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ORIGINAL RESEARCH

Long-Term Outcomes of Transcatheter Aortic Valve Replacement in Patients With End-Stage Renal Disease

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BACKGROUND: Aortic stenosis is prevalent in end-stage renal disease. Transcatheter aortic valve replacement (TAVR) is a plausible alternative for surgical aortic valve replacement. However, little is known regarding long-term outcomes in patients with end-stage renal disease who undergo TAVR.

METHODS AND RESULTS: We identified all patients with end-stage renal disease who underwent TAVR from 2011 through 2016 using the United States Renal Data System. The primary end point was 5-year mortality after TAVR. Factors associated with 1- and 5-year mortality were analyzed. A total of 3883 TAVRs were performed for patients with end-stage renal disease. Mortality was 5.8%, 43.7%, and 88.8% at 30 days, 1 year, and 5 years, respectively. Case volumes increased rapidly from 17 in 2011 to 1495 in 2016. Thirty-day mortality demonstrated a dramatic reduction from 11.1% in 2012 to 2.5% in 2016 (P=0.01). Age 75 or older (hazard ratio [HR], 1.14; 95% CI, 1.05–1.23 [P=0.002]), body mass index <25 (HR, 1.18; 95% CI, 1.08–1.28 [P<0.001]), chronic obstructive pulmonary disease (HR, 1.25; 95% CI, 1.1–1.35 [P<0.001]), diabetes mellitus as the cause of dialysis (HR, 1.22; 95% CI, 1.11–1.35 [P<0.001]), hypertension as the cause of dialysis (HR, 1.17; 95% CI, 1.06–1.29 [P=0.004]), and White race (HR, 1.17; 95% CI, 1.06–1.3 [P=0.002]) were independently associated with 5-year mortality.

CONCLUSIONS: Short-term outcomes of TAVR in patients with end-stage renal disease have improved significantly. However, long-term mortality of patients on dialysis remains high.

Key Words: aortic stenosis ■ aortic valve replacement ■ dialysis ■ end-stage renal disease

End-stage renal disease (ESRD) is prevalent among the US population, with 746 557 patients on hemodialysis in 2017.[1] Furthermore, the number continues to grow and 124 500 patients were newly registered to the United States Renal Data System (USRDS) in 2017. Aortic stenosis (AS) is frequently seen in patients on hemodialysis. Although the prognosis of AS in patients on dialysis without surgical intervention has not been well-described, some evidence suggests that the advanced progression of the disease with dialysis in addition to the fact that the expected survival of symptomatic AS in the nondialysis population is 2 to 3 years with conservative management.[2,3] Therefore, a surgical intervention is recommended for symptomatic severe AS.[3,4] Historically, surgical aortic valve replacement (SAVR) has been the mainstay of treatment; however, transcatheter aortic valve replacement (TAVR), first approved by the US Food and Drug Administration in 2011, has gained popularity and is now approved for patients at all levels of risk since 2019.[5,6] The recent TVT (Transcatheter Valve Therapy) registry reported

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CLINICAL PERSPECTIVE

What Is New?

- Both perioperative and long-term outcomes for patients with end-stage renal disease undergoing transcatheter aortic valve replacement are improving.

What Are the Clinical Implications?

- Experience of transcatheter aortic valve replacement is growing in the end-stage renal disease population.
- Transcatheter aortic valve replacement may be safely performed in this population with reasonable outcomes.

Nonstandard Abbreviations and Acronyms

CMS	Centers for Medicare & Medicaid Services
PARTNER	Placement of Aortic Transcatheter Valves
PVD	peripheral vascular disease
SAVR	surgical aortic valve replacement
TAVR	transcatheter aortic valve replacement
TVT	Transcatheter Valve Therapy
USRDS	United States Renal Data System

over 63 000 cases in 2018 from 598 sites in the United States.[7]

Clinical experience as well as iterative device design has contributed to improved clinical outcomes. Yet, patients with ESRD remain at higher overall risk for early and late death than the general population, perhaps attributable to altered systematic physiology, platelet dysfunction, or electrolytes disturbance, as well as other comorbidities such as coronary artery disease (CAD).[8] TAVR may be a preferable alternative to SAVR in this population given its lower overall procedural risk,[9–11] and recent registry reports have demonstrated its feasibility at 30 days and 1 year.[12] There is a paucity of outcomes data for TAVR in patients with ESRD as most randomized controlled trials excluded patients with ESRD. Here, we aim to describe the demographic data and changes in long-term survival after TAVR using a national, ESRD-specific database.

METHODS

This study was approved with waiver of consent by the institutional review board at New York-Presbyterian/Queens. Anonymized data and materials have been made publicly available at the USRDS and can be accessed at https://www.usrds.org/.

Database

The USRDS, which prospectively collects data on all patients with ESRD, defined as patients either on dialysis, on a waiting list for renal transplant, or post renal transplant, in the United States, was analyzed.[1] As patients with ESRD are enrolled in Medicare, the USRDS data are primarily derived from the Centers for Medicare & Medicaid Services (CMS). Identification of patients with ESRD and comorbidities rely on the ESRD Medical Evidence Form (CMS 2728). Patients who sustained acute renal failure without need of chronic dialysis were not registered in the database. USRDS also collects inpatient data via Medicare claims. Date of death is identified by the ESRD Death Notification form (CMS 2746), which identifies >90% of deaths, and USRDS uses other supplemental data to ascertain a death.

Patients

A total of 4211 patients on dialysis, who had undergone TAVR between January 2011 and December 2016, were identified in the USRDS using *International Classification of Diseases*, *Ninth Revision* (*ICD-9*), and *International Classification of Diseases, Tenth Revision* (*ICD-10*), codes (*ICD-9*: 35.05 or 35.06, and *ICD-10*: 02RF37H, 02RF37Z, 02RF38H, 02RF38Z, 02RF3JH, 02RF3JZ, 02RF3KH, 02RF3KZ, 02RF47Z, 02RF48Z, 02RF4JZ, or 02RF4KZ). Exclusion criteria included patients aged <18 years, patients who had functioning transplant kidney on the day of intervention, patients who were not on dialysis, and patients whose dialysis induction was after the index intervention (Figure S1). Patient demographics at baseline including comorbidities were collected from the ESRD Medical Evidence Form (CMS 2728), which allowed us to collect more accurate data then identifying comorbidities with *ICD* codes. To account for technological innovation, improvement of operator experience, and perioperative care, eras were classified as before (before August 2015) and after (after August 2015) considering the number of patients between the cohorts.

