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ORIGINAL ARTICLE

Hospital procedure volume does not predict acute kidney injury after coronary artery bypass grafting—a nationwide study

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Abstract

Background: Acute kidney injury (AKI) is common after coronary artery bypass grafting (CABG) and is associated with poor outcome. Increased hospital procedure volume has been associated with better outcomes. However, the impact of hospital CABG volume on AKI needing dialysis (AKI-D) is less clear. We designed this study to examine (i) the impact of number of annual CABG procedures per hospital (CABG-vol) on AKI-D and inpatient mortality and (ii) if it modifies the relationship between AKI-D and mortality.

Methods: Using the Nationwide Inpatient Sample database from 2000 to 2010, we identified admissions with CABG and those with AKI-D using International Classification of Diseases, Ninth Revision, Clinical Modification codes. Multivariable logistic regressions were used to assess the impact of CABG-vol on AKI-D and mortality. We used restricted cubic splines to account for the nonlinear relationship between CABG-vol and mortality. We also evaluated the *a priori* interaction term between CABG-vol and AKI-D in the model for mortality.

Results: Of 4 002 730 hospitalizations for CABG, 0.7% (24 126) had AKI-D. On adjusted analysis, CABG-vol did not correlate with odds of developing AKI-D [odds ratio (OR) 0.99; 95% confidence interval (CI) 0.99–1.00] but was associated with mortality, though the association was nonlinear. AKI-D was a significant predictor of mortality with OR 7.58 (95% CI 6.81–8.44). The interaction of CABG-vol and AKI-D was not significant ($P = 0.8$).

Conclusions: Lower annual CABG hospital procedure volume is significantly associated with higher mortality but not with a higher incidence of AKI-D. AKI-D is associated with higher mortality in those undergoing CABG. However, there is no differential effect of hospital volume on odds of mortality due to AKI-D.

Key words: AKI, coronary artery disease, dialysis, epidemiology, myocardial infarction

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Introduction

Acute kidney injury (AKI) affects ~6–8% patients undergoing coronary artery bypass grafting (CABG) with ~1% patients experiencing AKI requiring dialysis (AKI-D), and is associated with high mortality [1–3]. Even though the mortality associated with AKI after CABG is on the decline, there is an increasing incidence of AKI and AKI-D after CABG and mortality attributable to both AKI and AKI-D after CABG is on the rise [3]. The treatment for AKI is nonspecific and relies on prevention of further injury by hemodynamic optimization and avoidance of nephrotoxins, and management of AKI-driven metabolic, electrolyte, acid–base and volume complications. As there is no specific therapy for AKI, prevention is the primary goal.

Hospital volume can be used as a surrogate marker for experience in management of patients, which becomes even more important in the case of surgical procedures where a higher number of procedures may result in greater skill in performing them. Hospital procedural volume has been associated with mortality for a variety of procedures including CABG [4–8]. In fact, there has been a recent push towards the use of minimum procedure volume standards for surgical procedures in major medical centers [9]. Therefore, understanding how surgical complications such as AKI-D and their impact on mortality are affected by procedural volume is also important and can help with referral of patients to appropriate centers based on their risk of AKI-D development. It is conceivable that less experience with CABG procedure could in effect lead to longer bypass times, increased postoperative complications and potentially increased AKI incidence.

We therefore designed this study to evaluate the impact of annual hospital CABG volume (CABG-vol) on AKI-D and its relationship with mortality for those undergoing CABG.

Materials and methods

We designed this study using data from the Healthcare Cost and Utilization Project—Nationwide Inpatient Sample (NIS) from years 2000 to 2010. As the largest all-payer inpatient care database that is publicly available in the USA, NIS includes data from 20% stratified sample of US community hospitals [10]. The information about age, race and sex along with primary insurance and hospital characteristics—teaching status, location (rural versus urban), size of hospital and hospital region—is provided in the database for hospitalization. Each hospitalization entry also provides information about a principal diagnosis, secondary diagnoses and procedural diagnoses.

