneous interventions and cardiac valve surgery. In this study cohort, 3.6% of patients experienced a major complication. The frequency of major complications in patients undergoing transcatheter structural cardiac interventions was higher among older individuals (≥65 years old) and those previously taking anticoagulants or antiplatelets. This study reaffirmed the increased risk for TEE-related complications in complex structural interventions versus TEE alone for image acquisition that was seen previously in smaller studies. Additionally, it is interesting to note that TEE used during transcatheter interventions was found to have an overall higher relative risk for major complications compared with TEE for intraoperative interventions. This is likely related to the role of TEE in helping guide procedures for percutaneous interventions, whereas during surgical intervention TEE plays less of an active role. The higher relative risk of death is a likely sequela of the inherent risk with open heart surgery compared with minimally invasive procedures. The trends in the frequency of major complications stratified by geographic region are interesting given the significantly higher risk of a major complication in the Midwest compared with other regions. Despite the results, it is difficult to draw any conclusions due to the nature of the database and the number of participating institutions

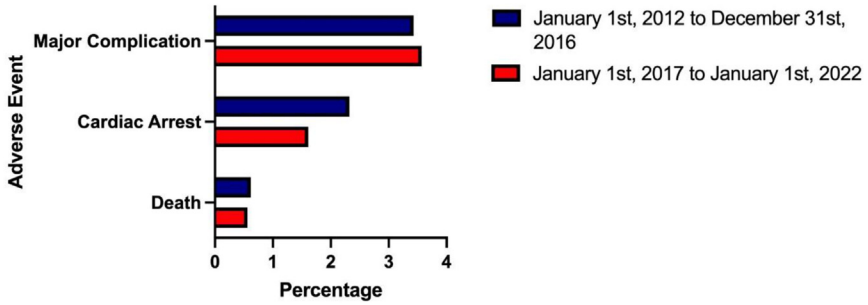

Figure 3 Temporal trends of major complications, cardiac arrest, and death within 72 hours of TEE-guided transcatheter intervention. The frequency of major complications within 72 hours of a TEE-guided structural procedure between January 1, 2012, and December 31, 2016, and January 1, 2017, and January 1, 2022, is presented as a percentage.

Table 4 Periprocedural transesophageal echocardiography–related outcomes stratified by intervention type

Procedure	Total no. of patients	Death, % (*n*)	Cardiac arrest, % (*n*)	Major complications, % (*n*)
LAAO	3,042	0.13 (4)	1.12 (34)	8.61 (262)
TAVR	1,761	0.85 (15)	1.76 (31)	1.82 (32)
Transcatheter MVR	1,711	0.53 (9)	2.34 (40)	2.46 (42)
Paravalvular leak replacement	168	0 (0)	0.60 (1)	1.79 (3)
ASD repair	154	0.65 (1)	0.65 (1)	2.60 (4)
PFO repair	40	0 (0)	0 (0)	0 (0)
VSD repair	37	8.10 (3)	10.81 (4)	2.70 (1)
Transcatheter pulmonary valve replacement	36	0 (0)	0 (0)	5.56 (2)
Transcatheter TVR	29	0 (0)	3.45 (1)	6.90 (2)

in each region. These results represent an area of future study to compare the frequency of complications from TEE-guided percutaneous interventions among different regions and institutions. The temporal trends in the frequency of major complications are also important to note given the massive switch to transcatheter structural heart interventions over the last several years. This lack of improvement is likely related to TEE operation remaining largely unchanged over the past decade compared with an improvement in transcatheter approaches. While TEE guidance during a procedure is classically thought to be relatively benign, there are known risks, and the frequency of complications has persisted.