Outcomes

The primary end point was all-cause 5-year mortality. Secondary outcome was in-hospital mortality and 1-year mortality. Absent of the event of interest, data from patients were censored on September 1, 2018. No patients received kidney transplant after TAVR.

Statistical Analysis

All statistical test values were 2-sided. Only 5.1% of patients had missing data and these patients were

treated with case-complete analysis (Table S1). Continuous variables were analyzed with Mann-Whitney *U* test since none of the variables were normally distributed by Shapiro-Wilk test and expressed as median (interquartile range). Categorical variables were evaluated with chi-square test and Fisher exact test where expected values were <5, and expressed as number (percentage). Logistic regression model with backward stepwise selection was used to assess in-hospital mortality. While we performed univariable analysis to identify factors that had *P* values <0.1, we decided to include all available variables we had as they were clinically important to predict mortalities in patients with ESRD. The variables included in the model were age, sex, race, body mass index (BMI), CAD, congestive heart failure (CHF), chronic obstructive pulmonary disease (COPD), cerebrovascular accident, diabetes mellitus, hypertension, peripheral vascular disease (PVD), primary cause of dialysis, duration of dialysis, and era. Cox hazard model was applied for the 1- and 5-year mortality. The same variables were included as the above. Sensitivity analysis was performed with bootstrapping simulation (Data S1, Tables S2 through S4). Cox hazard model assumption was tested with Schoenfeld residuals (Data S2, Tables S5 through S7). Kaplan-Meier curve was generated for 5-year mortality. Linear regression was used to assess the trend of mortality. The year of surgery was used as the continuous variable to predict mortality of each year. All statistics were analyzed using R version 1.41 (R Foundation for Statistical Computing) and the graphical user interface EZR.[13]

Table 1. Baseline Patient Characteristics

Characteristic	No. (%) n=3883
Age, median (IQR), y	75.3 (68.3–81.4)
Men	2409 (62)
BMI, median (IQR), kg/m^2	28.4 (24.7–33.4)
Comorbidities	
CAD	874 (23)
CHF	166 (31.3)
COPD	321 (8.6)
Cerebrovascular accident	269 (7.2)
Diabetes mellitus	1835 (49.8)
Hypertension	3293 (88.2)
PVD	409 (11.0)
Smoker	135 (3.6)
Race	
White	3104 (79.9)
Black	625 (16.1)
Other*	154 (4.0)
Cause of dialysis	
Diabetes mellitus	1529 (39.4)
Hypertension	1219 (31.4)
Glomerulonephritis	471 (12.1)
Others	664 (17.1)
Duration of dialysis, median (IQR), y	4.08 (1.68–7.56)

BMI indicates body mass index; CAD, coronary artery disease; CHF, congestive heart failure; COPD, chronic obstructive pulmonary disease; IQR, interquartile range; and PVD, peripheral vascular disease.

*Other includes American Indian/Alaskan Native, Asian, Native Hawaiian or other Pacific Islander, Mid-East/Arabian, and Indian Sub-Continent.

RESULTS

Demographic Data

A total of 3883 TAVRs were performed for patients with ESRD during the study period (Table 1). The median age was 75.3 years and 2409 (62%) were men. Median BMI was 28.4, and CAD, CHF, diabetes mellitus, and hypertension were commonly seen (23%, 31%, 50%, and 88%, respectively). White race was more prevalent (80%). The most common cause of ESRD was diabetes mellitus (39%), followed by hypertension (31%) and glomerulonephritis (12%). The median duration of dialysis was 4.08 years before TAVR (interquartile range, 1.68–7.56 years).

Baseline characteristic differences along with older and newer era are shown in Table S1 (Table S8). The median age was slightly younger in the newer era (74.5 years versus 76.4 years, *P*<0.001). BMI was similar between both cohorts (28.6 versus 28.2 in the older era, *P*=0.39). Cardiovascular comorbidities were less prevalent in the newer era: CAD (21.1% versus 24.7% in the older era, *P*=0.009), CHF (28.% versus 34.2%, *P*<0.001), and PVD (9.9% versus 12.1% in the older era, *P*=0.04).

Outcomes

For the overall study period, in-hospital mortality was 4.2% and 30-day mortality was 5.8% (Table 2). Estimated 1-year mortality and 5-year mortality were 43.7% and 88.8%, respectively (Figure 1). Outcomes were significantly better in patients who underwent

Table 2. Primary and Secondary Outcomes

Outcomes	No. (%) n=3883
Length of intensive care unit stay, median (IQR), d	3.00 (2.00–7.00)
In-hospital mortality	165 (4.2)
30-d Mortality	227 (5.8)
1-y Mortality	1309 (33.7)
5-y Mortality	2703 (69.6)

IQR indicates interquartile range.

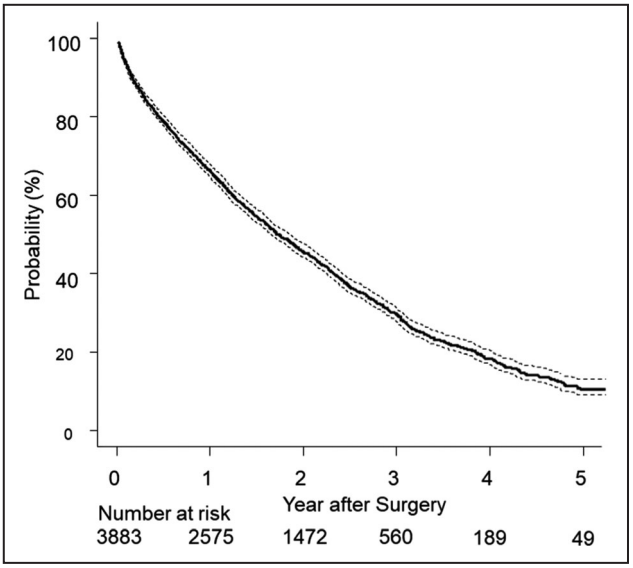

Figure 1. Kaplan-Meier survival curve for 5 years after transcatheter aortic valve replacement.
The cumulative incidence of survival was plotted against time after surgery with 95% CIs. The number of patients at risk are shown in the bottom of each graph.

