Published in final edited form as:

J Cardiothorac Vasc Anesth. 2019 January ; 33(1): 118–133. doi:10.1053/j.jvca.2018.07.040.

Practice Pattern Variation in the Use of Transesophageal Echocardiography for Open Valve Cardiac Surgery

Emily J. MacKay, DO^{a,d,e,f}, Peter W. Groeneveld, MD, MS^{b,e,f}, Lee A. Fleisher, MD^{a,d,f}, Nimesh D. Desai, MD, PhD^{c,e,f}, Jacob T. Gutsche, MD, FASE^a, John G. Augoustides, MD, FASE^a, Prakash A. Patel, MD, FASE^{a,e}, and Mark D. Neuman, MD, MS^{a,e,f}

^aDepartment of Anesthesiology & Critical Care, Perelman School of Medicine at the University of Pennsylvania, Philadelphia

^bDepartment of Internal Medicine, Perelman School of Medicine at the University of Pennsylvania, Philadelphia

^cDivision of Cardiovascular Surgery, Perelman School of Medicine at the University of Pennsylvania, Philadelphia

^dPenn Center for Perioperative Outcomes Research and Transformation (CPORT), University of Pennsylvania, Philadelphia

^ePenn's Cardiovascular Outcomes, Quality and Evaluative Research Center (CAVOQER), University of Pennsylvania, Philadelphia

^fLeonard Davis Institute of Health Economics (LDI), University of Pennsylvania, Philadelphia

Abstract

Objective: We sought to assess for the presence of practice variation in the use of intraoperative transesophageal echocardiography (TEE) for open, cardiac valve surgery.

Design: This study was a retrospective cohort analysis

Setting: The administrative claims data used for this investigation was multi-institutional and a representative sample of commercially-insured patients in the US between 2010 and 2015.

Participants: The cohort consisted of adult patients, aged 18 years or older undergoing open mitral valve (MV) or aortic valve (AV) surgery.

Interventions: This was an observational analysis without interventions.

Correspondence: Dr. Emily J. MacKay, DO, 511 Blockley Hall, 423 Guardian Drive, Philadelphia, PA 19104, **Office:** 215-746-7468, **Fax:** 215-349-5078, **Cell:** 412-728-8793, emily.mackay@uphs.upenn.edu, mackay.ej@gmail.com, petergro@upenn.edu, lee.fleisher@uphs.upenn.edu, nimesh.desai@uphs.upenn.edu, jacob.gutsche@uphs.upenn.edu, yianni.augoustides@uphs.upenn.edu, prakash.patel@uphs.upenn.edu, mark.neuman@uphs.upenn.edu

Conflicts of Interest:

All co-authors declare no competing interests

Publisher's Disclaimer: This is a PDF file of an unedited manuscript that has been accepted for publication. As a service to our customers we are providing this early version of the manuscript. The manuscript will undergo copyediting, typesetting, and review of the resulting proof before it is published in its final citable form. Please note that during the production process errors may be discovered which could affect the content, and all legal disclaimers that apply to the journal pertain.

Measurements and Main Results: Of 19,386 valve surgeries, 12,313 (64%) underwent AV replacement, 6,192 (32%) underwent MV repair or replacement and 881 (<5%) underwent both MV and AV surgery. The overall rate of intraoperative TEE was 82% (95% Confidence Interval (CI): 81 – 82%); less frequently observed in AV procedures compared to MV or combined MV-AV procedures (80% vs 85% $p<0.001$). Rates of intraoperative TEE claims varied markedly across US states. After adjustment, the relative odds of an intraoperative TEE claim ranged across states from 0.26 (Louisiana; 95% CI: 0.18 – 0.36; $p<0.001$) to 2.10 (North Carolina 95% CI: 1.57 – 2.82; $p<0.001$).

Conclusions: Among adult patients undergoing open aortic or mitral valve surgery in the US, 82% had a claim for an intraoperative TEE with marked variability across US states. Increasing adherence to intraoperative TEE guidelines for valve surgery may represent an unrecognized opportunity to improve the quality of cardiac surgical care.

Keywords

Health Services; Guideline Compliance and Adherence; Transesophageal Echocardiography; Intraoperative Echocardiography; Cardiovascular Surgery; Mitral Valve Surgery; Aortic Valve Surgery; Ethics and Policy

Introduction

Cardiac valve disease currently affects between 4.2 and 5.6 million adults in the United States (US).¹ Surgery is a key component of effective treatment of advanced cardiac valve disease, with heart valve procedures comprising approximately 25% of nearly 300,000 open cardiac surgeries performed in the US each year.²

Since 2010, the American Society of Anesthesiology (ASA)³ and the Society of Cardiovascular Anesthesiology (SCA)³ have recommended the routine use of intraoperative transesophageal echocardiography (TEE) for all open cardiac valve procedures, with subsequent endorsement of broad recommendations for TEE use for valve surgery by other organizations, including the American Society of Echocardiography (ASE),⁴ the American College of Cardiology (ACC)⁵ and the American Heart Association (AHA).⁵ For valve surgery patients, intraoperative TEE permits real-time confirmation of valve pathology,^{3, 5, 6} screening for cardiac diagnoses,^{3, 6} assessment of the repaired or replaced valve,^{3, 7} identification of air emboli⁸ and continuous hemodynamic monitoring.^{5, 9–11}

At present, little is known regarding adherence to current intraoperative TEE guidelines for open cardiac valve surgery in the US. While single-institution studies^{10, 11} have reported high rates of intraoperative TEE within selected referral centers, the extent of TEE utilization across diverse institutions and patient populations remains relatively unexplored. From the standpoint of health policy, characterizing the nature of variability in TEE use for cardiac valve surgery in the US may provide insight into current gaps in the quality of intraoperative care and help identify targets for local and national efforts to improve such care.

In order to assess national patterns of TEE utilization in cardiac valve surgery, we carried out a retrospective cohort analysis of patients undergoing open mitral valve (MV) and aortic valve (AV) procedures between 2010 and 2015 using claims data from one large national insurer. Our project had three principal goals. First, we sought to estimate the overall rate of intraoperative TEE utilization among patients undergoing open MV or AV surgery; hypothesizing that TEE use would be higher among MV compared to AV procedures. Second, we aimed to assess variations in the use of intraoperative TEE for valve surgery across geographic areas and according to patient medical and surgical characteristics. Finally, we sought to explore differences in relevant covariates associated with intraoperative TEE across patients undergoing AV and MV surgery.

Methods

Data Source

We used 2010–2015 data from the Optum Clinformatics (Eden Prairie, MN) database. Optum is a proprietary research database containing de-identified claims from over 60 million individuals. The available data consists of patient sociodemographic characteristics, inpatient medical diagnoses and surgical procedure hospital claims, individual physician billing claims, pharmacy prescriptions and laboratory test results.¹² The database is geographically diverse, representing all 50 US states;¹³ evaluated against the typical insured US population, Optum has a lower proportion of those aged 65 years or older,¹⁴ is less racially and ethnically diverse with fewer individuals of black race and Hispanic ethnicity,¹⁴ but has comparable annual salary and education level.¹⁴ Because these data are de-identified, this study was exempted from review by the Institutional Review Board of the University of Pennsylvania, Philadelphia.

Population

We included all hospital discharges among adults aged 18 or older with a claim for an open MV repair, MV replacement, or AV replacement between January 1, 2010 and October 1, 2015. Surgical discharge claims were identified using *International Classification of Disease-9-Clinical Modification* (ICD-9-CM)¹⁵ procedure codes^{16–20} for open MV repair or replacement (ICD-9-CM procedure codes 35.13, 35.23–4) or AV replacement (ICD-9-CM procedure codes 35.21–2). Discharges among patients receiving both an MV and AV procedure during one hospitalization were eligible for inclusion in our cohort. For our primary analysis, patients who underwent both an MV procedure and an AV procedure (MV-AV) were grouped with other patients undergoing MV surgery. We expected, a priori, that TEE use for MV-AV procedures would be similar to MV-only procedures (vs AV-only procedures) given the important role TEE has for MV surgery, such as guiding surgical repairs,^{21–23} or deciding on an MV replacement.²⁴ However, supplementary analyses excluded patients undergoing combined MV-AV surgeries to allow for comparison of patients undergoing either AV or MV surgery, but not both.

Patients were excluded if they had missing data on age, sex or state of residence in hospital or provider claims. We restricted our sample to discharges occurring in the 50 US states (i.e. excluding claims originating from US territories or federal districts). As our goal was to

assess the overall rate of TEE use among patients undergoing open MV or AV surgery, we conducted our analysis at the visit-level rather than at the level of the individual patient; as such, if a patient had more than one discharge for valve surgery over the period, all eligible discharges were included in our analysis.

Outcome Variable

The primary outcome for this analysis was receipt of a TEE within 1 calendar day of the index surgery. We assessed receipt of an intraoperative TEE using Current Procedural Terminology (CPT) codes for TEE in provider claims associated with that hospitalization (CPT Codes 93312–5; 93317–8; 93320–1; 93325). Physician service (CPT) claims are designed to reimburse specialty-specific consultation, procedures or imaging²⁵ and have been used to identify echocardiography receipt in both surgical²⁶ and non-surgical populations.²⁷ CPT claims have superior validity over hospital discharge claims for identifying echocardiography.^{28, 29} To identify intraoperative TEE procedures, we matched date of TEE to the date of open cardiac valve surgery using physician service claims with CPT codes corresponding to AV (33400–1; 33403; 33405–6; 33410–7) and MV (33420; 33422; 33425–7; 33430) cardiothoracic surgery procedures. The TEE was considered intraoperative if the date of the TEE claim occurred within 1 calendar day of the date of the surgical procedure claim for AV or MV surgery. As a secondary outcome, we assessed TEE receipt at any point during the hospitalization, regardless of temporal relationship to the date of surgery.

