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Intracardiac versus transesophageal echocardiography to guide transcatheter closure of interatrial communications: Nationwide trend and comparative analysis

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Abstract

Objectives—This study aimed to assess current temporal trends in utilization of ICE versus TEE guided closure of interatrial communications, and to compare periprocedural complications and resource utilization between the two imaging modalities.

Background—While transesophageal echocardiography (TEE) has historically been used to guide percutaneous structural heart interventions, intracardiac echocardiography (ICE) is being increasingly utilized to guide many of these procedures such as closure of interatrial communications.

Methods—Using the Nationwide Inpatient Sample, all patients aged >18 years, who underwent ASD or PFO closure with either ICE or TEE guidance between 2003 and 2014 were included. Comparative analysis of outcomes and resource utilization was performed using a propensity score-matching model.

Results—ICE guidance for interatrial communication closure increased from 9.7% in 2003 to 50.6% in 2014. In the matched model, the primary endpoint of major adverse cardiovascular events occurred less frequently in the ICE group versus the TEE group (11.1% vs 14.3%, respectively, $P = 0.008$), mainly driven by less vascular complications in the ICE group (0.5% vs 1.3%, $P = 0.045$). Length of stay was shorter in the ICE group (3 ± 4 vs 4 ± 4 days, $P < 0.0001$). Cost was similar in the two groups $18\,454 \pm 17\,035$ in the TEE group vs $18\,278 \pm 15\,780$ in the ICE group ($P = 0.75$).

Conclusions—Intracardiac echocardiogram utilization to guide closure of interatrial communications has plateaued after a rapid rise throughout the 2000s. When utilized to guide interatrial communication closure procedure, ICE is as safe as TEE and does not increase cost or prolonged hospitalizations.

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SUPPORTING INFORMATION

Additional Supporting Information may be found online in the supporting information tab for this article.

DISCLOSURE

All authors listed meet the authorship criteria according to the latest guidelines of the International Committee of Medical Journal Editors, and all authors are in agreement with the manuscript.

Keywords

atrial septal defect; intracardiac echocardiography; patent foramen ovale; transcatheter closure; transesophageal echocardiography

1 INTRODUCTION

Percutaneous closure of Interatrial communication (IAC) was first introduced by King et al in 1976 to treat a 17-year-old girl with secundum atrial septal defect (ASD). This technique became widely adopted and further expanded to closure of Patent Foramen Ovale (PFO) in the late 1980s.¹ Although these procedures have been occasionally done with fluoroscopy-guidance, transesophageal echocardiography (TEE) has historically been the modality of choice for intraoperative guidance. In 1991, ultrasound cardioscopy, later termed intracardiac echocardiography (ICE), was introduced to guide ASD closure.^{2,3} Since then, both modalities have been used successfully to guide IAC closure and other structural heart interventional procedures.^{4,5} These two modalities (TEE and ICE) are very different in terms of availability, ease of use, imaging quality, and cost. Single center studies have suggested the safety and possibly the superiority of ICE over TEE in guiding ASD and PFO closure cases.⁶⁻¹⁷ However, no large-scale comparative studies between the two modalities have been performed.

Our study aims to utilize a large nationwide database to:

1. Assess the temporal trends in utilization of ICE versus TEE to guide percutaneous IAC closure in the United States.
2. Compare periprocedural complications in patients undergoing IAC closure with ICE versus TEE.
3. Compare resource utilization (cost and hospital length of stay) between ICE and TEE in percutaneous IAC closure.

2 MATERIALS AND METHODS

2.1 Study data

The Nationwide Inpatient Sample (NIS) was used to derive patient relevant information between January 2003 and December 2014. The NIS is the largest publicly available all-payer administrative claims-based database and contains information about patient discharges from approximately 1000 non-federal hospitals in 45 states. It contains clinical and resource utilization information on 5–8 million discharges annually, with safeguards to protect the privacy of individual patients, physicians, and hospitals. These data are stratified to represent approximately 20% of US inpatient hospitalizations across different hospital and geographic regions (random sample). National estimates of the entire US hospitalized population were calculated using the Agency for Healthcare Research and Quality sampling and weighting method.

2.2 Study population

We analyzed the NIS dataset between 2003 and 2014 using the International Classification of Diseases, 9th Revision, Clinical Modification (ICD-9-CM) codes. Patients >18 years of age with diagnosis ASD/PFO (diagnosis code 745.5), who underwent percutaneous closure (procedure code 35.52) were included. Codes 372.8 and 88.72 were used to identify ICE and TEE procedures, respectively. We excluded all patients who had both ICE and TEE during same admission (Fig. 1).