TAVR after August 2015 (Table 3). Univariable analysis identified that BMI, CHF, diabetes mellitus, PVD, era, and White race were associated with in-hospital mortality (Table S9). Multivariable analysis identified a BMI of 30 to 40 versus 25 to 30 (odds ratio [OR], 0.6; 95% CI, 0.41–0.88 [*P*=0.008]), PVD (OR, 2.48; 95% CI, 1.68–3.66 [*P*<0.001]), and older era (OR, 2.05; 95% CI, 1.46–2.88 [*P*<0.001]) were independently associated with worse in-hospital mortality (Table 4).

Univariable analysis for 1-year mortality is shown in Table S10. Cox hazard analysis showed age ≥75 years (hazard ratio [HR], 1.24; 95% CI, 1.11–1.39 [*P*<0.001]), BMI <25 versus 25 to 30 (HR, 1.2; 95% CI, 1.07–1.36 [*P*=0.003]), and older era (HR, 1.22; 95% CI, 1.09–1.36 [*P*<0.001]) were independent prognostic factors for 1-year mortality (Table 5).

Univariable analysis for 5-year mortality is shown in Table S11. Cox hazard analysis showed age ≥75 years (HR, 1.13; 95% CI, 1.04–1.23 [*P*=0.003]), BMI <25 (HR, 1.08; 95% CI, 1.08–1.29 [*P*<0.001]), COPD (HR, 1.25; 95% CI, 1.1–1.43 [*P*<0.001]), diabetes mellitus as the cause of dialysis (HR, 1.22; 95% CI, 1.11–1.35 [*P*<0.001]), hypertension as the cause of dialysis (HR, 1.17; 95% CI, 1.06–1.29 [*P*=0.003]), White race (HR, 1.17; 95% CI, 1.06–1.29 [*P*=0.003]), and older era (HR, 1.1; 95% CI, 1.02–1.21 [*P*=0.01]) were independently associated with 5-year mortality (Table 5).

The median overall survival was 1.76 years (95% CI, 1.67–1.85) until death and 5-year follow-up. Although the number of patients at risk at 5 years represented only 1.3% of the initial cohort in Kaplan-Meier curve because of death events, the follow-up for survival data are almost 100% given the aforementioned nature of ESRD and CMS data collection.

Table 3. Outcome Differences Between the Older and Newer Eras

Outcomes	Before August 2015, No. (%) n=1933	After August 2015, No. (%) n=1950	*P* Value
In-hospital mortality	110 (5.7)	55 (2.8)	<0.001
30-d Mortality	142 (7.3)	85 (4.4)	<0.001
1-y Mortality	699 (36.2)	610 (31.3)	0.001

Annual Trends

Case volumes increased rapidly from 17 in 2011 to 1495 in 2016 (Figure 2). Median age fell from 77.6 years in 2012 to 74.3 years in 2016. Mean length of intensive care unit stay also decreased from 7.3 in 2011 to 4.71 in 2016 (Figure 3). In-hospital mortality and 30-day mortality demonstrated a dramatic reduction from 11.1% in 2012 to 2.5% in 2016 (*P*=0.01). The 1-year mortality for those 2 groups of patients who underwent TAVR in 2012 and 2016 was similarly improved from 40.4% to 31.3% (*P*=0.002). Despite improvements in in-hospital cardiovascular mortality and 30-day cardiovascular mortality, 1-year cardiovascular mortality did not change (Figure S2). The annual 5-year mortality is not shown because of limited 5-year data in this cohort from patients from 2014 to 2016.

DISCUSSION

The use of TAVR has expanded significantly over the past 10 years but its utility, longer-term outcomes, and trends in patients with ESRD have not been clearly defined. Here, we report the most recent demographic features and outcomes of TAVR in patients with ESRD. As experience accumulates, their outcomes have also improved, almost similar to non-ESRD populations in short-term.[10,14] Our primary findings in patients undergoing TAVR with ESRD are the following: (1) in-hospital mortality was 2.5%; (2) 1-year mortality and 5-year mortality were 43.7%, and 88.8%, respectively; and (3) outcomes improved significantly over time although longer-term outcomes remain dismal.

TAVR has rapidly gained in popularity and potentially offers many tangible advantages, particularly in

Table 4. Logistic Regression for In-Hospital Mortality

Variable	OR (95% CI)	*P* Value
BMI, 30≦, <40	0.6 (0.41–0.88)	0.008
PVD	2.48 (1.68–3.66)	<0.001
Older era (before August 2015)	2.05 (1.46–2.88)	<0.001

BMI indicates body mass index; OR, odds ratio; and PVD, peripheral vascular disease.

Table 5. Multivariable Analysis for 1- and 5-Year Mortality

Variable	HR (95% CI)	*P* Value
1 y		
Age ≤75 y	1.24 (1.11–1.39)	<0.001
BMI <25	1.2 (1.07–1.36)	0.003
Older era (before August 2015)	1.22 (1.09–1.36)	<0.001
5 y		
Age ≤75 y	1.13 (1.04–1.23)	0.003
BMI <25	1.18 (1.08–1.29)	<0.001
COPD	1.25 (1.1–1.43)	<0.001
Diabetes mellitus as the cause of dialysis	1.22 (1.11–1.35)	<0.001
Hypertension as the cause of dialysis	1.16 (1.05–1.3)	0.005
White race	1.17 (1.06–1.29)	0.003
Older era (before August 2015)	1.1 (1.02–1.21)	0.01

BMI indicates body mass index; COPD, chronic obstructive pulmonary disease; and HR, hazard ratio.