Independent variables

We collected data on admission year and patient age, sex, race, and ethnicity from the hospital discharge claim. Due to limitations of the available data, race was categorized as black, white, other, and unknown. Because specific data on race were not available for patients classified as being Hispanic, race was considered to be unknown among these individuals.

Additional data collected from the hospital discharge claim included 14 comorbidities, which were determined by secondary ICD-9-CM diagnosis codes based on established algorithms.^{30, 31} Data on the surgical procedure was obtained via ICD-9-CM procedure codes in the discharge claim and included: procedure type (MV repair, MV replacement, or AV replacement), performance of a coronary artery bypass graft (CABG) surgery (ICD-9-CM procedure codes 36.10–7, 36.19). Multiple valve surgery was defined as undergoing an MV-AV surgery or a concurrent replacement or repair of the tricuspid valve (TV) or pulmonic valve (PV) (ICD-9-CM procedure codes 35.13–4, 35.25–8). Data on the US state in which the procedure was performed was obtained from physician provider claims associated with each hospital discharge.

Statistical analysis

We used descriptive statistics to characterize the percentage of surgical procedures with an associated TEE claim (1) among all discharges in our sample; (2) among discharges for an AV replacement without a concurrent procedure on the MV; and (3) among discharges for MV repair or MV replacement, with or without a concurrent procedure on the AV.

Additionally, we assessed variation in intraoperative TEE claims in the overall sample and by procedure category according to patient demographic, medical, and surgical factors and across US states. States with fewer than 100 discharges over the period (in the overall sample or either of the procedure subgroups) were grouped together for purposes of analysis. We used logistic regression to estimate the probability that an intraoperative TEE would be performed during a given admission for cardiac valve surgery as a function of geographic location by state.

This logistic regression analysis adjusted for demographics (age, sex, race, ethnicity and discharge year), surgical factors (AV replacement, MV replacement, MV repair, additional valve procedures and simultaneous CABG surgery) and medical characteristics (arrhythmia, congestive heart failure, coagulopathy, chronic obstructive pulmonary disease, diabetes mellitus, hypertension, pulmonary hypertension, peripheral vascular disease and unstable angina).

We repeated our regression analysis on subgroups restricted to discharges for an AV replacement without a concurrent procedure on the mitral valve; and among discharges for MV repair or replacement, with or without a concurrent procedure on the AV. A supplementary analysis excluded patients who underwent MV surgery *plus* AV surgery (MV-AV) during the same hospitalization. Finally, we repeated all analyses for our secondary endpoint of a TEE claim at any point during hospitalization.

All significance tests were two-sided and used a p-value of <0.05 for statistical significance. Analyses used SAS 9.4 (SAS Institute, Cary, NC), and STATA 15.0 (StataCorp, College Station, TX). Figures were created using Tableau Desktop 9.2 (Tableau, Seattle, WA) and modified using Sketch Version 47.1 (Sketch, Hague, the Netherlands).

Results

Characteristics of Study Sample:

We identified 21,944 discharges among individuals aged 18 or older with a discharge procedure code indicating receipt of an eligible study procedure. After excluding 455 discharges due to missing age, sex, or geographic data, 117 discharges not occurring in one of 50 US States and 1,986 discharges without an AV or MV cardiac surgery CPT code we obtained a final sample of 19,386 discharges (**Table 1**). Of these, 12,313 (64%) underwent an AV replacement, 6,192 (32%) underwent an MV repair or replacement and 881 (<5%) underwent MV-AV surgery.

Within our sample, 3,607 (51%) of discharges for MV surgery were for MV replacements and 3,466 (49%) were for MV repairs. Among all MV surgeries 1,002 (14%) were performed with additional valve procedures and 1,750 (25%) underwent a concurrent CABG surgery. Of the 12,313 discharges for AV replacements (without concurrent MV surgery), 109 (<1%) were performed with additional valve procedures and 4,641 (38%) underwent a concurrent CABG surgery. Compared to patients undergoing AV surgery, MV (and MV-AV) patients demonstrated a greater burden of serious cardiopulmonary disease with higher rates

of arrhythmia (35% vs. 29%; $p<0.001$), congestive heart failure (37% vs. 27%; $p<0.001$) and pulmonary hypertension (10% vs. 5%; $p<0.001$).

Within the overall sample 82% (95% confidence interval (CI): 81 – 82%) of open cardiac valve procedures had a corresponding intraoperative TEE claim. TEE claims occurred less frequently for AV procedures (80%; 95% CI: 79 – 81%) compared to MV (and MV-AV) procedures (85%; 95% CI: 84 – 86%; $p<0.001$). Rates of intraoperative TEE claims within the study cohort varied markedly across states both within the entire cohort and within the AV and MV (and MV-AV) subgroups. Among states with greater than 100 cardiac valve surgery cases within the overall cohort, the incidence of intraoperative TEE claims ranged from 61% in both Alabama (95% CI: 56 – 66%) and Louisiana (95% CI: 53 – 68%) to 92% (North Carolina; 95% CI: 90 – 94%) (**Figure 1**). Similar patterns of variation were seen among discharges for AV procedures, (**Figure 2**) and for MV (and combined MV-AV) procedures (**Figure 3**).

The analysis using the secondary endpoint of a hospitalization TEE claim at any point during hospitalization for cardiac valve surgery revealed findings similar to the primary endpoint of an intraoperative TEE claim. This hospital-level analysis included the 1,986 discharges with an ICD-9 code but without a CPT code for AV or MV surgery (**Appendix 1**). Within the overall sample 83% (95% CI: 83 – 84%) of 21,372 open cardiac valve procedures had a corresponding *hospitalization* TEE claim; TEE claims occurred less frequently for AV procedures (81%; 95% CI: 80 – 82%) compared to MV (and MV-AV) procedures (88%; 95% CI 87 – 88%; $p<0.001$) and demonstrated corresponding geographic variation.

Covariates Associated with TEE

In unadjusted analyses (**Table 2**), we observed marked variation in the odds of an intraoperative TEE claim across states. Compared to Minnesota (reference), the relative odds of a TEE claim ranged across states from 0.27 in both Alabama (95% CI: 0.21 – 0.35; $p<0.001$) and Louisiana (95% CI: 0.19 – 0.38; $p<0.001$) to 2.00 (North Carolina; 95% CI: 1.50 – 2.68; $p<0.001$). Compared to MV replacement, MV repair was associated with a greater odds (OR: 1.19, 95% CI: 1.05 – 1.36; $p=0.01$) and AV replacement was associated with a lower odds (OR: 0.76, 95% CI: 0.69 – 0.84; $p<0.001$) of an intraoperative TEE claim. Additionally, undergoing a concurrent CABG surgery was associated with an increased odds of an intraoperative TEE claim (OR: 1.24; 95% CI: 1.15 – 1.34; $p<0.001$). Patients of Hispanic ethnicity demonstrated a lower odds of an intraoperative TEE claim compared to non-Hispanic ethnicity (OR: 0.67, 95% CI: 0.58 – 0.78; $p<0.001$). Although no comorbidity was found to be associated with a lower odds of an intraoperative TEE claim, comorbid conditions of coagulopathy (OR: 1.16; 95% CI: 1.04 – 1.30; $p=0.10$) and peripheral vascular disease (OR: 1.19; 95% CI: 1.01 – 1.40; $p=0.03$) were associated with a greater odds of an intraoperative TEE claim. Finally, year in which the surgery was performed demonstrated no association with an intraoperative TEE claim. Overall, similar results were obtained in adjusted analyses (**Table 2**) with the exception of MV repair, which did not remain significantly associated with an intraoperative TEE claim compared to MV replacement following adjustment (OR: 1.08, 95% CI: 0.93 – 1.24; $p=0.30$).

The analysis using the secondary endpoint of a TEE claim at any point during hospitalization for cardiac valve surgery revealed similar marked geographic variation (**Appendix 2**). Following adjustment, the relative odds of a hospitalization TEE claim ranged across states from 0.28 in both Alabama (95% CI: 0.22 – 0.37; $p<0.001$) and Louisiana (95% CI: 0.20 – 0.39; $p<0.001$) to 2.06 (North Carolina; 95% CI: 1.54 – 2.73; $p<0.001$). An additional corresponding finding was that compared to MV replacement, AV replacement was associated with a lower adjusted odds of a hospitalization TEE claim (OR: 0.63, 95% CI: 0.56 – 0.71; $p<0.001$).

Subgroup Analyses

Among the 12,313 discharges for AV replacement, the adjusted odds of an intraoperative TEE claim varied by US state, but demonstrated wider geographic distribution compared to the overall population (**Table 3**). The relative adjusted odds of an intraoperative TEE claim ranged across states from 0.20 (Alabama, 95% CI: 0.14 – 0.28; $p<0.001$) to 2.50 (North Carolina, 95% CI: 1.74 – 3.59; $p<0.001$). As in the main regression, peripheral vascular disease was associated with a greater adjusted odds of an intraoperative TEE claim (OR: 1.32; 95% CI: 1.10 – 1.58; $p=0.002$). In contrast to the overall findings, Hispanic ethnicity was not significantly associated with a lower adjusted odds of an intraoperative TEE claim (OR: 0.72; 95% CI: 0.47 – 1.10; $p=0.13$) and undergoing a concurrent CABG surgery was not significantly associated with a greater adjusted odds on an intraoperative TEE claim (OR: 1.03; 95% CI: 0.93 – 1.13; $p=0.61$).