A retrospective review of 1,249 transcatheter structural cardiac cases with TEE guidance at the Quebec Heart Institute (1,037 undergoing TAVR and 214 undergoing other procedures) noted that the complication frequency for those undergoing transcatheter MVR, paravalvular leak closure, and LAAO was 2.8%. In those undergoing TAVR, the frequency of major complications was significantly lower at 0.6%, with both procedure type and time determined to be independent risk factors for TEE-related complications.[12] Given the higher frequency of TEE-related complications in non-TAVR structural interventions, the same group completed a prospective study of TEE-related injuries with pre- and postprocedural esophagogastroduodenoscopies (EGDs) to identify the percentage of injuries seen. A staggering 86.0% (43/50) of patients' postprocedural EGDs were found to have a new injury, and 40.0% (20/50) of patients developed a complex lesion such as an intramural hematoma or mucosal laceration of the esophagus.[11] All TEEs were performed by a highly experienced and trained interventional echocardiographer with more than 1 year of experience. Despite this, over 80% of patients had a complication following TEE. Freitas-Ferraz *et al.*[11] completed a prospective study with every patient completing an EGD after their TEE-guided procedure to identify both major and minor complications following their procedure. In our retrospective cross-sectional study, we identified complications as reported by individual operators who reported complications following their procedure with ICD-10-CM coding. Thus, the frequency of TEE-related complications may be underreported in the patient population included in this study. In a retrospective study of patients completing adult cardiac surgery, Purza *et al.*[8] identified 1,074 patients, of which 73 (6.8%) had an esophageal or gastric injury. Advanced age, low body mass index (BMI), and prolonged cardiopulmonary bypass time were noted to be independent risk factors associated with TEE-related complications. Regardless, TEEs are frequently cited as having a strong safety profile with complications described as exceedingly rare during routine TEEs.[11,12] Long probe manipulation time during transcatheter structural cardiac interventions, performed in older individuals with multiple comorbidities, contributed to the relatively higher frequency of TEE-related complications.[8,11,12] This was highlighted in our study by the relatively increased risk for a major complication during LAAO and MVR. Transcatheter MVRs have a higher dependence on TEE guidance and are usually longer in duration compared with other transcatheter-based interventions, thereby increasing the risk for TEE-related complications.[13,14] LAAO is typically much shorter in duration; however, the patient population typically receiving this implant has a known history of either major bleeding, nonmajor bleeding, or a higher risk of bleeding.[6,12,15] A small subset of patients who completed VSD repair was found to have a higher frequency of complications. We suspect this is because these procedures were performed in patients with acute myocardial infarction complicated by cardiogenic shock, thus representing a sicker patient population

than typically encountered for the other procedures. The poor clinical profile in these patients may explain the higher frequency of complications compared with other procedures. Unfortunately, in our database, we were unable to assess the clinical profile of patients before these procedures were completed. Further investigations are needed to assess the granular phenotypic characteristics and prognostic implications of TEE-related complications among patients undergoing complex transcatheter structural cardiac interventions.

This study offers some key insights into the risk of TEE-related complications during transcatheter structural cardiac procedures. Previous studies evaluating the risk of TEE-related injuries during procedures involved only a single-center design, whereas this study assesses the data across multiple large academic medical centers in the United States. Additionally, our study population mirrors the patient population undergoing transcatheter structural interventions. These patients have high surgical mortality given their age, comorbidities, and medications including anticoagulation.[31] Percutaneous interventions offer a less invasive approach to repairing and replacing valvular issues than conventional surgery. Studies show that these transcatheter interventions have effective clinical outcomes in this high-risk elderly population with an improved safety profile.[32-34] Accordingly, multiple randomized controlled trials have established the use of TEE for intraprocedural guidance. In a study evaluating mortality after transcatheter aortic valve implantation, the authors found that the use of intraoperative TEE was associated with a lower risk of mortality (hazard ratio = 0.57).[35] As the role of less invasive percutaneous techniques continues to expand, the need for concurrent use of TEE is equally important to provide real-time visualization of both cardiac structures and catheter location. Thus, it is important to develop an understanding of common TEE-related complications and ways to mitigate the risk of complications.

As noted in our investigation and by others, there are multiple nonmodifiable risk factors for TEE-related complications.[8,11,12,31] Patient-related factors that increase the risk for negative outcomes include age, medical history, and prescribed medications. In our cohort over 91% of patients were either on anticoagulants or platelet-aggregation inhibitors increasing their risk for intramural hematomas and hemorrhages during TEE. Another factor is the complexity of the procedure. For example, an MVR is a prolonged procedure that requires frequent manipulation of the probe to obtain the optimal views needed for procedural guidance.[36] The necessities involved in completing these procedures increase the risk for adverse outcomes from direct mechanical trauma, high contact pressure at the surface of the mucosa, and thermal injury caused by the heat of the TEE probe.[7,8]

Multiple modifiable risk factors can be addressed during the procedure including sedation techniques. When patients are under general anesthesia, they are unable to swallow the probe and the operators must blindly insert the probe with potential forced manipulation leading to esophageal injury secondary to direct mechanical trauma. In contrast, patients under conscious sedation can swallow to help facilitate insertion and minimize risk.[11] In our study, 78.7% of the major complications were secondary to gastrointestinal hemorrhage. Avoiding unnecessary manipulation of the probe or keeping it locked for long periods can also help to minimize harm as a longer duration of active TEE use has been noted to be an independent risk factor for complications.[11,12,31] After the procedure, patients should be closely followed to assess for evidence of any complications. Minor complications may not be clinically significant, but any symptomatic burden a patient experiences after TEE can be relieved through conservative management with either viscous lidocaine (i.e., a gastrointestinal cocktail) or proton-pump inhibitors.