We included hospitalizations of adults aged 20 years or older with International Classification of Diseases, Ninth Revision, Clinical Modification (ICD-9-CM) procedure codes for CABG (36.1, 36.10, 36.11, 36.12, 36.13, 36.14, 36.15, 36.16, 36.17, 36.19) during the study period. Patients with end-stage renal disease and renal transplant were excluded. Using time to procedures from admission provided in the NIS database, we also excluded patients who received acute dialysis before the day of their CABG. We defined AKI-D using the ICD-9-CM code for AKI (584.X) along with the procedure code for hemodialysis (39.95). These codes have demonstrated excellent positive and negative predictive value to identify admissions with AKI-D in administrative databases [11]. Percutaneous intervention (PCI) (36.01, 36.02, 36.03, 36.04, 36.05, 36.06, 36.07, 00.66), valve surgery (35.1, 35.10, 35.11, 35.12, 35.13, 35.14, 35.2, 35.20, 35.21, 35.22, 35.23, 35.24, 35.25, 35.26, 35.27, 35.28), use of cardiopulmonary bypass (39.61), use of balloon pump (37.61), presence of prolonged mechanical ventilation (≥96 h; procedure code 96.72) and presence of cardiogenic shock (785.51) during the same admission were also identified using ICD-9-CM codes. Demographic characteristics (age, sex and race), hospital characteristics (location and teaching status, bed size and region), primary payer, admission type (elective or non-elective) are provided in the NIS database. We determined the CABG-vol for hospitals for each specific year. We used Charlson's comorbidity index to examine the burden of co-morbid diseases [12].

The primary outcomes of interest were the incidence of AKI-D and inpatient mortality in those undergoing CABG. We then assessed the association of CABG-vol with AKI-D and mortality for those undergoing CABG. We also examined if AKI-D is an independent predictor of CABG mortality and if CABG-vol modifies the relationship between AKI-D and mortality.

National estimates for the number of overall hospitalizations with CABG were generated using weights provided in the NIS database. Appropriate survey procedures were used to account for the complex survey methodology of the database. Chi-square test was used to compare categorical variables. STATA 14.0 (College Station, TX, USA) was used for all statistical analyses.

We used a multivariable logistic regression model to estimate odds of AKI-D and all-cause inpatient mortality. The multivariable model for AKI-D as the dependent variable was adjusted for age, sex, race, primary payer, Charlson's score, hospital teaching status and location, hospital region, hospital bed size, year of admission, use of cardiopulmonary bypass, type of admission (or nonelective), concomitant valve surgery, concomitant PCI, need for prolonged mechanical ventilation (≥96 h), cardiogenic shock, use of balloon pump and CABG-vol. The C-statistic of the model was 0.79. The model for mortality was also adjusted for the presence of AKI-D with the C-statistic of the model at 0.85 suggesting excellent predictive value. As spline functions are more accurate in characterizing nonlinear relationships [13–15], restricted cubic spline transformation of CABG-vol using five knots was used to model the nonlinear relationship with CABG-vol and dependent variables (AKI-D and mortality). Restricted cubic spline transformation was retained in the final regression model if the relationship between CABG-vol and dependent variable was nonlinear, which was true in the case of regression model with mortality as the dependent variable. As there was no evidence of nonlinear relationship between CABG-vol and AKI-D, CABG-vol was used a continuous variable in the model with AKI-D as the dependent variable. To examine if the CABG-vol modifies the relationship between AKI-D and mortality, an interaction term between CABG-vol and AKI-D was examined in the model with mortality as the dependent variable.

Among those with AKI-D, time from admission to acute dialysis or CABG was missing in 29.3% population. We therefore performed a sensitivity analysis by excluding those patients and thus restricting our sample to only those who were confirmed not to have received acute dialysis before the day of their CABG. Missing data was <1% for all variables except race, which was missing in approximately 20% of observations. Casewise deletion was used to handle missing data. To ensure that this methodology of handling missing data did not affect our results, we performed another sensitivity analysis by including missing values of race under the 'missing' category in variable for race in logistic regression.

Table 1. Baseline characteristics of those undergoing CABG, stratified based on the presence of AKI-D