Among 7,073 patients undergoing MV (and MV-AV) surgeries, consistent with both the main regression and the AV surgery subgroup analysis, the adjusted odds of an intraoperative TEE claim varied by US state (**Table 3**). Notably, the MV (and MV-AV) subgroup demonstrated a narrower geographic distribution than either the overall cohort or the AV subgroup; and while Tennessee was associated with the lowest adjusted odds of an intraoperative TEE claim (OR: 0.32, 95% CI: 0.20 – 0.52; $p<0.001$), the state with the greatest adjusted odds for an intraoperative TEE claim (Utah) did not reach statistical significance (OR: 1.80 95% CI: 0.83 – 3.92; $p=0.14$). Consistent with both the main regression, and the AV subgroup regression, coagulopathy was associated with a greater adjusted odds of an intraoperative TEE claim (OR: 1.33; 95% CI: 1.06 – 1.68; $p=0.01$). Consistent with the main regression but in contrast to AV subgroup analysis, Hispanic ethnicity was associated with a lower adjusted odds of an intraoperative TEE claim (OR: 0.54; 95% CI: 0.30 – 0.95; $p=0.03$) and a concurrent CABG surgery was associated with a greater adjusted odds of TEE receipt (OR: 1.42, 95% CI: 1.22 – 1.65; $p<0.001$). We obtained similar results when the analysis was repeated excluding the 881 (<5%) discharges in which patients received both an MV and an AV (combined MV-AV) surgery during the same hospitalization (**Appendix 3**).

The subgroup analyses using the secondary endpoint of a hospitalization TEE claim revealed similar geographic variation in both the AV and the MV (and MV-AV) subgroup analyses (**Appendix 4**). Among 14,010 AV procedures, the relative adjusted odds of a hospitalization TEE claim ranged across states from 0.24 (Alabama; 95% CI: 0.17 – 0.32; $p<0.001$) to 2.52 (North Carolina; 95% CI: 1.80 – 3.551; $p<0.001$). Among 7,362 MV (and MV-AV)

procedures, the relative adjusted odds of a hospitalization TEE claim ranged from 0.22 (Tennessee; 95% CI: 0.13 – 0.38; $p < 0.001$) to 1.06 (North Carolina; 95% CI: 0.60 – 1.89; $p = 0.83$). An additional corresponding finding included that among the MV (and MV-AV) surgeries, undergoing a concurrent CABG surgery demonstrated a greater adjusted odds of a hospitalization TEE claim (OR: 1.26; 95% CI: 1.07 – 1.48; $p = 0.01$).

Discussion

Among 19,386 adults undergoing cardiac valve surgery, we observed that 82% had a claim for an intraoperative TEE with the likelihood of a TEE claim being greater among patients undergoing MV (and combined MV-AV) procedures compared to patients undergoing AV procedures (85% vs 80%). Interestingly the odds of an intraoperative TEE claim varied according to selected patient medical and surgical characteristics, such as coagulopathy and concurrent coronary artery bypass graft (CABG) surgery. One possible explanation for this finding might be that more complicated (cardiac valve *plus* CABG), higher-risk cases requiring longer cardiopulmonary bypass times (directly linked to coagulopathic bleeding)^{32–34} are typically performed at large, high-volume, academic centers where intraoperative TEE may be more of a standard of practice. Still, while intraoperative TEE claims varied according to these medical and surgical factors, non-medical factors accounted for a substantial amount of variation. Notably, TEE claims varied according to ethnicity and geography. Specifically, those with a Hispanic ethnicity were less likely to have a TEE claim, and across US states, a 1.5-fold difference was observed between states with the highest and lowest rates of claims for intraoperative TEE. This variation was observed both within our overall sample, and in subgroups limited to patients undergoing AV procedures and MV procedures.

Intraoperative TEE has been a standard of care for open cardiac valve surgery since 2010, when its routine use was first recommended by the American Society of Anesthesiologists (ASA)³ and the Society of Cardiovascular Anesthesiologists (SCA).³ Since then, the Society of Thoracic Surgeons (STS),^{5, 8} the American Society of Echocardiography (ASE),⁴ the American College of Cardiologists (ACC)^{4, 5} and the American Heart Association (AHA)⁵ have all recommend its routine use in open cardiac valve surgery.^{4, 5, 8} TEE permits real-time confirmation of valve pathology,^{3, 6} pre-surgical assessment of the mechanism of valve dysfunction³ and post-surgical assessment of the function of the repaired or replaced valve.^{6, 7, 35} In addition, TEE allows for continuous monitoring that may reduce the incidence of air emboli^{6, 7} following open heart procedures and improve the diagnosis and treatment of complications associated with cardiopulmonary bypass such as cardiac failure^{6, 36} or aortic dissection.^{6, 8}

Despite widespread agreement on the value of intraoperative TEE,^{3–5, 8} little prior research exists to characterize national patterns of intraoperative TEE use for open cardiac valve surgery. Work in the general health services literature has shown that adherence to high quality processes of care in the US is frequently less than 100%.^{37–44} In this context, we found that nearly one in five patients undergoing cardiac valve surgery lacked a claim for a TEE within one day of an open cardiac valve procedure, highlighting the possibility that a substantial proportion of patients may fail to receive guideline-concordant care for open

cardiac valve surgery in this domain.^{4, 5, 8} Our results suggest that this potential quality gap may be most pronounced in the AV subgroup where more than one in five patients lacked a claim for an intraoperative TEE. Claims for TEE at the time of surgery were more common in the MV (or combined MV-AV) subgroup where only one in seven patients lacked an intraoperative TEE claim. This observation may be due to the unique role TEE has in surgical planning in MV procedures, particularly MV repair.^{5, 6, 10, 22–24, 45–47} Nonetheless, even in this context, claims for intraoperative TEE were well below 100%.

In addition to our overall findings, our work suggests that claims for intraoperative TEE may vary both by patient factors and by geography. This finding adds to prior work that has identified quality gaps in healthcare according to race and ethnicity.^{38, 40} After accounting for a wide range of demographic, medical and surgical factors we found evidence of variation according to Hispanic versus non-Hispanic ethnicity. Among the entire cohort, and among the MV (or combined MV-AV) subgroup, Hispanic patients were found to have a lower rate of intraoperative TEE claims. Although this result did not achieve statistical significance within the AV subgroup, the trend toward a lower rate of intraoperative TEE claims among Hispanic patients persisted.

Besides the variation we observed according to patient ethnicity, we observed substantial geographic variation in intraoperative TEE claims. A 1.5-fold difference was observed between the states with the highest (North Carolina) and the lowest (Louisiana) rates of TEE utilization within our overall sample. This geographic variation was more extreme among the AV procedures (1.9-fold difference) and less extreme among the MV (or combined MV-AV) procedures (1.3-fold difference). While the present work doesn't allow for an explanation for the observed arbitrary variation, it highlights a previously unrecognized inequality in the use of intraoperative TEE as a standard of care not accounted for by observed demographic, medical and surgical factors.

Our study should be interpreted with awareness of several limitations. First, although Optum is a large data source, it represents a commercially insured population. As such, these findings may not be applicable to the Medicare population. Second, due to data limitations, we were limited in our ability to explore potential factors, such as hospital-level differences in care or billing, that could explain some of the geographic variations we observe here. Third, while our model controlled for observed demographic, medical and surgical factors, we cannot exclude unobserved confounding in our analysis. Finally, it is possible that some patients may have undergone a TEE for which no procedure claim was submitted. If this were to occur, our analysis would underestimate the rate of TEE utilization. Nonetheless, our use of physician service claims, rather than hospital claims data may mitigate this concern because physician billing codes have high fidelity for echocardiography.^{26–29} Moreover, our results were consistent across different outcome specifications that considered both TEE claims filed within one day of surgery, and TEE claims filed at any point during the hospital stay, regardless of their temporal association with surgery.

In conclusion, this analysis of claims data from a national sample of commercially insured adults undergoing open cardiac valve surgery found the overall rate of intraoperative TEE claims associated with cardiac valve surgery to be 82%. We observed variation in the

likelihood of a TEE claim according to surgical procedure, and according to patient and geographic factors. Future work will focus on validating the present findings and identifying potential variations in practice across physicians or hospitals that may explain differences in the incidence of claims for intraoperative TEE across US states. Finally, our approach to using claims for surveillance of intraoperative TEE use in cardiac surgery highlights potential opportunities for claims-based quality measurement and benchmarking related to TEE use.

Acknowledgments

The authors gratefully acknowledge Lin Yang, MS (Department of Internal Medicine, Perelman School of Medicine at the University of Pennsylvania, Philadelphia) for her help programming in SAS for the data query.

Sources of Funding

This work was supported by a National Institutes of Health (NIH) Training Grant T32 (5T32HL098054-07) to E.J.M.