patients with ESRD in whom durability may be less of a concern and immediate procedural risk may have greater importance. Previously, another study using USRDS data reported the outcomes of patients on dialysis who underwent SAVR.[15] The in-hospital mortality and 1-year mortality were 20% and 46%, respectively, which are much higher than the mortality rates of 2% and 18%, respectively, in the nondialysis population.[15] The 2014 American Heart Association/American College of Cardiology guidelines previously recommended TAVR for inoperable patients and suggested SAVR for high-risk patients.[4,16] Subsequently, the

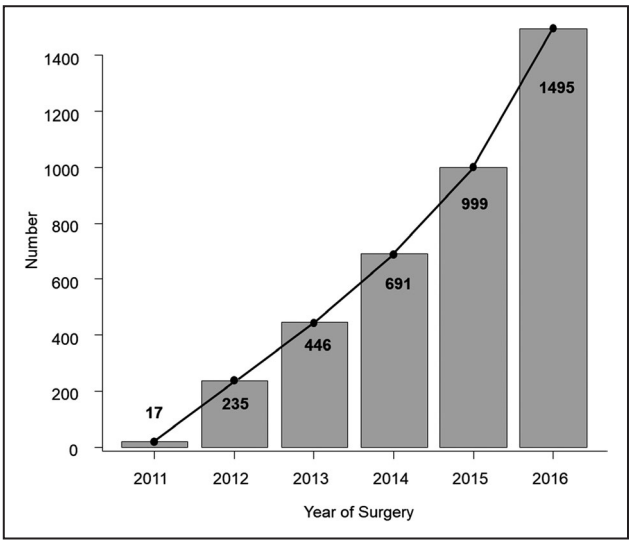

Figure 2. Annual number of transcatheter aortic valve cases per year from 2011, the first year of commercialization, to 2016, in the United States.
The number on each bar graph represents actual case numbers.

indication was expanded to intermediate-risk patients in the updated guidelines based on recent studies. The risk of stroke also dropped as a result of a combination of factors, including accumulation of operative experience, technical innovation including smaller devices, and development of embolic protection devices. This metric appears to favor TAVR in higher-risk populations when coupled with the use of cerebral protection devices. These advantages of TAVR are particularly germane to the ESRD population, in whom severe calcium rapidly develops, thus increasing stroke risk. As such, TAVR has rapidly increased in both the non-ESRD and ESRD populations—4000 cases of TAVRs were performed in 2012, and increased to 54 000 cases in 2015.[14] Newer-generation devices including SAPIEN 3 from Edwards and Evolut R from CoreValve became commercially available in 2015 and 2017, respectively.

The present study showed an in-hospital mortality rate of 4.2% and a 1-year mortality rate of 43%. These results are consistent with a recent study from the TVT registry, which investigated 72 631 patients who underwent TAVR.[12] They compared short-term outcomes between patients with and without ESRD and showed that patients with ESRD had significantly higher in-hospital mortality (5% versus 3% in patients without ESRD, $P<0.01$), as well as a higher rate of 1-year mortality (36% versus 18%, $P<0.01$) and major bleeding (1.4% versus 1.0%, $P=0.03$), although only 3053 (4%) patients had ESRD, which might limit meaningful comparison. In the present study, we extend the survival analysis to 5 years, showing a steep decline in survival. We also analyzed ESRD-related parameters, which are known to affect the prognosis of patients with ESRD. In-hospital mortality improved from 11.1% in 2011 to 2.6% in 2016, which is in line with the risk of the general TAVR population as per the 2016 TVT annual report.[14] However, the 1-year mortality rate remained high in our dialysis patients (31% versus 21% in the non-ESRD population, unmatched comparison), while 5-year mortality was exceedingly high at 88.8%. These high mid- and long-term outcomes might be attributed to their shorter expected lifespan as well as their physiologic differences compared to the general population, especially in the elderly. While life expectancy at age 65 years is >15 years in the US population, it is only 5 years in patients on hemodialysis.[1] As the life expectancy of patients with ESRD has improved over the past 2 decades, mid- and long-term mortality of patients with ESRD after TAVR may also further improve, as demonstrated in the current study. Patients have become younger and have fewer comorbidities such as CAD and CHF in the newer era, and these trends were likely influenced by recent randomized trials leading to approval in intermediate- and even low-risk patients.[10,11] With continued improvements in clinical outcomes in renal and cardiac disease, it is expected