Characteristic	No AKI-D, % ($n = 3\,974\,373$)	With AKI-D, % ($n = 28\,357$)	P-value*
Age group (years)			<0.001
20–44	2.8	1.4	
45–54	13.0	6.5	
55–64	26.7	17.0	
65–74	32.9	32.4	
≥75	24.6	42.7	
Sex			
Male	71.4	63.3	<0.001
Race			
White	63.6	67.7	<0.001
Black	4.5	6.9	
Hispanic	4.9	6.4	
Asian	1.6	2.9	
Native American	0.4	0.3	
Others	2.6	3.6	
Missing	22.4	12.2	
Primary payer			
Medicare	54.5	70.8	<0.001
Medicaid	4.8	5.2	
Private	34.6	20.1	
Self-pay	3.2	1.9	
No charge	0.3	0.1	
Other	2.6	1.9	
Charlson's score			
0	25.1	13.0	<0.001
1–3	68.5	62.7	
4–6	5.9	21.9	
≥7	0.5	2.4	
Valve surgery	13.2	30.0	<0.001
Percutaneous intervention	3.1	3.4	0.2
Cardiopulmonary bypass use	76.9	80.0	<0.001
Prolonged mechanical ventilation	2.4	34.9	<0.001
Cardiogenic shock	3.1	21.7	<0.001
Use of balloon pump	8.7	26.1	<0.001
Elective admission	47.4	36.4	<0.001
Hospital location and teaching status			
Rural	3.8	3.1	0.3
Urban non-teaching	36.6	35.6	
Urban teaching	59.6	61.3	
Hospital bed size			
Small	6.3	6.0	0.1
Medium	19.2	17.1	
Large	74.5	76.9	
Hospital region			
Northeast	17.7	18.7	<0.001
Midwest	23.8	25.5	
South	42.7	31.7	
West	15.8	24.1	
Year of admission			
2000	9.5	5.7	<0.001
2001	9.5	6.6	
2002	8.8	7.2	
2003	8.3	6.6	
2004	7.3	7.6	
2005	6.6	7.4	
2006	7.2	7.3	
2007	5.9	7.1	
2008	6.1	6.8	
2009	6.3	7.6	
2010	5.0	5.9	
2011	4.9	6.4	
2012	4.9	6.0	
2013	4.8	5.7	
2014	4.9	6.1	

*P-value, as per global chi-square test among the categories.

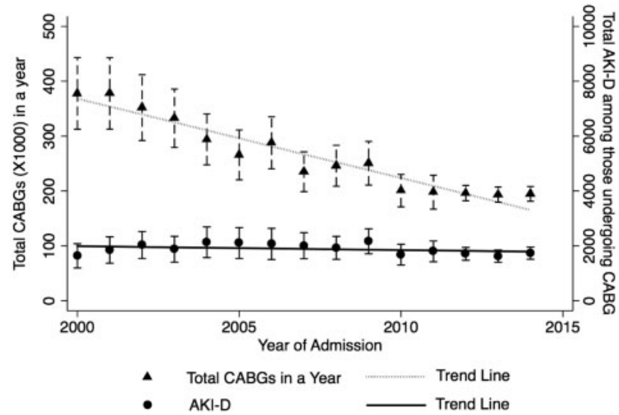

Fig. 1. Trends of total CABG hospitalizations and AKI-D among them over time. Trend P for CABG <0.001. Trend P for AKI-D = 0.2.

Results

Baseline characteristics

There were an estimated 4 002 730 [95% confidence interval (CI) 3 761 267–4 244 192] admissions with CABG performed at hospitalization. Of them 0.7% (28 357; 95% CI 25 803–30 911) had AKI-D. Those with AKI-D were older, females (36.7% versus 28.6%; $P < 0.001$), Blacks (7.8% versus 5.7%; $P < 0.001$) and with primary payer as Medicare or Medicaid (75.9% versus 59.3%; $P < 0.001$). Those with AKI-D also had a higher comorbidity burden as evidenced by higher Charlson's scores and were more often admitted to hospitals that were urban teaching and large bed size. The incidence of AKI-D was lower among those with elective admissions (36.4% versus 47.4%; $P < 0.001$). A higher proportion of AKI-D was seen in patients with concomitant valve repair, use of cardiopulmonary bypass balloon pump, prolonged mechanical ventilation or presence of cardiogenic shock (Table 1).

Trends of AKI-D

The total numbers of hospitalizations have steadily decreased from 377 835 in 2000 to 194 725 in 2014 ($P < 0.001$ for trend); however, the annual number and proportion of AKI-D over the years have stayed steady (Figure 1).

Predictors for AKI-D

After adjustment for measurable confounders, CABG-vol did not seem to be an independent predictor for developing AKI-D in patients undergoing CABG [odds ratio (OR) 0.99; 95% CI 0.99–1.00] (Table 2). Increasing age, female sex, Black or Asian race, higher Charlson's comorbidity index, concomitant valve surgery, cardiogenic shock, use of balloon pump, cardiopulmonary bypass or prolonged mechanical ventilation were all independent predictors for development of AKI-D.