Appendix

Appendix 1:

Characteristics of study sample, overall and by location of the principal valve procedure (Secondary outcome: Hospitalization TEE Claim) (N=21,372)

		Overall (n = 21,372)	Principal valve procedure: aortic (n = 14,010)	Principal valve procedure: mitral (n = 7,362)	P (aortic vs mitral)
Demographics					
Age in years [mean, SD]		68 ± 0.08	69 ± 0.10	66 ± 0.14	<0.001
Sex [n, (%)]					
	Female	8,026 (38)	4,747 (34)	3,279 (45)	<0.001
	Male	13,346 (62)	9,263 (66)	4,083 (55)	
Race [n, (%)]					
	White	16,684 (78)	11,034 (79)	5,650 (77)	<0.001
	Black	1,692 (8)	1,009 (7)	683 (9)	
	Other	1,452 (7)	950 (7)	502 (7)	
	Unknown	1,544 (7)	1,017 (7)	527 (7)	
Ethnicity [n, (%)]					
	Hispanic	1,094 (5)	759 (5)	335 (5)	0.01
	Non-Hispanic	20,278 (95)	13,251 (95)	7,027 (95)	
Year [n, (%)]					
	2010	3,338 (16)	2,180 (16)	1,158 (16)	0.45
	2011	3,354 (16)	2,147 (15)	1,207 (16)	
	2012	3,711 (17)	2,450 (17)	1,261 (17)	
	2013	3,981 (19)	2,630 (19)	1,351 (18)	
	2014	3,902 (18)	2,567 (18)	1,335 (18)	

		Overall (n = 21,372)	Principal valve procedure: aortic (n = 14,010)	Principal valve procedure: mitral (n = 7,362)	P (aortic vs mitral)
	2015	3,086 (14)	2,036 (15)	1,050 (14)	
Surgical factors					
Principal surgery type [n, (%)]					
	Mitral valve replacement	3,757 (18)	n/a	3,757 (51)	<0.001
	Mitral valve repair	3,605 (17)	n/a	3,605 (49)	
	Aortic valve replacement	14,010 (66)	14,010 (100)	n/a	
Additional valve procedures performed [n, (%)]		1,165 (5)	121 (1)	1,044 (14)	<0.001
Coronary artery bypass graft performed [n, (%)]		6,925 (32)	5,097 (36)	1,828 (25)	<0.001
Comorbidities [n, (%)]					
Arrhythmia		6,504 (30)	3,967 (28)	2,537 (34)	<0.001
Congestive heart failure		6,418 (30)	3,678 (26)	2,740 (37)	<0.001
Coagulopathy		2,717 (13)	1,874 (13)	843 (11)	<0.001
Chronic obstructive pulmonary disease		2,222 (10)	1,289 (9)	933 (13)	<0.001
Diabetes mellitus		1,231 (6)	1,054 (8)	177 (2)	<0.001
Hypertension		3,196 (15)	2,392 (17)	804 (11)	<0.001
Pulmonary hypertension		1,382 (6)	654 (5)	728 (9)	<0.001
Peripheral vascular disease		1,963 (9)	1,830 (13)	133 (2)	<0.001
Unstable angina		386 (2)	311 (2)		<0.001
Primary Study outcome					
Underwent transesophageal echocardiography during hospitalization for index valve surgery		17,808 (83)	11,365 (81)	6,443 (88)	<0.001

Appendix 2:

Unadjusted and adjusted covariates associated with TEE (hospitalization claim) in the overall study population (N = 21,372)

		Unadjusted			Adjusted		
		Odds ratio	95% confidence interval	P	Odds ratio	95% confidence interval	P
Demographics							
Age							
	18–45	Reference	-	-	-	-	-
	45–54	0.92	0.75–1.14	0.44	0.96	0.77–1.19	0.69
	55–65	1.00	0.82–1.21	0.99	1.04	0.85–1.26	0.71
	>65	0.80	0.67–0.95	0.01	0.85	0.70–1.02	0.09
Sex							
	Female	Reference	-	-	-	-	-
	Male	1.01	0.94–1.09	0.83	1.05	0.97–1.13	0.22

		Unadjusted			Adjusted		
		Odds ratio	95% confidence interval	P	Odds ratio	95% confidence interval	P
Race							
	White	Reference	-	-	-	-	-
	Black	0.98	0.85–1.12	0.73	0.99	0.86–1.14	0.89
	Other	0.76	0.66–0.87	<0.001	1.05	0.78–1.41	0.77
	Unknown	1.03	0.89–1.19	0.68	1.02	0.88–1.18	0.76
Ethnicity							
	Non-Hispanic	Reference	-	-	-	-	-
	Hispanic	0.69	0.59–0.79	<0.001	0.72	0.52–1.00	0.05
States with 100 cases (35)							
	Minnesota	Reference	-	-	-	-	-
	Alabama	0.28	0.22–0.37	<0.001	0.28	0.22–0.37	<0.001
	Arizona	1.12	0.81–1.53	0.50	1.15	0.84–1.59	0.38
	California	1.01	0.75–1.35	0.97	0.98	0.73–1.32	0.90
	Colorado	0.73	0.54–1.00	0.05	0.68	0.50–0.94	0.02
	Connecticut	0.60	0.46–0.79	<0.001	0.66	0.50–0.87	0.004
	Florida	0.82	0.68–0.99	0.04	0.88	0.73–1.06	0.17
	Georgia	1.28	1.01–1.62	0.04	1.28	1.00–1.63	0.05
	Iowa	0.95	0.66–1.38	0.80	1.04	0.72–1.51	0.83
	Illinois	0.55	0.43–0.69	<0.001	0.56	0.45–0.71	<0.001
	Indiana	0.60	0.46–0.79	<0.001	0.62	0.47–0.82	0.001
	Kansas	0.66	0.41–1.06	0.09	0.66	0.41–1.07	0.09
	Kentucky	1.14	0.68–1.90	0.63	1.14	0.68–1.92	0.61
	Louisiana	0.28	0.20–0.39	<0.001	0.28	0.20–0.39	<0.001
	Massachusetts	1.36	0.98–1.90	0.07	1.49	1.07–2.08	0.02
	Maryland	0.35	0.25–0.48	<0.001	0.33	0.24–0.45	<0.001
	Michigan	0.82	0.49–1.37	0.46	0.80	0.48–1.34	0.40
	Missouri	0.69	0.55–0.87	0.001	0.72	0.58–0.90	0.01
	North Carolina	1.95	1.47–2.59	<0.001	2.06	1.54–2.73	<0.001
	North Dakota	0.85	0.55–1.31	0.45	0.96	0.62–1.48	0.85
	Nebraska	0.47	0.33–0.67	<0.001	0.49	0.35–0.70	<0.001
	New Hampshire	1.82	0.87–3.80	0.11	2.02	0.96–4.23	0.06
	New Jersey	0.45	0.35–0.57	<0.001	0.50	0.39–0.64	<0.001
	New York	0.81	0.65–1.00	0.05	0.86	0.69–1.06	0.16
	Ohio	0.89	0.72–1.09	0.26	0.86	0.70–1.07	0.18
	Oklahoma	0.54	0.35–0.83	0.01	0.53	0.34–0.83	0.01
	Oregon	0.62	0.44–0.87	0.01	0.67	0.47–0.95	0.03
	Pennsylvania	1.20	0.85–1.70	0.29	1.22	0.86–1.72	0.27
	Rhode Island	1.23	0.81–1.87	0.34	1.35	0.88–2.06	0.17

		Unadjusted			Adjusted		
		Odds ratio	95% confidence interval	P	Odds ratio	95% confidence interval	P
	Tennessee	0.48	0.37–0.62	<0.001	0.50	0.38–0.65	<0.001
	Texas	0.53	0.43–0.65	<0.001	0.53	0.43–0.66	<0.001
	Utah	1.01	0.73–1.41	0.93	1.07	0.77–1.49	0.67
	Virginia	1.21	0.83–1.77	0.32	1.23	0.84–1.80	0.29
	Washington	1.42	0.93–2.17	0.11	1.48	0.96–2.27	0.07
	Wisconsin	0.87	0.70–1.08	0.21	0.92	0.74–1.14	0.44
States with <100 cases (15)		0.65	0.51–0.82	<0.001	0.70	0.55–0.88	0.003
Year							
	2010 & 2011	Reference	-	-	-	-	-
	2012 & 2013	1.05	0.96–1.15	0.28	1.08	0.98–1.18	0.12
	2014 & 2015	0.97	0.89–1.06	0.51	1.01	0.92–1.11	0.87
Surgical factors							
Principal surgery type							
	Mitral valve replacement	Reference	-	-	-	-	-
	Aortic valve replacement	0.66	0.59–0.73	<0.001	0.63	0.56–0.71	<0.001
	Mitral valve repair	1.16	1.01–1.33	0.03	1.07	0.92–1.25	0.35
Additional valve procedures performed		0.76	0.64–0.91	0.002	0.99	0.82–1.20	0.94
Coronary artery bypass graft performed		1.18	1.09–1.27	<0.001	1.09	1.00–1.18	0.05
Comorbidities							
Arrhythmia		0.96	0.89–1.04	0.35	0.93	0.85–1.00	0.06
Congestive heart failure		1.04	0.96–1.13	0.31	0.97	0.89–1.05	0.45
Coagulopathy		1.12	1.00–1.25	0.05	1.10	0.98–1.24	0.09
Chronic obstructive pulmonary disease		0.84	0.76–0.95	0.004	0.81	0.69–0.95	0.01
Diabetes mellitus		0.82	0.71–0.94	0.01	0.95	0.81–1.10	0.46
Hypertension		0.81	0.74–0.90	<0.001	0.85	0.77–0.94	0.002
Pulmonary hypertension		0.95	0.83–1.10	0.52	1.01	0.82–1.23	0.94
Peripheral vascular disease		1.03	0.91–1.17	0.64	1.10	0.97–1.26	0.15
Unstable angina		0.83	0.64–1.07	0.14	0.96	0.73–1.25	0.74

Appendix 3:

Adjusted covariates associated with TEE (physician claim; intraoperative) of mitral subgroup, excluding combined MV-AV surgeries

Principal valve procedure: MV (excluding N = 881 MV-AV surgeries) (N = 6,192)			
	Odds ratio	95% confidence interval	P
Demographics			