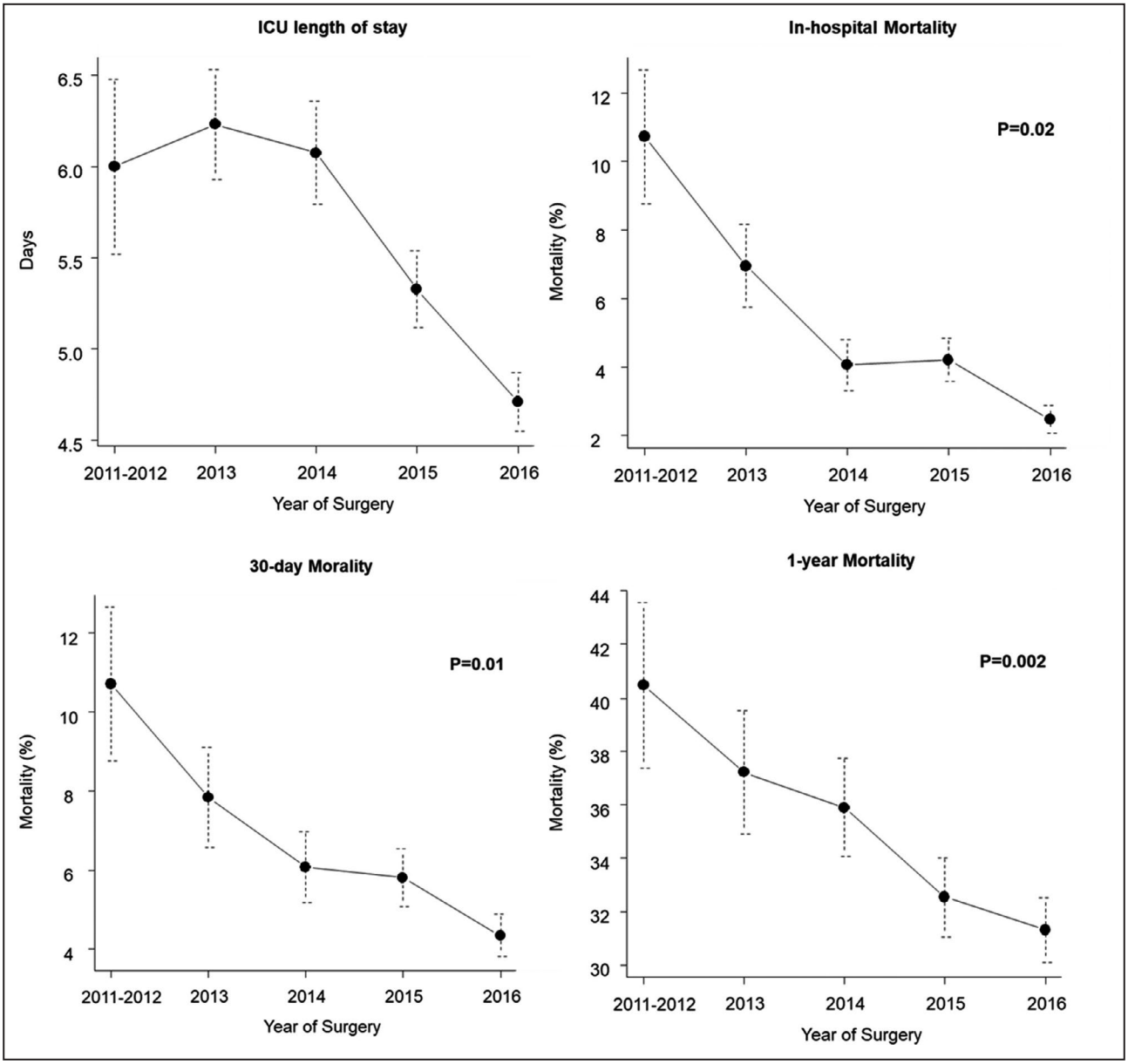

Figure 3. Annual trend of outcomes.
The annual trends of each outcome were plotted against time after surgery with error bars, which represent standard error. Only 17 cases were performed in 2011 and they were combined with cases in 2012. ICU indicates intensive care unit.

that TAVR will play an important role in prolonging life in patients with ESRD, as well as improving quality of life, rather than simply being relegated to "futile" patients with poor survival potential.[17]

BMI and White race were associated with higher risk of 5-year mortality in the present study. While obesity is related to morbidity and mortality in general, our study showed that lower BMI is associated with a higher risk of mortality. This obesity paradox has been noted in some pathologies such as cardiovascular disease and heart failure.[18] In addition, the PARTNER (Placement of Aortic Transcatheter Valves) trial revealed that higher BMI was related to better long-term survival in patients who had undergone TAVR.[19] A large cohort study investigating the TVT registry reported better mortality for patients whose BMIs were >25.[20] They suggested that lower BMI may imply more frailty, which resulted in worse prognosis than the same cohort with higher BMI. This obesity paradox was consistent even in our patients on dialysis. White race is an important prognostic factor for patients on dialysis when compared with Black race. A large observational study analyzing USRDS data enrolled 1 330 007 patients and revealed higher

mortality in patients of White race overall during the study period (63.5% versus 57.1% of Black race).[21] This relationship has been known and there is some potential rationale for this including differences of sensitivity to dialysis dose, difference of nutritional status, and immunologic response; however, the answer remains unclear.[21] While Black patients had a higher risk of death in younger age in the study, White race had a worse prognosis in patients aged >50 years. The patient population who undergo TAVR tends to be older, and this association between White race and higher mortality in our study is in line with their study. Finally, PVD and COPD were also shown to be independent prognostic factors for mortality. PVD is a known risk factor for cardiac surgery including SAVR.[22,23] However, a relationship between PVD and TAVR has not been well-reported and this could be attributed to the approach differences between transfemoral and transapical procedures, of which information we are unable to obtain in this database. In terms of COPD, an observational study investigated 319 consecutive patients who underwent TAVR, of whom 29.5% had COPD.[24] These patients showed worsening survival with COPD (70.6% versus 84.5% without COPD) and COPD was an independent risk factor for mortality.

In the present study, the primary cause of dialysis (diabetes mellitus and hypertension) was related to 5-year mortality. Furthermore, the overall median survival was 1.75 years post-TAVR. These facts might suggest that the long-term outcome is mainly affected by comorbidities associated with ESRD rather than the valvular intervention. The cause of dialysis is known to be a prognostic factor for patients on dialysis and the main causes are diabetes mellitus, hypertension, glomerulonephritis, and cystic kidney disease. The results of the present study are in line with previous studies, which showed that diabetes mellitus as the cause of dialysis was a risk factor for survival and cystic kidney disease was associated with better survival likely because of a higher prevalence in younger population.[25,26]

This study has several limitations. First, it used a national database, which may inherently have selection bias. However, our main findings are in line with previous studies and the major outcomes such as death are likely valid. Second, in-depth procedural and perioperative details are lacking in this database such as urgency of procedure, approach differences (transfemoral and transapical), and complications, as well as cardiac-related parameters such as ejection fraction, concomitant valve disease, paravalvular leak, heart failure, myocardial infarctions, and atrial fibrillation.[22] Third, although we considered the era effect and device development, we are unable to obtain the actual device used for each procedure given the nature of *ICD* codes. This may play a significant role in outcomes. Finally, surgical risk level was unable to be determined, and the context of the longer-term outcomes of TAVR in ESRD is challenging without a better understanding of baseline risk.

CONCLUSIONS

Mid- and long-term outcomes of TAVR in patients with ESRD have significantly improved and TAVR may be offered in these medically complex patients with acceptable risk. Improving results are likely from device improvements, increasing procedural experience, and expanding the indication of TAVR into lower-risk patients. Long-term mortality of patients on dialysis remains exceedingly high, likely because of the comorbid nature of ESRD, which highlights the need for careful patient selection and emphasis on consideration of quality of life in dialysis-dependent patients.

ARTICLE INFORMATION

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Disclosures

None.

Supplementary Material

Data S1–S2
Tables S1–S11
Figures S1–S2

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SUPPLEMENTAL MATERIAL

Data S1.