Another technique that can be incorporated into transcatheter structural interventions is intracardiac echocardiography (ICE), which allows for high-resolution visualization of intracardiac anatomy to guide catheter manipulation.[37] While it has been widely utilized in the electrophysiology lab, it has more recently gained traction in some transcatheter structural cases such as ASD and PFO closures.[38-40] Additionally, a recent study evaluating ICE in transcatheter left atrial appendage closure was associated with a decreased risk for gastrointestinal complications, which are the most common complications TEE-guided structural interventions face. However, there was a higher risk of developing vascular complications, and while there was no difference in the length of hospital stay, the associated costs of using ICE were significantly higher.[41] Developing smaller probes for more frail patients should also be strongly considered. Purza *et al.*[8] showed in their large trial that patients with a lower weight had a greater risk for major complications. In pediatric patients, TEE probe selection is based on the weight of the patient and the size of the probe.[42,43] Creating a standardized approach to assign probe sizes to specific BMI categories could help further decrease the risk for complications, although it would be important to ensure image quality is not sacrificed as a result. This study has notable implications from the public health perspective. In the setting of complex cardiovascular disease, a comprehensive heart team approach is needed to optimize education about risks, benefits, and alternative options in a patient-centric approach.[44] The field of structural cardiology continues to evolve and offers interventions to reduce symptomatic burden in patients when surgery is not a viable option. As the volume of percutaneous interventions increases, we must remain cognizant of the risks of TEE-related complications in TEE-guided procedures.[45] Discussion with patients about the risks of upper gastrointestinal hemorrhage, an esophageal injury requiring surgical intervention, and even death allows for clearly defined expectations, especially in non-TAVR procedures that carry a higher risk of adverse events. Further efforts are needed to study mechanisms to reduce the risk of TEE complications and potential alternative approaches that can be utilized. This study highlights the importance of implementing new practices in clinical care as they can help reduce the risk for both major and minor complications.

There are several limitations to our study. First, we collected patient outcomes based on the ICD-10-CM coding schema. While this structured approach allowed for maximal data extraction, there is an inherent risk for incomplete data results secondary to coding errors and incomplete reporting.[46,47] However, the coding protocol is largely standardized across health care systems, which helps counteract this issue.[48] Second, there is selection bias in our patient population as we are limited to institutions that integrate their electronic health records into the TriNetX research database.[23] Another limitation of using the TriNetX research database is that most health care organizations included in our study are from the Southeast. There are fewer health care organizations from the West Coast included in the database. This limited our ability to achieve a more balanced geographic distribution of the population for our analysis. The third limitation stems from using group-level data as a proxy for individual-level data. By using TriNetX, we are unable to complete a standardized pre- and postprocedure evaluation for major complications that may have resulted after a TEE-guided structural intervention.[49] Fourth, due to the limitations of the database, we were unable to assess whether procedure duration was a contributing factor to complications. Furthermore, we could not evaluate whether complications led to an increased length of hospital stay. Additionally, the database we used lacked the indication for procedures

performed, which limits our ability to understand the role of the patient's clinical profile in complications. Finally, it should be noted that our findings reflect practices in large academic medical centers and may not apply to other types of practices given the nature of our database. Regardless, this largest-to-date nationwide study demonstrates that there is an increased risk of major complications from TEE being used concurrently to guide structural heart cases. Likewise, it is important to develop a standardized process with a heart team approach to evaluate the likelihood of the potential risks a patient may develop undergoing a transcatheter structural cardiac intervention.

In conclusion, this study found that the prevalence of complications from TEE used to guide structural heart interventions was 3.6%, which represents a higher level of risk than classically thought. With a shift to poor surgical candidates completing less invasive procedures, the future of TEE-guided procedures relies on an updated, comprehensive risk discussion. While the benefits of TEE-guided procedures are innumerable, there are serious risks that require attention. Further studies are needed to see whether additional modalities, such as three-dimensional TEE or ICE during structural cardiac interventions, help decrease the risk of TEE-related complications compared with conventional methods.[50]

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