		Principal valve procedure: MV (excluding N = 881 MV-AV surgeries) (N = 6,192)		
		Odds ratio	95% confidence interval	P
Age				
	18–45	Reference	-	-
	45–54	0.91	0.62–1.35	0.66
	55–64	0.88	0.61–1.26	0.48
	65	0.77	0.54–1.09	0.14
Sex				
	Female	Reference	-	-
	Male	1.02	0.88–1.18	0.80
Race				
	White	Reference	-	-
	Black	0.95	0.73–1.23	0.70
	Other	1.30	0.75–2.26	0.35
	Unknown	1.05	0.79–1.38	0.75
Ethnicity				
	Non-Hispanic	Reference	-	-
	Hispanic	0.56	0.30–1.05	0.07
States with >100 cases (MV:21)				
	Minnesota	Reference	-	-
	Alabama	0.39	0.23–0.68	0.001
	Arizona	0.97	0.49–1.92	0.94
	California	1.08	0.57–2.05	0.82
	Colorado	0.42	0.24–0.74	0.002
	Connecticut	0.71	0.39–1.31	0.28
	Florida	0.57	0.39–0.84	0.01
	Georgia	0.79	0.50–1.25	0.30
	Illinois	0.60	0.37–0.97	0.04
	Indiana	0.49	0.29–0.84	0.01
	Massachusetts	0.98	0.51–1.86	0.94
	Montana	0.39	0.25–0.61	<0.001
	North Carolina	1.27	0.74–2.17	0.39
	New Jersey	0.43	0.26–0.72	0.001
	Ohio	0.75	0.49–1.15	0.19
	Pennsylvania	0.49	0.28–0.86	0.01
	Tennessee	0.27	0.16–0.44	<0.001
	Texas	0.65	0.41–1.04	0.07
	Utah	1.46	0.66–3.22	0.35
	Virginia	0.88	0.42–1.83	0.73
	Wisconsin	0.56	0.36–0.85	0.01

		Principal valve procedure: MV (excluding N = 881 MV-AV surgeries) (N = 6,192)		
		Odds ratio	95% confidence interval	P
States with <100) (MV: 30)		0.58	0.40–0.83	0.003
Year				
	2010 & 2011	Reference	-	-
	2012 & 2013	1.04	0.87–1.24	0.64
	2014 & 2015	0.90	0.75–1.07	0.23
Surgical factors				
Principal surgery type				
	Mitral valve replacement	Reference	-	-
	Mitral valve repair	1.09	0.94–1.27	0.26
	Aortic valve replacement	n/a	n/a	n/a
Additional valve procedures performed		1.16	0.89–1.53	0.29
Coronary artery bypass graft performed		1.42	1.21–1.67	<0.001
Comorbidities				
Arrhythmia		0.92	0.79–1.06	0.25
Congestive heart failure		0.95	0.82–1.11	0.54
Coagulopathy		1.18	0.93–1.50	0.06
Chronic obstructive pulmonary disease		0.98	0.69–1.40	0.91
Diabetes mellitus		1.19	0.74–1.91	0.47
Hypertension		0.91	0.72–1.15	0.44
Pulmonary hypertension		0.87	0.59–1.214	0.48
Peripheral vascular disease		1.24	0.65–2.38	0.51
Unstable angina		1.00	0.55–1.83	1.00

Appendix 4:

Adjusted covariates associated with TEE (hospitalization claim), by location of principal valve procedure (aortic and mitral)

		Principal valve procedure: aortic (N = 14,010)			Principal valve procedure: mitral (IST = 7,362)		
		Odds ratio	95% confidence interval	P	Odds ratio	95% confidence interval	P
Demographics							
Age							
	18–45	Reference	-	-	Reference	-	-
	45–54	0.90	0.69–1.18	0.46	1.11	0.77–1.59	0.59
	55–64	1.09	0.85–1.39	0.50	1.02	0.73–1.43	0.90
	65	0.86	0.68–1.08	0.20	0.95	0.69–1.31	0.77
Sex							

		Principal valve procedure: aortic (N = 14,010)			Principal valve procedure: mitral (IST = 7,362)		
		Odds ratio	95% confidence interval	P	Odds ratio	95% confidence interval	P
	Female	Reference	-	-	Reference	-	-
	Male	1.06	0.97–1.16	0.21	1.02	0.88–1.18	0.76
Race							
	White	Reference	-	-	Reference	-	-
	Black	0.97	0.82–1.16	0.76	0.93	0.73–1.20	0.59
	Other	0.97	0.67–1.41	0.89	1.11	0.68–1.81	0.68
	Unknown	1.02	0.86–1.20	0.18	1.04	0.78–1.37	0.81
Ethnicity							
	Non-Hispanic	Reference	-	-	Reference	-	-
	Hispanic	0.76	0.50–1.14	0.18	0.71	0.40–1.26	0.25
States with 100 cases (AV: 30) (MV:21)							
	Minnesota	Reference	-	-	Reference	-	-
	Alabama	0.24	0.17–0.32	<0.001	0.33	0.19–0.58	<0.001
	Arizona	1.44	0.99–2.09	0.06	0.56	0.30–1.06	0.07
	California	1.05	0.74–1.50	0.77	0.68	0.37–1.26	0.22
	Colorado	0.86	0.58–1.26	0.44	0.36	0.20–0.64	0.001
	Connecticut	0.75	0.55–1.04	0.08	0.41	0.23–0.74	0.003
	Florida	1.01	0.82–1.25	0.90	0.53	0.35–0.80	0.003
	Georgia	1.64	1.23–2.18	0.001	0.61	0.37–0.99	0.05
	Iowa	1.06	0.71–1.59	0.76	n/a	n/a	n/a
	Illinois	0.61	0.46–0.79	<0.001	0.40	0.24–0.66	<0.001
	Indiana	0.67	0.49–0.93	0.02	0.44	0.25–0.78	0.01
	Louisiana	0.32	0.22–0.49	<0.001	n/a	n/a	n/a
	Massachusetts	1.82	1.24–2.69	0.002	0.75	0.38–1.47	0.40
	Maryland	0.39	0.27–0.56	<0.001	n/a	n/a	n/a
	Montana	0.89	0.68–1.15	0.36	0.37	0.23–0.60	<0.001
	North Carolina	2.52	1.80–3.51	<0.001	1.06	0.60–1.89	0.83
	North Dakota	1.11	0.68–1.82	0.67	n/a	n/a	n/a
	Nebraska	0.51	0.35–0.75	0.001	n/a	n/a	n/a
	New Jersey	0.57	0.43–0.77	<0.001	0.31	0.18–0.52	<0.001
	New York	1.11	0.86–1.43	0.43	n/a	n/a	n/a
	Ohio	0.92	0.72–1.18	0.51	0.64	0.40–1.02	0.06
	Oregon	0.78	0.53–1.15	0.21	n/a	n/a	n/a
	Pennsylvania	1.70	1.10–2.61	0.02	0.50	0.27–0.94	0.03
	Rhode Island	1.42	0.89–2.26	0.14	n/a	n/a	n/a
	Tennessee	0.65	0.48–0.90	0.01	0.22	0.13–0.38	<0.001
	Texas	0.59	0.46–0.76	<0.001	0.35	0.22–0.55	<0.001
	Utah	1.35	0.91–2.00	0.14	0.53	0.28–0.98	0.04

		Principal valve procedure: aortic (N = 14,010)			Principal valve procedure: mitral (IST = 7,362)		
		Odds ratio	95% confidence interval	P	Odds ratio	95% confidence interval	P
	Virginia	1.42	0.92–2.21	0.12	0.77	0.35–1.68	0.51
	Washington	1.60	0.99–2.59	0.05	n/a	n/a	n/a
	Wisconsin	1.12	0.87–1.43	0.39	0.47	0.30–0.75	0.001
States with <100) (AV: 21) (MV: 30)		0.91	0.72–1.15	0.44	0.41	0.28–0.61	<0.001
Year							
	2010 & 2011	Reference	-	-	Reference	-	-
	2012 & 2013	1.08	0.97–1.21	0.14	1.05	0.89–1.25	0.55
	2014 & 2015	1.01	0.90–1.13	0.87	0.99	0.83–1.18	0.92
Surgical factors							
Principal surgery type							
	Mitral valve replacement	Reference	-	-	Reference	-	-
	Mitral valve repair	n/a	n/a	n/a	1.07	0.92–1.25	0.28
	Aortic valve replacement	n/a	n/a	n/a	n/a	n/a	n/a
Additional valve procedures performed		0.59	0.33–1.04	0.07	1.07	0.86–1.31	0.55
Coronary artery bypass graft performed		1.03	0.94–1.14	0.50	1.26	1.07–1.48	0.01
Comorbidities							
Arrhythmia		0.95	0.86–1.04	0.26	0.87	0.75–1.01	0.06
Congestive heart failure		1.02	0.92–1.13	0.65	0.87	0.75–1.00	0.06
Coagulopathy		1.07	0.94–1.22	0.30	1.18	0.93–1.50	0.17
Chronic obstructive pulmonary disease		0.78	0.65–0.93	0.01	0.91	0.65–1.28	0.59
Diabetes mellitus		0.96	0.82–1.13	0.63	0.83	0.54–1.25	0.37
Hypertension		0.88	0.79–0.99	0.04	0.73	0.59–0.91	0.01
Pulmonary hypertension		1.06	0.83–1.37	0.64	0.87	0.60–1.26	0.46
Peripheral vascular disease		1.14	0.99–1.31	0.06	0.91	0.54–1.53	0.71
Unstable angina		0.93	0.70–1.25	0.64	1.06	0.54–2.11	0.86

References

References

1. Nkomo VT, Gardin JM, Skelton TN, et al.: Burden of valvular heart diseases: a population-based study. *Lancet*. 368:1005–1011, 2006. [PubMed: 16980116]
2. Surgeons ESSoT: Executive Summary Adult Cardiac Surgery Database. vol 2016 Society of Thoracic Surgeons 2015.
3. American Society of A, Society of Cardiovascular Anesthesiologists Task Force on Transesophageal E: Practice guidelines for perioperative transesophageal echocardiography. An updated report by the American Society of Anesthesiologists and the Society of Cardiovascular Anesthesiologists Task Force on Transesophageal Echocardiography. *Anesthesiology*. 112:1084–1096, 2010. [PubMed: 20418689]