Supplemental Methods

Sensitivity Analysis for Factors Associated with Mortality Using Bootstrapping Simulation

We applied bootstrapping method with 1000 samples for sensitivity analysis using “Boot” function. The resutls were shown in Table S2-S4. The resutls for in-hospital mortality and 5-year mortality were compatible to the origianl analysis. In regard to 1-year mortality, chronic obstructive pulmonary disease, peripheral vascular disease, and white race were also indepently associated with 1-year mortailty in the index analysis, however, the sensitivity analysis showed no significant difference. Therefore, new model was created with rest of variables as reported in the main manuscript (Table 4).

Data S2.

Cox Hazard Model Assumption

We texted Cox hazard model assumpation using the Schoenfelt residuals (Table S5). Body mass index, era, and global model violated the assumption. We performed subsequent multivariable analysis with stratification using body mass index and era (Table S6). The following Cox hazard assumpations were satisfied (Table S7).

Table S1. Missing Data.

Variables	%
Age	0
Male	0
Body mass index	3.5
Comorbidities	
Coronary artery disease	1.8
Diabetes mellitus	5.1
Congestive heart failure	4.1
COPD	4.1
Cerebrovascular accident	4.1
Peripheral artery disease	4.1
Hypertension	3.8
Race	0
Cause of dialysis	0
Duration of dialysis	0
Any	5.1

Table S2. Sensitivity Analysis for In-hospital Mortality with Bootstrapping Simulation

Variables	OR (95%CI)	OR (95%CI) with Bootstrapping
Body mass index, 30≦, ≦40	0.6 (0.41-0.88)	0.6 (0.41-0.89)
Peripheral vascular disease	2.48 (1.68-3.66)	2.46 (1.65-3.74)
Older era (before August 2015)	2.05 (1.46-2.88)	2.05 (1.48-2.86)

Table S3. Sensitivity Analysis for 1-year Mortality with Bootstrapping Simulation.

Variables	HR (95%CI)	HR (95%CI) with Bootstrapping
Age 75≦	1.21 (1.08-1.35)	1.51 (1.21-1.68)
Body mass index < 25	1.22 (1.08-1.38)	1.35 (1.09-1.51)
Chronic obstructive pulmonary disease	1.21 (1.01-1.46)	1.03 (0.55-1.5)
Peripheral vascular disease	1.24 (1.05-1.47)	1.33 (0.91-1.62)
White race	1.21 (1.04-1.4)	1.12 (0.89-1.25)
Older era (before August 2015)	1.21 (1.04-1.4)	1.4 (1.12-1.56)

Table S4 Sensitivity Analysis for 5-year Mortality with Bootstrapping Simulation.

Variables	HR (95%CI)	HR (95%CI) with Bootstrapping
Age 75≦	1.13 (1.04-1.23)	1.21 (1.1-1.27)
Body mass index < 25	1.18 (1.08-1.29)	1.15 (1.04-1.22)
Chronic obstructive pulmonary disease	1.25 (1.1-1.43)	1.26 (1.04-1.39)
Diabetes as cause of dialysis	1.22 (1.11-1.35)	1.26 (1.11-1.34)
Hypertension as cause of dialysis	1.16 (1.05-1.3)	1.21 (1.06-1.29)
White race	1.17 (1.06-1.29)	1.13 (1.0-1.2)
Older era (before August 2015)	1.1 (1.02-1.21)	1.13 (1.02-1.19)

Table S5. Cox Hazard Model Assumption with the Schoenfeld Residuals.

Variables	P-value
Age	0.54
Male	0.78
Body mass index	0.02
Coronary artery disease	0.5
Congestive heart failure	0.73
Chronic obstructive pulmonary disease	0.61
Cerebrovascular accident	0.93
Diabetes mellitus	0.6
Hypertension	0.42
Peripheral vascular disease	0.051
Smoker	0.05
Race	0.61
Cause of dialysis	0.05
Duration of dialysis	0.08
Era	<0.001
Global	0.001

Table S6. Multivariable Analysis for 5-year Mortality after Stratification by Body Mass Index and Era.

Variable	Hazard Ratio (95%CI)	*P* value
Age 75≦	1.15 (1.06-1.24)	<0.001
Chronic obstructive pulmonary disease	1.25 (1.09-1.42)	0.001
Glomerulonephritis as cause of dialysis	0.85 (0.75-0.96)	0.01
White race	1.14 (1.03-1.26)	0.01
Male	0.92 (0.85-0.99)	0.03

Table S7. Sensitivity Analysis for Cox Hazard Model Assumption with the Schoenfeld Residuals.

Variables	P-value
Age	0.59
Male	0.83
Coronary artery disease	0.49
Congestive heart failure	0.73
Chronic obstructive pulmonary disease	0.53
Cerebrovascular accident	0.88
Diabetes mellitus	0.52
Hypertension	0.39
Peripheral vascular disease	0.07
Smoking	0.07
Race	0.57
Cause of dialysis	0.04
Duration of dialysis	0.08
Global	0.14

Table S8. Baseline Characteristics Difference between Older and Newer era.

Characteristics	Before August 2015, No.(%) n=1933	After August 2015, No.(%) n=1950	*P* value
Age, median (IQR), years	76.1 (68.9 - 82.0)	74.6 (67.7 - 81.0)	<0.001
Male	1199 (62.0)	1210 (62.1)	1
Body mass index, median (IQR)	28.3 (24.6 - 33.3)	28.5 (24.7 - 33.5)	0.45
Comorbidities			
Coronary artery disease	470 (24.7)	404 (21.1)	0.009
Congestive heart failure	634 (34.2)	532 (28.4)	<0.001
Chronic obstructive pulmonary disease	157 (8.5)	164 (8.8)	0.77
Cerebrovascular accident	146 (7.9)	123 (6.6)	0.15
Diabetes mellitus	895 (48.9)	940 (50.7)	0.26
Hypertension	1648 (88.6)	1645 (87.9)	0.54
Peripheral vascular disease	224 (12.1)	185 (9.9)	0.04
Smoker	72 (3.9)	63 (3.4)	0.43
Race			0.13
White	1569 (81.2)	1535 (78.7)	
Black	296 (15.5)	329 (16.9)	
Others	68 (3.5)	86 (4.4)	
Cause of dialysis			0.01
Diabetes mellitus	740 (38.3)	789 (40.5)	
Hypertension	639 (33.1)	580 (29.7)	
Glomerulonephritis	212 (11.0)	259 (13.3)	
Others	334 (17.4)	302 (15.6)	
Duration of dialysis, median (IQR), years	4.0 (1.67 - 7.25)	4.12 (1.68 - 7.84)	0.13

Table S9. Univariable Analysis between Survivor and Non-survivor for In-hospital Mortality.