2.3 Trends and outcomes of ICE and TEE

The trends of intracardiac and TEE utilization in patients, who underwent percutaneous ASD/PFO closure during the 12-year study period were assessed. Patients' baseline demographic, comorbidity, and hospital characteristics were described. In-hospital morbidity and mortality outcomes of ICE and TEE were assessed.

2.4 Comparative outcomes analysis

We compared the outcomes of ICE and TEE utilization to guide percutaneous ASD/PFO closure. To account for potential confounders and reduce the effect of selection bias, a propensity score-matching model was developed using logistic regression to derive two matched groups for comparative outcomes analysis. After excluding patients, who underwent open/surgical ASD/PFO and concomitant TEE and ICE (during the same admission), patients who underwent "isolated" ICE or TEE were entered into a nearest neighbor 1:1 variable ration, parallel, balanced propensity-matching model using a caliper of 0.01.^{18,19} Propensity scores were derived from 41 hospital, clinical, and demographic covariates including the Elixhauser comorbidity index (eTable S1). The primary endpoint was a composite end point of major adverse cardiovascular events (MACCE = one of the following: procedure related death, in-hospital death, vascular complications, pacemaker implantation, cerebral vascular accidents, acute kidney injury, blood transfusion, cardiac tamponade, new onset atrial fibrillation). Procedure related death was defined as death occurring on the same day of the procedure. Secondary end points were cost and hospital length of stay.

2.5 Statistical analysis

Descriptive statistics are presented as frequencies with percentages for categorical variables and as means with standard deviations for continuous variables. Baseline characteristics were compared using a Pearson chi-squared test and Fisher's exact test for categorical variables and an independent-samples *t*-test for continuous variables. We performed multiple imputations to impute missing values for race (missing in 23% of observations) using the fully conditional specification (FCS) method (an iterative Markov Chain Monte Carlo algorithm) in SPSS 24. A Cochran-Armitage test was used to evaluate trends in ICE versus TTE in patients, who underwent percutaneous closure of ASD/PFO. To estimate the cost of hospitalization, the NIS data were merged with cost-to-charge ratios available from the Healthcare Cost and Utilization Project. We estimated the cost of each inpatient stay by multiplying the total hospital charge with cost-to-charge ratios. Univariate logistic regression was performed to estimate odds ratios with 95% confidence intervals to determine predictors

of vascular complications. Matched categorical variables were presented as frequencies with percentages and compared using McNemar's test. Matched continuous variables were presented as means with standard deviations and compared using a paired-samples *t* test. A type I error rate of <0.5 was considered statistically significant. All statistical analyses were performed using SPSS version 24 (IBM corporation, Armonk, NY) and R, version 3.3.1.²⁰

3 RESULTS

3.1 Temporal trends and baseline characteristics

A total of 4213 patients, who underwent closure of ASD or PFO between 2003 and 2014 were included. (National estimates [NE] = 20 779). ICE utilization increased from 9.7% in 2003 to 50.6% in 2014 (Fig. 2). Patient mean age was 53 ± 16 and 54 ± 16 years in the TEE and ICE groups, respectively. Chronic pulmonary disease, atrial fibrillation/flutter, coagulopathy, and coronary artery disease were more frequent in patients, who underwent TEE to guide IAC closure than those who underwent ICE, while peripheral vascular disease was more frequent in the ICE group. Baseline patient-level characteristics are shown in Table 1. ICE guidance was used more frequently than TEE guidance at teaching hospitals (80.6% vs 72.4%, $P < 0.001$).

3.2 Outcomes of TEE and ICE utilization to guide IAC closure

In the unmatched groups, the primary endpoint of MACCE occurred in 18% and 9.9% of IAC closures utilizing TEE and ICE guidance, respectively ($P < 0.0001$) (Table 2). Compared with patients who underwent ICE, those who underwent TEE had higher incidence of vascular complications, acute kidney injury, permanent pacemaker implantation, clinical stroke, and blood transfusion. TEE patients had longer length of stay and higher overall hospitalization cost (Table 2).