4. American College of Cardiology Foundation Appropriate Use Criteria Task F, American Society of E, American Heart A, et al.: ACCF/ASE/AHA/ASNC/HFSA/HRS/SCAI/SCCM/SCCT/SCMR 2011 Appropriate Use Criteria for Echocardiography. A Report of the American College of Cardiology Foundation Appropriate Use Criteria Task Force, American Society of Echocardiography, American Heart Association, American Society of Nuclear Cardiology, Heart Failure Society of America, Heart Rhythm Society, Society for Cardiovascular Angiography and Interventions, Society of Critical Care Medicine, Society of Cardiovascular Computed Tomography, and Society for Cardiovascular Magnetic Resonance Endorsed by the American College of Chest Physicians. *J Am Coll Cardiol.* 57:1126–1166, 2011. [PubMed: 21349406]
5. Nishimura RA, Otto CM, Bonow RO, et al.: 2014 AHA/ACC guideline for the management of patients with valvular heart disease: a report of the American College of Cardiology/American Heart Association Task Force on Practice Guidelines. *J Thorac Cardiovasc Surg.* 148:e1–e132, 2014. [PubMed: 24939033]
6. Hahn RT, Abraham T, Adams MS, et al.: Guidelines for performing a comprehensive transesophageal echocardiographic examination: recommendations from the American Society of Echocardiography and the Society of Cardiovascular Anesthesiologists. *J Am Soc Echocardiogr.* 26:921–964, 2013. [PubMed: 23998692]
7. Zoghbi WA, Chambers JB, Dumesnil JG, et al.: Recommendations for evaluation of prosthetic valves with echocardiography and doppler ultrasound: a report From the American Society of Echocardiography's Guidelines and Standards Committee and the Task Force on Prosthetic Valves, developed in conjunction with the American College of Cardiology Cardiovascular Imaging Committee, Cardiac Imaging Committee of the American Heart Association, the European Association of Echocardiography, a registered branch of the European Society of Cardiology, the Japanese Society of Echocardiography and the Canadian Society of Echocardiography, endorsed by the American College of Cardiology Foundation, American Heart Association, European Association of Echocardiography, a registered branch of the European Society of Cardiology, the Japanese Society of Echocardiography, and Canadian Society of Echocardiography. *J Am Soc Echocardiogr.* 22:975–1014; quiz 1082–1014, 2009. [PubMed: 19733789]
8. Svensson LG, Adams DH, Bonow RO, et al.: Aortic valve and ascending aorta guidelines for management and quality measures. *Ann Thorac Surg.* 95:S1–66, 2013. [PubMed: 23688839]
9. Nishimura RA, Otto CM, Bonow RO, et al.: 2017 AHA/ACC Focused Update of the 2014 AHA/ACC Guideline for the Management of Patients With Valvular Heart Disease: A Report of the American College of Cardiology/American Heart Association Task Force on Clinical Practice Guidelines. *J Am Coll Cardiol.* 70:252–289, 2017. [PubMed: 28315732]
10. Silva F, Arruda R, Nobre A, et al.: Impact of intraoperative transesophageal echocardiography in cardiac surgery: retrospective analysis of a series of 850 examinations. *Rev Port Cardiol.* 29:1363–1382, 2010. [PubMed: 21179978]
11. Eltzhig HK, Rosenberger P, Löffler M, et al.: Impact of intraoperative transesophageal echocardiography on surgical decisions in 12,566 patients undergoing cardiac surgery. *Ann Thorac Surg.* 85:845–852, 2008. [PubMed: 18291154]
12. Wallace PJ, Shah ND, Dennen T, et al.: Optum Labs: building a novel node in the learning health care system. *Health Aff (Millwood).* 33:1187–1194, 2014. [PubMed: 25006145]
13. Bureau USDoCEaSAUSC: Census Regions and Divisions of the United States 2016.
14. Vornovitskey JCBaMS: Health Insurance Coverage in the United States: Current Population Reports United States Census Bureau, 2016.
15. (AMA) AMA: Physician ICD-9-CM 2 Vol. Set (AMA), American Medical Association Press; 1 edition (9 1, 2014), 2014.
16. Herzog CA, Ma JZ, Collins AJ: Long-term survival of dialysis patients in the United States with prosthetic heart valves: should ACC/AHA practice guidelines on valve selection be modified? *Circulation.* 105:1336–1341, 2002. [PubMed: 11901045]
17. Haskins AE, Siewers AE, Malenka DJ, et al.: Characteristics of new cardiac surgery programs in the United States: mitigating the learning curve. *Am Heart J.* 159:919–925, 2010. [PubMed: 20435206]
18. Epstein AJ, Polsky D, Yang F, et al.: Coronary revascularization trends in the United States, 2001–2008. *JAMA.* 305:1769–1776, 2011. [PubMed: 21540420]

19. Matlock DD, Groeneveld PW, Sidney S, et al.: Geographic variation in cardiovascular procedure use among Medicare fee-for-service vs Medicare Advantage beneficiaries. *JAMA*. 310:155–162, 2013. [PubMed: 23839749]
20. Holmes DR, Jr., Brennan JM, Rumsfeld JS, et al.: Clinical outcomes at 1 year following transcatheter aortic valve replacement. *JAMA*. 313:1019–1028, 2015. [PubMed: 25756438]
21. Gillinov AM, Blackstone EH, Cosgrove DM, 3rd, et al.: Mitral valve repair with aortic valve replacement is superior to double valve replacement. *J Thorac Cardiovasc Surg*. 125:1372–1387, 2003. [PubMed: 12830057]
22. Dahm M, Iversen S, Schmid FX, et al.: Intraoperative evaluation of reconstruction of the atrioventricular valves by transesophageal echocardiography. *Thorac Cardiovasc Surg*. 35 Spec No 2:140–142, 1987. [PubMed: 2451312]
23. Stewart WJ, Currie PJ, Salcedo EE, et al.: Evaluation of mitral leaflet motion by echocardiography and jet direction by Doppler color flow mapping to determine the mechanisms of mitral regurgitation. *J Am Coll Cardiol*. 20:1353–1361, 1992. [PubMed: 1430686]
24. Omran AS, Woo A, David TE, et al.: Intraoperative transesophageal echocardiography accurately predicts mitral valve anatomy and suitability for repair. *J Am Soc Echocardiogr*. 15:950–957, 2002. [PubMed: 12221412]
25. Services CfMaM: Medicare Learning Network Fact Sheet 2018, pp. Definitions and reimbursement information for ICD-9/10-CM, ICD-19/10-PCS and CPT coding.
26. Wijeyesundera DN, Beattie WS, Karkouti K, et al.: Association of echocardiography before major elective non-cardiac surgery with postoperative survival and length of hospital stay: population based cohort study. *BMJ*. 342:d3695, 2011. [PubMed: 21724560]
27. Alter DA, Stukel TA, Newman A: Proliferation of cardiac technology in Canada: a challenge to the sustainability of Medicare. *Circulation*. 113:380–387, 2006. [PubMed: 16432069]
28. Porter J, Mondor L, Kapral MK, et al.: How Reliable Are Administrative Data for Capturing Stroke Patients and Their Care. *Cerebrovasc Dis Extra*. 6:96–106, 2016. [PubMed: 27750249]
29. Quan H, Parsons GA, Ghali WA: Validity of procedure codes in International Classification of Diseases, 9th revision, clinical modification administrative data. *Med Care*. 42:801–809, 2004. [PubMed: 15258482]
30. Elixhauser A, Steiner C, Harris DR, et al.: Comorbidity measures for use with administrative data. *Med Care*. 36:8–27, 1998. [PubMed: 9431328]
31. Quan H, Sundararajan V, Halfon P, et al.: Coding algorithms for defining comorbidities in ICD-9-CM and ICD-10 administrative data. *Med Care*. 43:1130–1139, 2005. [PubMed: 16224307]
32. Harker LA: Bleeding after cardiopulmonary bypass. *N Engl J Med*. 314:1446–1448, 1986. [PubMed: 3702953]
33. Woodman RC, Harker LA: Bleeding complications associated with cardiopulmonary bypass. *Blood*. 76:1680–1697, 1990. [PubMed: 2224118]
34. Khuri SF, Wolfe JA, Josa M, et al.: Hematologic changes during and after cardiopulmonary bypass and their relationship to the bleeding time and nonsurgical blood loss. *J Thorac Cardiovasc Surg*. 104:94–107, 1992. [PubMed: 1614220]
35. Rizzoli G, Guglielmi C, Toscano G, et al.: Reoperations for acute prosthetic thrombosis and pannus: an assessment of rates, relationship and risk. *Eur J Cardiothorac Surg*. 16:74–80, 1999. [PubMed: 10456407]
36. Kubitz JC, Kemming GI, Schultheiss G, et al.: The influence of PEEP and tidal volume on central blood volume. *Eur J Anaesthesiol*. 23:954–961, 2006. [PubMed: 16784550]
37. McGlynn EA, Asch SM, Adams J, et al.: The quality of health care delivered to adults in the United States. *N Engl J Med*. 348:2635–2645, 2003. [PubMed: 12826639]
38. Ma J, Stafford RS: Quality of US outpatient care: temporal changes and racial/ethnic disparities. *Arch Intern Med*. 165:1354–1361, 2005. [PubMed: 15983283]
39. Mangione-Smith R, DeCristofaro AH, Setodji CM, et al.: The quality of ambulatory care delivered to children in the United States. *N Engl J Med*. 357:1515–1523, 2007. [PubMed: 17928599]
40. Asch SM, Kerr EA, Keesey J, et al.: Who is at greatest risk for receiving poor-quality health care? *N Engl J Med*. 354:1147–1156, 2006. [PubMed: 16540615]