Inpatient mortality

Overall mortality for those undergoing CABG was 2.8%. Mortality was significantly higher in those with AKI-D (34.3% versus 2.6%; $P < 0.001$). On adjusted analysis, AKI-D was an independent predictor of mortality with OR 7.58 (95% CI 6.81–8.44) (Table 3). Similarly, hospital volume was also an independent predictor of mortality, however the effect was nonlinear (Figure 2). The interaction term between AKI-D and CABG-vol was not significant ($P = 0.5$), suggesting no differential effect of

Table 2. Predictors of AKI-D after adjustment for confounding variables

Characteristic	OR	95% CI
Annual hospital CABG volume	0.99	0.99–1.00
Age group (years)		
20–44	Reference	
45–54	1.04	0.79–1.38
55–64	1.22	0.95–1.58
65–74	1.54	1.19–1.99
≥75	2.29	1.76–2.97
Sex		
Female	1.11	1.04–1.19
Race		
White	Reference	
Black	1.43	1.25–1.63
Hispanic	1.14	0.99–1.32
Asian	1.33	1.10–1.61
Native American	0.68	0.38–1.19
Others	1.20	0.98–1.47
Primary payer		
Medicare	Reference	
Medicaid	1.02	0.87–1.20
Private	0.85	0.76–0.96
Self-pay	0.78	0.61–0.99
No charge	0.57	0.31–1.05
Other	0.90	0.71–1.14
Charlson's score		
0	Reference	
1–3	1.48	1.34–1.62
4–6	4.27	3.79–4.80
≥7	5.75	4.54–7.28
Concomitant valve surgery	1.85	1.71–2.00
Percutaneous intervention	0.71	0.59–0.84
Cardiopulmonary bypass use	1.11	1.00–1.22
Prolonged mechanical ventilation	10.22	9.26–11.29
Cardiogenic shock	2.31	2.09–2.57
Use of balloon pump	1.54	1.40–1.70
Elective admission	0.83	0.78–0.89
Hospital location and teaching status		
Rural	Reference	
Urban non-teaching	0.90	0.65–1.24
Urban teaching	1.05	0.89–1.36
Hospital bed-size		
Small	Reference	
Medium	0.93	0.77–1.13
Large	1.05	0.89–1.25
Hospital region		
Northeast	Reference	
Midwest	1.35	1.04–1.75
South	0.94	0.73–1.21
West	1.52	1.18–1.95
Year of admission		
2000	Reference	
2001	1.10	0.85–1.42
2002	1.28	1.00–1.63
2003	1.17	0.90–1.53
2004	1.41	1.07–1.84
2005	1.54	1.15–2.06
2006	1.34	1.00–1.80
2007	1.35	1.04–1.77
2008	1.14	0.87–1.48
2009	1.09	0.83–1.43
2010	1.05	0.80–1.38
2011	0.96	0.73–1.26
2012	0.98	0.75–1.27
2013	0.87	0.67–1.13
2014	0.89	0.68–1.15

CABG-vol on mortality due to AKI-D. This is evident from Figure 3, where OR for mortality due to AKI-D (in comparison with without AKI-D) was 7.58 (95% CI 6.81–8.44) at all arbitrarily selected reference points. Increasing age, female sex, higher comorbidity burden, concomitant valve repair or PCI, cardiogenic shock, use of prolonged mechanical ventilation or balloon pump were other independent predictors of mortality.

Similar results for the impact of CABG-vol on AKI-D and its impact on mortality were seen when those with AKI-D who had missing time from admission to acute dialysis or CABG were excluded from the cohort or when missing race was included as a separate subgroup of race in the regression models (Supplementary data, Tables S1 and S2, and Figure S1a and b).

Discussion

This study using nationally representative data demonstrates that for those undergoing CABG, increasing annual hospital CABG volume is not associated with decline in risk of developing AKI-D but is significantly associated with the risk of decline in mortality. We also show that the annual hospital CABG volume does not modify the association of AKI-D with mortality.

We found that 0.7% of CABG procedures were associated with AKI-D. This is similar to the study by Lenihan *et al.* [3], who found 0.8% incidence of AKI-D with cardiac surgery procedures. They, however, included all patients with AKI-D whereas we have excluded those who were known to have been started on acute dialysis before the day of their CABG. In addition, they did not look at the effect of annual hospital procedure volume on the incidence of AKI-D.

We found a significant decrease in the number of CABG surgeries performed annually over time. However, the number of patients with AKI-D per year during these surgeries has remained the same. This is likely a function of increasing complexity of patients over the years, which is also evident from the fact that after multivariable adjustment, more recent years themselves were not an independent predictor for AKI-D.