3.3 Comparative outcomes in a propensity-matched cohort

Propensity score matching of patients utilizing TEE and ICE yielded a total of 3318 patients (1659 patients in each group, Fig. 1). Baseline characteristics were well matched between the two groups as detailed in Table 3. After propensity matching, the primary endpoint of MACCE in patients utilizing ICE remained lower than patients utilizing TEE (11.1% vs 14.3%, respectively, $P = 0.008$) (Fig. 3), driven mainly by the lower incidence of vascular complications (0.5% vs 1.3%, $P = 0.045$) (Fig. 4). Cost of hospitalization was not different between the two groups after propensity matching. However, length of stay remained significantly shorter in the group utilizing ICE compared to the TEE group (3 ± 4 vs 4 ± 4 days, $P < 0.0001$) (Table 4). In a subgroup analysis, the reduction of MACCE with IAC closure using ICE guidance vs TEE guidance was more pronounced at non-teaching hospitals, non-urgent admissions, and in the absence of significant comorbidities (e-Fig. S1).

4 DISCUSSION

The major findings of our study are: (1) The utilization of ICE for IAC closure increased significantly during the study period. Currently about half of IAC closures are done with

ICE guidance; (2) ICE closure of IAC was associated with less complications, shorter length of stay, and similar cost compared with TEE guided closure.

After a progressive significant upward trend between 2003 and 2009, the utilization of ICE for IAC closure plateaued since 2010 at about 50% of all IAC closures. This could be explained by the concerns about additional cost, relative lack of physician training, and/or fear of higher rates of complications (vascular complications, tamponade, etc.). Our study confirmed that in a contemporary nationwide cohort of patients, ICE guidance for IAC closure is at least as safe as TEE guided IAC closure is associated with significantly shorter length of stay, and does not increase the overall cost. Certain procedural complications that can be possibly attributed to navigating the ICE probe into and in the right atrium (tamponade and new onset atrial arrhythmia) were similar in the two groups. Vascular complications were surprisingly higher in the TEE guidance group. Possible plausible explanation include the frequent use of arterial lines in the TEE group for hemodynamic monitoring during general anesthesia, access site bleeding during or immediately after reversal of anesthesia after initial hemostasis, and other unmeasured confounders. Although further studies are needed to further investigate this finding, this study does, however, provide reassurance that the use of ICE does not increase the rate vascular complications.

Concerns about higher cost with ICE utilization have been addressed in two prior studies.^{5,21} Our findings confirmed that at a national level and in various settings, the use of ICE to guide IAC closure did not increase the global cost of hospitalization. The cost of TEE, general anesthesia, and the reduced length of stay likely offset the additional cost of the ICE catheter. Although our study is unable to perform a comparative assessment of the efficacy and accuracy of ICE versus TEE guidance, several cohort studies have shown that ICE guidance for IAC closure is associated with equivalent short-term efficacy rates and decreased procedure times compared to TEE guidance.^{13,15–17}

The field of structural heart disease interventions is rapidly expanding. The number and variety of novel structural heart interventional procedures have substantially increased in the last decade (e-Fig. S2). Many of these procedures were initially introduced for high-risk patients, who were deemed intolerant of traditional surgery. Therefore, there is a growing interest in the utilization of ICE to guide these procedures to mitigate the need for general anesthesia in these high-risk patients.^{6–12} The potential applications of ICE are likely to further expand with the ongoing modifications and improvement in ICE technology.²² IAC closure is a comparatively simple intervention and is therefore an ideal procedure for burgeoning ICE users, especially given its demonstrated safety, and cost-effectiveness.²³

5 LIMITATIONS

(1) The NIS is derived from hospital claims data without access to individual medical records and is therefore subject to the short-comings of administrative datasets. Inconsistencies related to diagnosis coding are however, addressed with several HCUP quality control measures to minimize these possibilities; (2) ICD-9-CM codes do not distinguish between ASD and PFO closure, which may have influenced our results. Perhaps TEE was chosen more for complex ASDs with deficient rims or for multi-fenestrated

defects. Also, compared with patients with PFOs, those with ASD more frequently have pulmonary hypertension and right ventricular dysfunction, which may have affected the outcomes; (3) clinical data such as the indication for the procedure, hemodynamics, procedural length, fluoroscopy time, and clinical efficacy are not captured in this administrative database. However, our goal was to perform a comparative analysis between TEE and ICE guidance in IAC closure with regards to complication rates and resource utilization. We believe these data are fairly accurate in the NIS and; (4) with any observational data there is potential for confounders biasing our results, though we believe that our vigorous propensity matching helped to mitigate this possibility in many cases.