41. Gibbons RJ, Jones DW, Gardner TJ, et al.: The American Heart Association's 2008 Statement of Principles for Healthcare Reform. *Circulation*. 118:2209–2218, 2008. [PubMed: 18820173]
42. Semrad TJ, Tancredi DJ, Baldwin LM, et al.: Geographic variation of racial/ethnic disparities in colorectal cancer testing among medicare enrollees. *Cancer*. 117:1755–1763, 2011. [PubMed: 21472723]
43. O'Connor GT, Quinton HB, Traven ND, et al.: Geographic variation in the treatment of acute myocardial infarction: the Cooperative Cardiovascular Project. *JAMA*. 281:627–633, 1999. [PubMed: 10029124]
44. Welch HG, Sharp SM, Gottlieb DJ, et al.: Geographic variation in diagnosis frequency and risk of death among Medicare beneficiaries. *JAMA*. 305:1113–1118, 2011. [PubMed: 21406648]
45. Foster GP, Isselbacher EM, Rose GA, et al.: Accurate localization of mitral regurgitant defects using multiplane transesophageal echocardiography. *Ann Thorac Surg*. 65:1025–1031, 1998. [PubMed: 9564922]
46. David TE, Ivanov J, Armstrong S, et al.: A comparison of outcomes of mitral valve repair for degenerative disease with posterior, anterior, and bileaflet prolapse. *J Thorac Cardiovasc Surg*. 130:1242–1249, 2005. [PubMed: 16256774]
47. Cosgrove DM, Stewart WJ: Mitral valvuloplasty. *Curr Probl Cardiol*. 14:359–415, 1989. [PubMed: 2667897]

Figure 1:

Geographic variation in TEE guideline adherence among 19,386 undergoing aortic valve or mitral valve surgery from 2010 – 2015. The overall rate of TEE utilization observed in the data set was 82% (95% CI 81 – 82%). Among states with a minimum of 100 eligible cases, TEE utilization varied from 61% in both AL (95% CI: 56 – 66%) and LA (95% CI: 53 – 68%) to 92% (NC, 95% CI: 90 – 94%).

Figure 2:

Geographic variation in TEE guideline adherence among 12,313 undergoing aortic valve replacement surgery from 2010–2015. The overall rate of TEE utilization observed in the aortic valve subgroup was 80% (95% CI 79 – 81%). Among states with a minimum of 100 cases, TEE utilization varied from 49% (AL; 95% CI 41 – 56%) to 92% (NC; 95% CI: 89 – 94%).

Figure 3:

Geographic variation in TEE guideline adherence among 7,073 undergoing mitral valve repair or replacement surgery from 2010 – 2015. The overall rate of TEE utilization observed in the mitral valve subgroup was 85% (95% CI 84 – 86%). Among states with a minimum of 100 cases, TEE utilization varied from 73% (TN; 95% CI: 65 – 80%) to 94% (UT; 95% CI: 88 – 97%).

Table 1:

Characteristics of study sample, overall and by location of the principal valve procedure (Primary outcome: Intraoperative TEE Claim) (N=19,386)

		Overall (n = 19,386)	Principal valve procedure: aortic (n = 12,313)	Principal valve procedure: mitral (n = 7,073)	P (aortic vs mitral)
Demographics					
Age in years [mean, SD]		69 ± 0.09	70 ± 0.10	66 ± 0.15	<0.001
Sex [n, (%)]					
	Female	7,398 (38)	4,258 (35)	3,140 (44)	<0.001
	Male	11,988 (62)	8,055 (65)	3,933 (56)	
Race [n, (%)]					
	White	15,147 (78)	9,707 (79)	5,440 (77)	<0.001
	Black	1,509 (8)	869 (7)	640 (9)	
	Other	1,304 (7)	819 (7)	485 (7)	
	Unknown	1,426 (7)	918 (7)	508 (7)	
Ethnicity [n, (%)]					
	Hispanic	976 (5)	652 (5)	324 (5)	0.03
	Non-Hispanic	18,410 (95)	11,661 (95)	6,749 (95)	
Year [n, (%)]					
	2010	3,024 (16)	1,914 (16)	1,110 (16)	0.21
	2011	3,051 (16)	1,881 (15)	1,170 (17)	
	2012	3,360 (17)	2,161 (18)	1,199 (17)	
	2013	3,617 (19)	2,331 (19)	1,286 (18)	
	2014	3,518 (18)	2,227 (18)	1,291 (18)	
	2015	2,816 (15)	1,799 (15)	1,017 (14)	
Surgical factors					
Principal surgery type [n, (%)]					
	Mitral valve replacement	3,607 (19)	n/a	3,607 (51)	<0.001
	Mitral valve repair	3,466 (18)	n/a	3,466 (49)	
	Aortic valve replacement	12,313 (64)	12,313 (100)	n/a	
Additional valve procedures performed [n, (%)]		1,111 (6)	109 (1)	1,002 (14)	<0.001
Coronary artery bypass graft performed [n, (%)]		6,391 (33)	4,641 (38)	1,750 (25)	<0.001
Comorbidities [n, (%)]					
Arrhythmia		5,990 (31)	3,535 (29)	2,455 (35)	<0.001
Congestive heart failure		5,931 (31)	3,309 (27)	2,622 (37)	<0.001
Coagulopathy		2,446 (13)	1,623 (13)	823 (12)	0.002
Chronic obstructive pulmonary disease		2,066 (11)	1,171 (10)	895 (13)	<0.001
Diabetes mellitus		1,152 (6)	982 (8)	170 (2)	<0.001
Hypertension		2,899 (15)	2,128 (17)	771 (11)	<0.001
Pulmonary hypertension		1,301 (7)	601 (5)	700 (10)	<0.001

	Overall (n = 19,386)	Principal valve procedure: aortic (n = 12,313)	Principal valve procedure: mitral (n = 7,073)	P (aortic vs mitral)
Peripheral vascular disease	1,155 (6)	1,031 (8)	124 (2)	<0.001
Unstable angina	365 (2)	291 (2)	74 (1)	<0.001
Primary Study outcome				
Underwent transesophageal echocardiography within one calendar day of index valve surgery	15,843 (82)	9,829 (80)	6,014 (85)	<0.001

Table 2:

Unadjusted and adjusted covariates associated with TEE (physician claim intraoperative) in the overall study population (N = 19,386)

		Unadjusted			Adjusted		
		Odds ratio	95% confidence interval	P	Odds ratio	95% confidence interval	P
Demographics							
Age							
	18–45	Reference	--	--	-	-	-
	45–54	1.03	0.83–1.29	0.78	1.08	0.86–1.35	0.53
	55–65	1.04	0.85–1.27	0.71	1.09	0.88–1.34	0.44
	65	0.81	0.67–0.98	0.03	0.86	0.71–1.05	0.14
Sex							
	Female	Reference	-	-	-	-	-
	Male	0.99	0.92–1.07	0.85	1.02	0.94–1.10	0.61
Race							
	White	Reference	-	-	-	-	-
	Black	0.99	0.86–1.13	0.87	1.01	0.87–1.17	0.93
	Other	0.76	0.66–0.87	<0.001	1.13	0.83–1.54	0.42
	Unknown	1.02	0.88–1.17	0.82	1.02	0.88–1.18	0.76
Ethnicity							
	Non-Hispanic	Reference	-	-	-	-	-
	Hispanic	0.67	0.58–0.78	<0.001	0.63	0.45–0.88	0.01
States with 100 cases (35)							
	Minnesota	Reference	-	-	-	-	-
	Alabama	0.27	0.21–0.35	<0.001	0.27	0.21–0.36	<0.001
	Arizona	1.35	0.95–1.91	0.09	1.39	0.97–1.97	0.07
	California	1.10	0.80–1.49	0.56	1.06	0.77–1.45	0.72
	Colorado	0.66	0.48–0.91	0.01	0.61	0.44–0.83	0.002
	Connecticut	0.63	0.48–0.84	0.001	0.70	0.53–0.93	0.02
	Florida	0.80	0.67–0.97	0.02	0.86	0.71–1.04	0.12
	Georgia	1.27	1.00–1.61	0.05	1.25	0.98–1.59	0.08
	Iowa	0.96	0.66–1.39	0.82	1.02	0.70–1.48	0.93
	Illinois	0.53	0.42–0.67	<0.001	0.55	0.43–0.69	<0.001
	Indiana	0.57	0.43–0.75	<0.001	0.59	0.45–0.78	<0.001
	Kansas	0.52	0.33–0.82	0.01	0.51	0.32–0.81	0.004
	Kentucky	0.82	0.50–1.33	0.42	0.79	0.48–1.29	0.34
	Louisiana	0.27	0.19–0.38	<0.001	0.26	0.18–0.36	<0.001
	Massachusetts	1.48	1.05–2.08	0.02	1.59	1.13–2.24	0.01
	Maryland	0.33	0.24–0.46	<0.001	0.31	0.22–0.43	<0.001
	Michigan	0.82	0.48–1.39	0.46	0.78	0.46–1.33	0.37