Variable	Survivor, No.(%) n=3718	Non-survivor, No.(%) n=165	*P* value
Age			
<65	600 (16.1)	24 (14.5)	0.66
65≦, <74	1210 (32.5)	55 (33.3)	0.9
75≦	1908 (51.3)	86 (52.1)	0.9
Male	2308 (62.1)	101 (61.2)	0.87
Body mass index			
<25	966 (26.9)	57 (36.1)	0.02
30≦, < 40	1183 (31.8)	36 (21.8)	0.006
40≦	303 (8.1)	10 (6.1)	0.38
Comorbidities			
Coronary artery disease	836 (22.9)	38 (23.3)	0.92
Congestive heart failure	1103 (30.9)	63 (39.6)	0.02
Chronic obstructive pulmonary disease	309 (8.7)	12 (7.5)	0.77
Cerebrovascular accident	254 (7.1)	15 (9.4)	0.27
Diabetes mellitus	1768 (50.1)	67 (42.7)	0.07
Hypertension	3156 (88.3)	137 (85.6)	0.32
Peripheral vascular disease	373 (10.5)	36 (22.6)	<0.001
Smoker	131 (3.7)	4 (2.5)	0.66
Race			
White	2962 (79.7)	142 (86.1)	0.05
Black	606 (16.3)	19 (11.5)	0.11
Cause of dialysis			
Diabetes mellitus	1470 (39.5)	59 (35.8)	0.37
Hypertension	1158 (31.1)	61 (37.0)	0.12
Glomerulonephritis	453 (12.2)	18 (10.9)	0.72
Duration of dialysis	4.08 (1.66 - 7.57)	3.99 (1.98 - 7.51)	0.36
Older era (before August 2015)	1823 (49.0)	110 (66.7)	<0.001

Table S10. Univariable Analysis for 1-year Mortality.

Variable	Hazzard Ratio (95%CI)	*P* value
Age		
65≦, <74	0.83 (0.74-0.93)	0.002
75≦	1.30 (1.16-1.45)	<0.001
Male	0.90 (0.81-1.01)	0.08
Body mass index		
<25	1.23 (1.09-1.39)	0.001
30≦, <40	0.85 (0.76-0.96)	0.009
40≦	0.91 (0.74-1.12)	0.36
Comorbidities		
Coronary artery disease	1.10 (0.97-1.25)	0.14
Congestive heart failure	1.08 (0.96-1.22)	0.19
Chronic obstructive pulmonary disease	1.25 (1.05-1.51)	0.02
Cerebrovascular accident	1.10 (0.89-1.35)	0.38
Diabetes mellitus	1.03 (0.93-1.16)	0.55
Hypertension	1.01 (0.85-1.2)	0.9
Peripheral vascular disease	1.29 (1.1-1.52)	0.002
Smoker	0.96 (0.71-1.29)	0.77
Race		
White	1.26 (1.09-1.45)	0.002
Black	0.80 (0.68-0.93)	0.005
Cause of dialysis		
Diabetes mellitus	1.01 (0.91-1.13)	0.83
Hypertension	1.03 (0.92-1.16)	0.63
Glomerulonephritis	0.98 (0.83-1.15)	0.78
Duration of dialysis	0.99 (0.99-1)	0.26
Older era (before August 2015)	1.22 (1.1-1.36)	<0.001

Table S11. Univariable Analysis for 5-year Mortality.

Variable	Hazzard Ratio (95%CI)	*P* value
Age		
65≦, <74	1.04 (0.92-1.17)	0.54
75≦	1.22 (1.09-1.36)	<0.001
Male	0.91 (0.84-0.96)	0.02
Body mass index		
<25	1.11 (1.00-1.22)	0.04
30≦, <40	0.94 (0.85-1.04)	0.22
40≦	0.91 (0.78-1.06)	0.22
Comorbidities		
Coronary artery disease	1.09 (1.0-1.19)	0.05
Congestive heart failure	1.11 (1.02-1.20)	0.01
Chronic obstructive pulmonary disease	1.28 (1.13-1.46)	<0.001
Cerebrovascular accident	1.11 (0.96-1.26)	0.15
Diabetes mellitus	1.04 (0.96-1.12)	0.31
Hypertension	0.95 (0.85-1.07)	0.43
Peripheral vascular disease	1.17 (1.04-1.32)	0.009
Smoker	1.15 (0.95-1.41)	0.16
Race		
White	1.33 (1.08-1.65)	0.009
Black	1.2 (0.96-1.51)	0.12
Cause of dialysis		
Diabetes mellitus	1.12 (1.0-1.25)	0.05
Hypertension	1.13 (1.01-1.27)	0.04
Glomerulonephritis	0.94 (0.81-1.08)	0.38
Duration of dialysis	0.99 (0.98-1.0)	0.002
Older era (before August 2015)	1.11 (1.02-1.2)	0.01

Figure S1. Flow Diagram of Patient Selection.