Strengths of our results include the large sample size, which suggests broad generalizability, and use of standardized definitions established by the Agency for Healthcare Research and Quality.

6 CONCLUSIONS

Intracardiac echo utilization to guide IAC closure has plateaued after a rapid rise throughout the 2000s. Compared with TEE guidance, ICE guidance of IAC closure does not increase total costs or rates of adverse events, and may reduce hospital length of stay. Confirmation of these findings requires further studies that are able to clearly separate ASD and PFO closure procedures.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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References

1. Bridges ND, Hellenbrand W, Latson L, et al. Transcatheter closure of patent foramen ovale after presumed paradoxical embolism. *Circulation*. 1992; 86:1902–1908. [PubMed: 1451261]
2. Valdes-Cruz LM, Sideris E, Sahn DJ, et al. Transvascular intracardiac applications of a miniaturized phased-array ultrasonic endoscope. Initial experience with intracardiac imaging in piglets. *Circulation*. 1991; 83:1023–1027. [PubMed: 1999007]
3. Seward JB, Packer DL, Chan RC, et al. Ultrasound cardioscopy: embarking on a new journey. *Mayo Clin Proc*. 1996; 71:629–635. [PubMed: 8656703]
4. Opatowsky AR, Landzberg MJ, Kimmel SE, et al. Percutaneous closure of patent foramen ovale and atrial septal defect in adults: the impact of clinical variables and hospital procedure volume on in-hospital adverse events. *Am Heart J*. 2009; 157:867–874. [PubMed: 19376313]
5. Singh V, Badheka AO, Patel NJ, et al. Influence of hospital volume on outcomes of percutaneous atrial septal defect and patent foramen ovale closure: a 10-years US perspective. *Catheter Cardiovasc Interv*. 2015; 85:1073–1081. [PubMed: 25534392]
6. Saji M, Ragosta M, Dent J, et al. Use of intracardiac echocardiography to guide percutaneous transluminal mitral commissurotomy: a 20-patient case series. *Catheter Cardiovasc Interv*. 2016; 87:E69–E74. [PubMed: 25946719]

7. Matsuo Y, Neuzil P, Petru J, et al. Left atrial appendage closure under intracardiac echocardiographic guidance: feasibility and comparison with transesophageal echocardiography. *J Am Heart Assoc.* 2016; 5:e003695. [PubMed: 27680664]
8. Frangieh, AH., Alibegovic, J., Templin, C., et al. Intracardiac versus transesophageal echocardiography for left atrial appendage occlusion with watchman. *Catheter Cardiovasc Interv.* 2016. <https://doi.org/10.1002/ccd.26805>
9. Saji M, Rossi AM, Ailawadi G, et al. Adjunctive intracardiac echocardiography imaging from the left ventricle to guide percutaneous mitral valve repair with the MitraClip in patients with failed prior surgical rings. *Catheter Cardiovasc Interv.* 2016; 87:E75–E82. [PubMed: 26105191]
10. Bartel T, Bonaros N, Muller L, et al. Intracardiac echocardiography: a new guiding tool for transcatheter aortic valve replacement. *J Am Soc Echocardiogr.* 2011; 24:966–975. [PubMed: 21641183]
11. Alkhouli M, Sarraf M, Maor E, et al. Techniques and outcomes of percutaneous aortic paravalvular leak closure. *JACC Cardiovasc Interv.* 2016; 9:2416–2426. [PubMed: 27931593]
12. Silvestry FE, Kadakia MB, Willhide J, et al. Initial experience with a novel real-time three-dimensional intracardiac ultrasound system to guide percutaneous cardiac structural interventions: a phase 1 feasibility study of volume intracardiac echocardiography in the assessment of patients with structural heart disease undergoing percutaneous transcatheter therapy. *J Am Soc Echocardiogr.* 2014; 27:978–983.
13. Kim NK, Park SJ, Shin JJ, et al. Eight-French intracardiac echocardiography—safe and effective guidance for transcatheter closure in atrial septal defects. *Circ J.* 2012; 76:2119–2123. [PubMed: 22975637]
14. Rigatelli G, Dell'Avvocata F, Cardaioli P, et al. Five-year follow-up of transcatheter intracardiac echocardiography-assisted closure of interatrial shunts. *Cardiovasc Revasc Med.* 2011; 12:355–361. [PubMed: 21715232]
15. Wang Y, Guo T, Liang G, et al. Safe and effective guidance by intracardiac echocardiography for transcatheter closure in atrial septal defects. *Int J Clin Exp Med.* 2015; 8:8015–8019. [PubMed: 26221364]
16. Bartel T, Konorza T, Neudorf U, et al. Intracardiac echocardiography: an ideal guiding tool for device closure of interatrial communications. *Eur J Echocardiogr.* 2005; 6:92–96. [PubMed: 15760685]
17. Bocalandro F, Baptista E, Muench A, et al. Comparison of intracardiac echocardiography versus transesophageal echocardiography guidance for percutaneous transcatheter closure of atrial septal defect. *Am J Cardiol.* 2004; 93:437–440. [PubMed: 14969617]
18. Hansen BB, Klopfer SO. Optimal full matching and related designs via network flows. *J comp Graph Stat.* 2006; 15:609–627.
19. Ho DE, Imai K, King G, et al. Matching as nonparametric preprocessing for reducing model dependence in parametric causal inference. *Polit Anal.* 2007; 15:199–236.
20. Team, RC. R: a language and environment for statistical computing. *R Found Stat Comput.* 2014. Available at: <http://www.R-project.org/>
21. Alboliras ET, Hijazi ZM. Comparison of costs of intracardiac echocardiography and transesophageal echocardiography in monitoring percutaneous device closure of atrial septal defect in children and adults. *Am J Cardiol.* 2004; 94:690–692. [PubMed: 15342315]
22. Hijazi ZM, Shivkumar K, Sahn DJ. Intracardiac echocardiography during interventional and electrophysiological cardiac catheterization. *Circulation.* 2009; 119:587–596. [PubMed: 19188519]
23. Bartel T, Muller S, Biviano A, et al. Why is intracardiac echocardiography helpful? Benefits, costs, and how to learn *Eur Heart J.* 2014; 35:69–76. [PubMed: 24144789]