		Unadjusted			Adjusted		
		Odds ratio	95% confidence interval	P	Odds ratio	95% confidence interval	P
	Missouri	0.66	0.52–0.82	<0.001	0.68	0.54–0.85	0.001
	North Carolina	2.00	1.50–2.68	<0.001	2.10	1.57–2.82	<0.001
	North Dakota	0.86	0.56–1.33	0.51	0.96	0.62–1.48	0.86
	Nebraska	0.47	0.33–0.67	<0.001	0.49	0.34–0.69	<0.001
	New Hampshire	1.23	0.66–2.29	0.52	1.39	0.74–2.59	0.31
	New Jersey	0.41	0.32–0.52	<0.001	0.46	0.36–0.59	<0.001
	New York	0.82	0.66–1.01	0.07	0.87	0.70–1.09	0.22
	Ohio	0.86	0.69–1.06	0.17	0.83	0.67–1.03	0.09
	Oklahoma	0.59	0.37–0.93	0.02	0.56	0.35–0.89	0.01
	Oregon	0.61	0.43–0.86	0.01	0.65	0.46–0.92	0.02
	Pennsylvania	0.94	0.68–1.30	0.71	0.94	0.68–1.31	0.73
	Rhode Island	1.35	0.88–2.08	0.17	1.47	0.96–2.27	0.08
	Tennessee	0.46	0.35–0.60	<0.001	0.47	0.36–0.62	<0.001
	Texas	0.58	0.47–0.72	<0.001	0.58	0.47–0.73	<0.001
	Utah	1.42	0.98–2.07	0.07	1.50	1.03–2.19	0.04
	Virginia	1.15	0.79–1.68	0.47	1.16	0.79–1.70	0.44
	Washington	1.58	1.01–2.45	0.04	1.65	1.06–2.56	0.03
	Wisconsin	0.83	0.67–1.02	0.08	0.87	0.70–1.09	0.22
States <100 cases (15)		0.65	0.51–0.82	<0.001	0.69	0.54–0.87	0.002
Year							
	2010 & 2011	Reference	-	-	-	-	-
	2012 & 2013	1.05	0.96–1.15	0.31	1.08	0.99–1.19	0.09
	2014 & 2015	0.93	0.85–1.02	0.14	0.98	0.89–1.08	0.73
Surgical factors							
Principal surgery type							
	Mitral valve replacement	Reference	-	-	-		-
	Aortic valve replacement	0.76	0.69–0.84	<0.001	0.72	0.64–0.81	<0.001
	Mitral valve repair	1.19	1.05–1.36	0.01	1.08	0.93–1.24	0.30
Additional valve procedures performed		0.89	0.75–1.04	0.15	1.05	0.88–1.27	0.58
Coronary artery bypass graft performed		1.24	1.15–1.34	<0.001	1.12	1.03–1.22	0.01
Comorbidities							
Arrhythmia		1.00	0.92–1.08	0.93	0.98	0.90–1.06	0.58
Congestive heart failure		0.99	0.92–1.07	0.84	0.97	0.89–1.05	0.43
Coagulopathy		1.16	1.04–1.30	0.01	1.18	1.05–1.32	0.01
Chronic obstructive pulmonary disease		0.91	0.81–1.02	0.10	0.97	0.82–1.15	0.73
Diabetes mellitus		0.92	0.79–1.07	0.26	1.02	0.87–1.19	0.81
Hypertension		0.96	0.87–1.06	0.43	0.97	0.88–1.08	0.64

	Unadjusted			Adjusted		
	Odds ratio	95% confidence interval	P	Odds ratio	95% confidence interval	P
Pulmonary hypertension	0.91	0.79–1.04	0.18	0.84	0.68–1.03	0.10
Peripheral vascular disease	1.19	1.01–1.40	0.03	1.24	1.05–1.47	0.01
Unstable angina	0.83	0.64–1.07	0.16	0.99	0.76–1.28	0.92

Author Manuscript

Author Manuscript

Author Manuscript

Author Manuscript

Table 3:

Adjusted covariates associated with transesophageal echocardiography (physician claim; intraoperative), by location of principal valve procedure (aortic and mitral)

		Principal valve procedure: aortic (N = 12,313)			Principal valve procedure: mitral (N = 7,073)		
		Odds ratio	95% confidence interval	P	Odds ratio	95% confidence interval	P
Demographics							
Age							
	18–45	Reference	-	-	Reference	-	-
	45–54	1.13	0.84–1.53	0.41	1.03	0.72–1.47	0.88
	55–64	1.26	0.96–1.65	0.10	0.94	0.68–1.30	0.71
	65	0.98	0.76–1.26	0.86	0.82	0.60–1.12	0.21
Sex							
	Female	Reference	-	-	Reference	-	-
	Male	1.03	0.94–1.14	0.52	1.00	0.87–1.15	0.99
Race							
	White	Reference	-	-	Reference	-	-
	Black	0.98	0.82–1.18	0.86	0.94	0.74–1.20	0.62
	Other	0.99	0.67–1.46	0.96	1.31	0.79–2.17	0.30
	Unknown	1.01	0.85–1.20	0.94	1.05	0.81–1.37	0.69
Ethnicity							
	Non-Hispanic	Reference	-	-	Reference	-	-
	Hispanic	0.72	0.47–1.10	0.13	0.54	0.30–0.95	0.03
States with 100 cases (AV: 30) (MV:21)							
	Minnesota	Reference	-	-	-	-	-
	Alabama	0.20	0.14–0.28	<0.001	0.44	0.27–0.72	0.001
	Arizona	1.68	1.08–2.59	0.02	0.93	0.51–1.70	0.82
	California	1.05	0.72–1.53	0.80	1.00	0.57–1.77	0.99
	Colorado	0.72	0.47–1.08	0.11	0.45	0.27–0.76	0.003
	Connecticut	0.67	0.48–0.93	0.02	0.81	0.46–1.42	0.46
	Florida	0.96	0.77–1.21	0.75	0.65	0.45–0.92	0.02
	Georgia	1.49	1.10–2.01	0.01	0.87	0.57–1.34	0.53
	Iowa	0.98	0.64–1.49	0.92	n/a	n/a	n/a
	Illinois	0.54	0.40–0.71	<0.001	0.55	0.35–0.85	0.01
	Indiana	0.61	0.43–0.85	0.003	0.54	0.33–0.89	0.02
	Louisiana	0.27	0.18–0.42	<0.001	n/a	n/a	n/a
	Massachusetts	1.81	1.21–2.72	0.004	1.17	0.62–2.19	0.63
	Maryland	0.37	0.24–0.56	<0.001	n/a	n/a	n/a
	Montana	0.82	0.62–1.07	0.15	0.43	0.29–0.66	<0.001
	North Carolina	2.50	1.74–3.59	<0.001	1.44	0.87–2.40	0.16
	North Dakota	0.98	0.60–1.60	0.93	n/a	n/a	n/a

		Principal valve procedure: aortic (N = 12,313)			Principal valve procedure: mitral (N = 7,073)		
		Odds ratio	95% confidence interval	P	Odds ratio	95% confidence interval	P
	Nebraska	0.46	0.31–0.68	<0.001	n/a	n/a	n/a
	New Jersey	0.49	0.36–0.66	<0.001	0.39	0.25–0.63	<0.001
	New York	1.04	0.80–1.36	0.76	n/a	n/a	n/a
	Ohio	0.85	0.66–1.10	0.23	0.76	0.51–1.14	0.18
	Oregon	0.66	0.45–0.99	0.04	n/a	n/a	n/a
	Pennsylvania	1.30	0.85–2.00	0.23	0.54	0.32–0.92	0.02
	Rhode Island	1.40	0.87–2.25	0.17	n/a	n/a	n/a
	Tennessee	0.56	0.40–0.79	0.001	0.32	0.20–0.52	<0.001
	Texas	0.57	0.44–0.75	<0.001	0.59	0.39–0.90	0.02
	Utah	1.40	0.90–2.16	0.13	1.80	0.83–3.92	0.14
	Virginia	1.27	0.80–2.00	0.31	0.98	0.49–1.97	0.96
	Washington	1.62	0.98–2.68	0.06	n/a	n/a	n/a
	Wisconsin	1.03	0.79–1.33	0.85	0.58	0.39–0.87	0.01
States with <100 (AV: 21) (MV: 30)		0.73	0.57–0.93	0.01	0.62	0.45–0.87	0.01
Year							
	2010 & 2011	Reference	-	-	Reference	-	-
	2012 & 2013	1.10	0.98–1.23	0.10	1.04	0.89–1.23	0.61
	2014 & 2015	1.01	0.90–1.14	0.80	0.91	0.77–1.07	0.26
Surgical factors							
Principal surgery type							
	Mitral valve replacement	Reference	-	-	Reference	-	-
	Mitral valve repair	n/a	n/a	n/a	1.07	0.93–1.24	0.35
	Aortic valve replacement	n/a	n/a	n/a	n/a	n/a	n/a
Additional valve procedures performed		0.67	0.39–1.16	0.16	1.11	0.91–1.35	0.31
Coronary artery bypass graft performed		1.03	0.93–1.13	0.61	1.42	1.22–1.65	<0.001
Comorbidities							
Arrhythmia		0.99	0.89–1.09	0.79	0.94	0.82–1.08	0.41
Congestive heart failure		1.00	0.90–1.11	0.99	0.93	0.81–1.07	0.29
Coagulopathy		1.10	0.96–1.26	0.17	1.33	1.06–1.68	0.01
Chronic obstructive pulmonary disease		0.95	0.78–1.15	0.61	1.00	0.72–1.39	0.98
Diabetes mellitus		0.99	0.83–1.17	0.92	1.23	0.78–1.94	0.36
Hypertension		1.01	0.89–1.14	0.88	0.88	0.71–1.09	0.23
Pulmonary hypertension		0.82	0.63–1.07	0.14	0.85	0.59–1.22	0.37
Peripheral vascular disease		1.32	1.10–1.58	0.002	0.95	0.57–1.57	0.83
Unstable angina		0.97	0.72–1.30	0.84	1.00	0.55–1.82	0.99