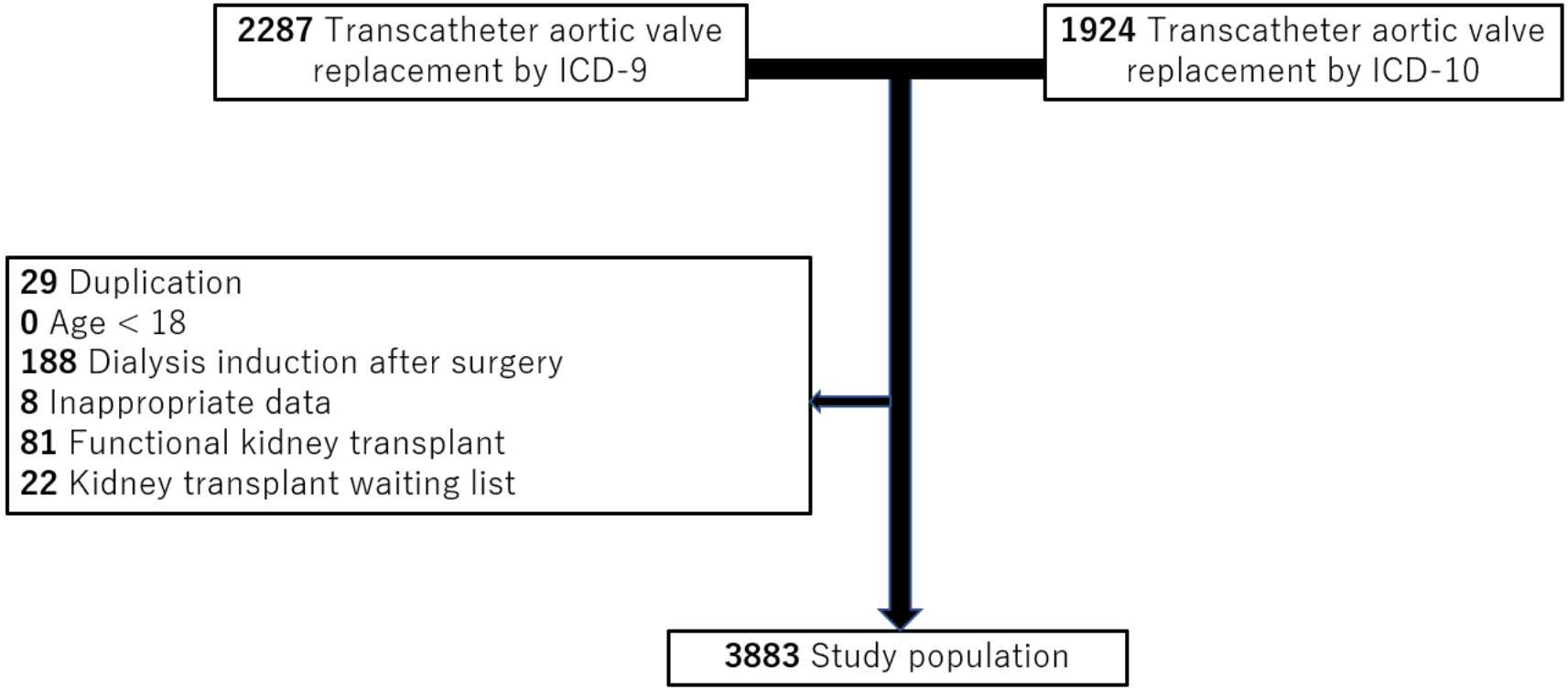
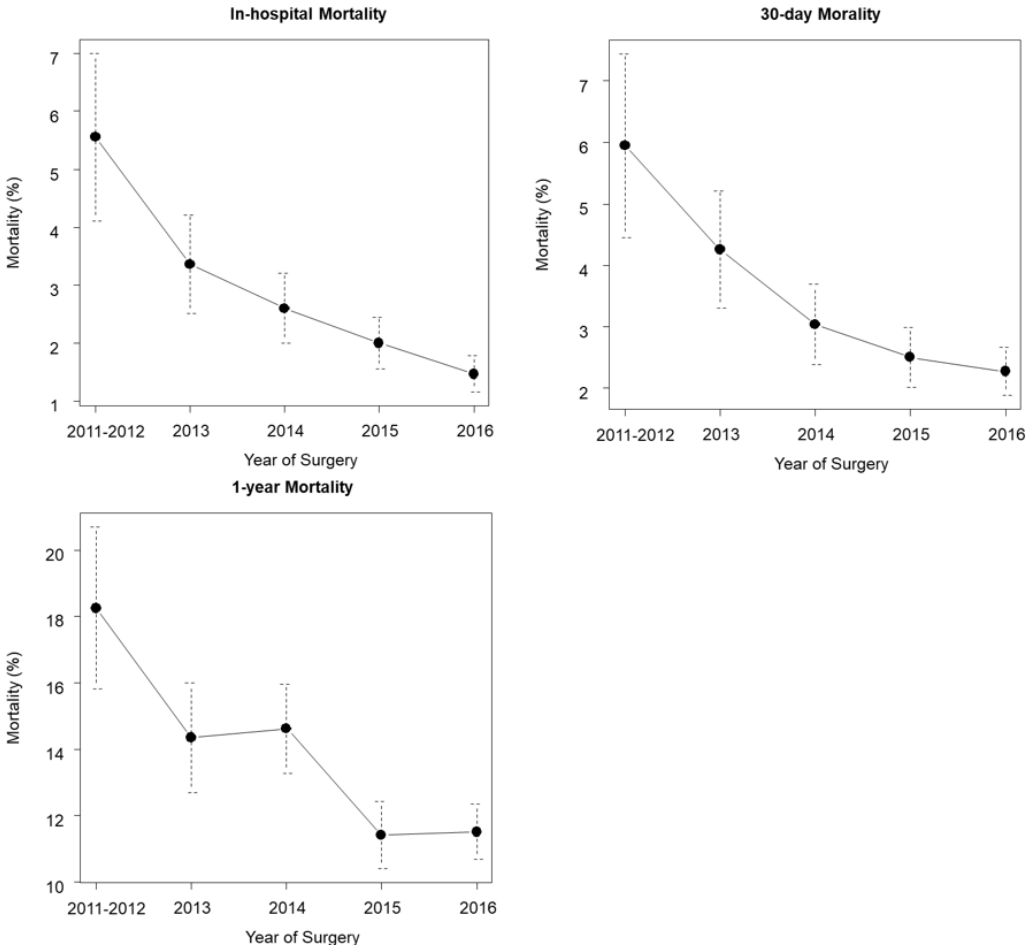


Figure S2. Annual Trend of Outcomes for Cardiovascular Death.



Annual trends of each outcome were plotted against time after surgery with error bars which represents standard error. Only 17 cases were performed in 2011 and they were combined to cases in 2012.