FIGURE 1.

Flow diagram of patients' selection from National Inpatient Sample (NIS) database

FIGURE 2.

Temporal trends of intracardiac versus transesophageal echocardiography to guide transcatheter closure of ASD/PFO in the United States between 2003 and 2014. TEE, Transesophageal echocardiography; ICE, Intracardiac echocardiography

FIGURE 3.

All adverse event of intracardiac versus transesophageal echocardiography to guide transcatheter closure of ASD/PFO in a propensity-matched cohort. TEE, Transesophageal echocardiography; ICE, Intracardiac echocardiography

FIGURE 4. In-hospital complications following intracardiac versus transesophageal echocardiography to guide transcatheter closure of ASD/PFO in a propensity-matched cohort

TABLE 1

Characteristics of patients undergoing ASD/PFO closure between 2003–2014

Characteristic	All patients (n = 4213)	TEE ^a guidance (n = 2237)	ICE ^b guidance (n = 1976)	P value
Age-mean (SD), y	53 (16)	53 (16)	54 (16)	0.008
Male-no (%)	2424 (57.5)	1299 (58.1)	1125 (56.9)	0.457
Teaching hospital-no (%)	3233 (76.7)	1803 (80.6)	1430 (72.4)	<0.0001
Race-no. (%)				0.007
Caucasian	3286 (78)	1710 (76.4)	1576 (79.8)	
African American	305 (7.2)	175 (7.8)	130 (6.6)	
Hispanic	373 (8.9)	226 (10.1)	147 (7.4)	
Non-elective admission status	1479 (35.1)	889 (39.7)	590 (29.9)	<0.0001
Medical Comorbidity-no (%)				
Hypertension	1763 (41.8)	910 (40.7)	853 (43.2)	0.102
Diabetes	531 (12.6)	275 (12.3)	256 (13)	0.518
Prior sternotomy	111 (2.6)	51 (2.3)	60 (3)	0.126
Pulmonary disease	440 (10.4)	261 (11.7)	179 (9.1)	0.006
Chronic renal failure	120 (2.8)	63 (2.8)	57 (2.9)	0.894
Atrial fibrillation/flutter	412 (9.8)	242 (10.8)	170 (8.6)	0.016
Deep venous thrombosis	25 (0.6)	17 (0.8)	8 (0.4)	0.134
Anemia	217 (5.2)	127 (5.7)	90 (4.6)	0.1
Coagulopathy	101 (2.4)	71 (3.2)	30 (1.5)	<0.0001
Conduction abnormalities	64 (1.5)	41 (1.8)	23 (1.2)	0.077
Peripheral Vascular disease	171 (4.1)	72 (3.2)	99 (5)	0.003
Coronary Artery disease	462 (11)	269 (12)	193 (9.8)	0.019
Metastatic Ccancer	9 (0.2)	5 (0.2)	4 (0.2)	0.882
Congestive heart failure	28 (0.7)	17 (0.8)	11 (0.6)	0.418
Concomitant procedures-no (%)				
Right heart catheterization	781 (18.5)	423 (18.9)	358 (18.1)	0.509
Left heart catheterization	200 (4.7)	115 (5.1)	85 (4.3)	0.201
Percutaneous coronary intervention	25 (0.6)	15 (0.7)	10 (0.5)	0.488
Primary payer-no (%)				0.694
Medicare/medicaid	1530 (36.3)	806 (36)	724 (36.6)	
Private	2444 (58)	1298 (58)	1146 (58)	
Self-pay/no charge/other	239 (5.7)	133 (5.9)	106 (5.4)	
Median household income				0.05
0–25th percentile	837 (20.4)	443 (20.4)	394 (20.4)	
26–50th percentile	989 (24.1)	486 (22.4)	503 (26)	
51–75th percentile	1058 (25.8)	579 (26.7)	479 (24.8)	
76–100th percentile	1220 (29.7)	661 (30.5)	559 (28.9)	

Characteristic	All patients (<i>n</i> = 4213)	TEE ^{<i>a</i>} guidance (<i>n</i> = 2237)	ICE ^{<i>b</i>} guidance (<i>n</i> = 1976)	<i>P</i> value
Hospital region				0.051
Northeast	911 (21.6)	503 (22.5)	408 (20.6)	
Midwest	1177 (27.9)	600 (26.8)	577 (29.2)	
South	1221 (29)	629 (28.1)	592 (30)	
West	904 (21.5)	505 (22.6)	399 (20.2)	

^{*a*}Transesophageal echocardiography.

^{*b*}Intracardiac echocardiography.

TABLE 2

In hospital outcomes of patients undergoing ASD/PFO closure with intracardiac versus transesophageal echo guidance

	All patients (n = 4213)	TEE guidance (n = 2237)	ICE guidance (n = 1976)	P value
Clinical outcome-no (%)				
All adverse events	598 (14)	403 (18)	195 (9.9)	<0.0001
In-hospital death	27 (0.6)	17 (0.8)	10 (0.5)	0.303
Procedural death	3 (0.1)	1 (0.04)	2 (0.1)	0.163
Vascular complications	39 (0.9)	30 (1.3)	9 (0.5)	0.003
Vascular complications requiring surgery	22 (0.5)	12 (0.5)	10 (0.5)	0.891
AKI	81 (1.9)	53 (2.4)	28 (1.4)	0.025
AKI requiring dialysis	7 (0.2)	6 (0.3)	1 (0.1)	0.084
Permanent pacemaker implantation	27 (0.6)	21 (0.9)	6 (0.3)	0.01
Transient Ischemic attack	180 (4.3)	99 (4.4)	81 (4.1)	0.601
Clinical stroke	180 (4.3)	117 (5.2)	63 (3.2)	0.01
Blood transfusion	108 (2.6)	70 (3.1)	38 (1.9)	0.013
Cardiac tamponade	12 (0.3)	8 (0.4)	4 (0.2)	0.346
Atrial fibrillation/flutter (new onset)	7 (2)	5 (2.4)	2 (1.4)	0.488
Length of stay-mean (SD), d	3 (5)	3 (5)	2 (4)	<0.0001
Cost of hospitalization (SD), \$	19121 (18337)	20386 (20781)	17676 (14942)	<0.0001
Hospital charges-mean (SD), \$	57944 (65824)	61843 (77342)	53531 (49309)	<0.0001
Discharged status				0.006
Discharged SNF/NH/IC	215 (5.1)	136 (6.1)	79 (4)	
Discharged home	3969 (94.2)	2082 (93.1)	1887 (95.5)	

TABLE 3

Characteristics of propensity matched patients undergoing ASD/PFO closure between 2003–2014

Characteristic	All patients (n = 3318)	TEE guidance (n = 1659)	ICE guidance (n = 1659)	P value
Age-mean (SD), y	53 (16)	53 (16)	53 (16)	0.608
Male-no (%)	1897 (57.2)	949 (57.2)	948 (57.1)	0.99
Teaching hospital-no (%)	2603 (78.5)	1290 (77.8)	1313 (79.1)	0.266
Race-no. (%)				0.424
Caucasian	2620 (79)	1312 (79.1)	1308 (78.8)	
African American	241 (7.3)	120 (7.2)	121 (7.3)	
Hispanic	276 (8.3)	138 (8.3)	138 (8.3)	
Non-elective admission status	1117 (33.7)	563 (33.9)	554 (33.4)	0.731
Medical comorbidity-no (%)				
Hypertension	1399 (42.2)	700 (42.2)	699 (42.1)	0.99
Diabetes	415 (12.5)	208 (12.5)	207 (12.5)	0.99
Prior sternotomy	83 (2.5)	42 (2.5)	41 (2.5)	0.99
Chronic pulmonary disease	327 (9.9)	165 (9.9)	162 (9.8)	0.904
Chronic renal failure	91 (2.7)	47 (2.8)	44 (2.7)	0.83
Atrial fibrillation/flutter	293 (8.8)	151 (9.1)	142 (8.6)	0.622
Deep venous thrombosis	14 (0.4)	7 (0.4)	7 (0.4)	0.99
Anemia	152 (4.6)	76 (4.6)	76 (4.6)	0.99
Coagulopathy	54 (1.6)	30 (1.8)	24 (1.4)	0.488
Conduction abnormalities	38 (1.1)	16 (1)	22 (1.3)	0.417
Peripheral vascular disease	119 (3.6)	59 (3.6)	60 (3.6)	0.99
Coronary artery disease	345 (10.4)	176 (10.6)	169 (10.2)	0.728
Metastatic cancer	6 (0.2)	3 (0.2)	3 (0.2)	0.99
Congestive heart failure	21 (0.6)	12 (0.7)	9 (0.5)	0.664
Concomitant procedures-no (%)				
Right heart catheterization	634 (19.1)	316 (19)	318 (19.2)	0.965
Left heart catheterization	163 (4.9)	84 (5.1)	79 (4.8)	0.746
Percutaneous coronary intervention	19 (0.6)	9 (0.5)	10 (0.6)	0.99

TABLE 4

In hospital outcomes of propensity matched patients undergoing ASD/PFO closure with intracardiac versus transesophageal echo guidance

	All patients (n = 3318)	TEE guidance (n = 1659)	ICE Guidance (n = 1659)	P value
Clinical outcome-no (%)				
All adverse event	422 (12.7)	237 (14.3)	185 (11.1)	0.008
In-hospital death	19 (0.6)	10 (0.6)	9 (0.5)	0.99
Procedural death	3 (0.1)	1 (0.1)	2 (0.1)	0.99
Vascular complications	30 (0.9)	21 (1.3)	9 (0.5)	0.045
Vascular complications requiring surgery	19 (0.6)	9 (0.5)	10 (0.6)	0.99
AKI	55 (1.7)	32 (1.9)	23 (1.4)	0.272
AKI requiring dialysis	4 (0.1)	3 (0.2)	1 (0.1)	0.625
Permanent pacemaker implantation	17 (0.5)	12 (0.7)	5 (0.3)	0.143
Transient Ischemic attack	142 (4.3)	73 (4.4)	69 (4.2)	0.798
Clinical stroke	127 (3.8)	69 (4.2)	58 (3.5)	0.363
Blood transfusion	79 (2.4)	45 (2.7)	34 (2)	0.229
Cardiac tamponade	7 (0.2)	3 (0.2)	4 (0.2)	0.99
Atrial fibrillation/flutter (new onset)	3 (0.1)	2 (0.1)	1 (0.1)	0.99
Length of stay-mean (SD), d	3 (4)	3 (4)	2 (4)	<0.0001
Cost of hospitalization (SD), \$	18366 (16417)	18454 (17035)	18278 (15780)	0.75
Hospital charges-mean (SD), \$	56128 (63294)	57683 (73391)	54573 (51222)	0.139
Discharged status				0.393
Discharged SNF/NH/IC	156 (4.7)	86 (5.2)	70 (4.2)	
Discharged home	3142 (94.7)	1562 (94.2)	1580 (95.2)	