AKI-D in our study was seen less often in patients admitted for elective surgery (36.4% versus 47.4%; $P < 0.001$). In fact, we noted elective admission to be independently associated with less risk of developing AKI-D (OR 0.83; 95% CI 0.78–0.89). As the prevention of AKI relies primarily on avoidance of nephrotoxins and optimization of renal perfusion, it is likely that those undergoing urgent surgery have not had a chance to be optimized before surgery and thus could have a higher risk of developing AKI. However, once AKI is established, close monitoring of these patients is essential to prevent further kidney injury by optimization in the postoperative setting. Acute dialysis is offered when renal function continues to decline despite conservative measures such that hyperkalemia, metabolic acidosis or volume overload becomes refractory to medical treatment. As higher hospital volume may translate into more experience in postoperative management of optimization of patients, it is reasonable to assume that higher hospital volume may be associated with less incidence of AKI-D. However, we did not find hospital annual CABG volume to be predictive of AKI-D. Greater attention to identifying AKI and involving nephrology early in the care of these patients regardless of the hospital procedure volume could be a possible explanation of these findings.

Similar to other studies [4–8], we did find higher hospital volume to be associated with lower in-hospital mortality in these patients; the relationship was, however, nonlinear. Our results can be most readily compared to those of Rathore *et al.* [6], who looked at the impact of annual hospital CABG volume on

Table 3. Predictors of inpatient mortality

Characteristic	OR	95% CI
AKI-D	7.58	6.81–8.44
Spline variable 1 for CABG-vol	0.99	0.99–0.99
Spline variable 2 for CABG-vol	1.03	1.01–1.06
Spline variable 3 for CABG-vol	0.91	0.86–0.97
Spline variable 4 for CABG-vol	1.05	1.00–1.10
Age group (years)		
20–44	Reference	
45–54	0.79	0.69–0.91
55–64	1.10	0.96–1.26
65–74	1.59	1.38–1.82
≥75	2.65	2.30–3.06
Sex		
Female	1.44	1.39–1.49
Race		
White	Reference	
Black	1.06	0.97–1.15
Hispanic	0.86	0.79–0.93
Asian	1.02	0.86–1.19
Native American	1.04	0.81–1.33
Others	0.99	0.89–1.10
Primary payer		
Medicare	Reference	
Medicaid	1.14	1.03–1.25
Private	0.75	0.70–0.80
Self-pay	1.05	0.92–1.20
No charge	0.82	0.60–1.12
Other	0.80	0.69–0.92
Charlson's score		
0	Reference	
1–3	1.26	1.20–1.21
4–6	1.49	1.39–1.61
≥7	2.06	1.70–2.50
Concomitant valve surgery	2.64	2.53–2.76
Percutaneous intervention	1.22	1.13–1.32
Cardiopulmonary bypass use	0.85	0.80–0.90
Prolonged mechanical ventilation	4.36	4.08–4.66
Cardiogenic shock	3.61	3.34–3.90
Use of balloon pump	4.53	4.29–4.78
Elective admission	0.83	0.80–0.87
Hospital location and teaching status		
Rural	Reference	
Urban non-teaching	1.08	0.94–1.24
Urban teaching	1.12	0.97–1.30
Hospital bed-size		
Small	Reference	
Medium	0.95	0.84–1.24
Large	0.97	0.87–1.07
Hospital region		
Northeast	Reference	
Midwest	1.09	0.98–1.21
South	1.48	1.34–1.64
West	0.99	0.89–1.09
Year of admission		
2000	Reference	
2001	0.87	0.80–0.95
2002	0.84	0.75–0.93
2003	0.77	0.69–0.87
2004	0.66	0.58–0.74
2005	0.55	0.49–0.61
2006	0.51	0.46–0.57
2007	0.46	0.41–0.53
2008	0.46	0.40–0.53
2009	0.37	0.33–0.42
2010	0.35	0.30–0.41
2011	0.34	0.29–0.40
2012	0.27	0.24–0.32
2013	0.27	0.24–0.32
2014	0.26	0.22–0.30

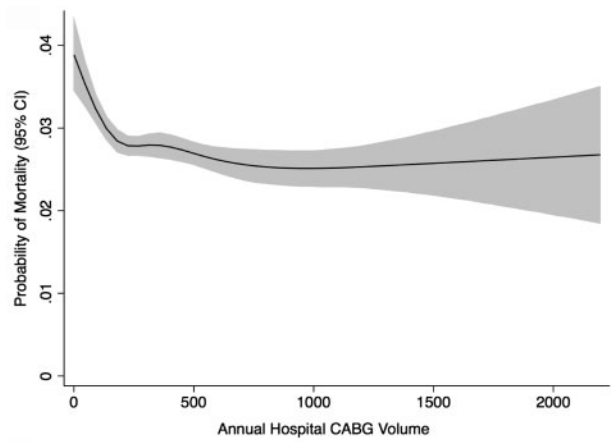

Fig. 2. Adjusted probabilities for mortality by annual hospital CABG volume.

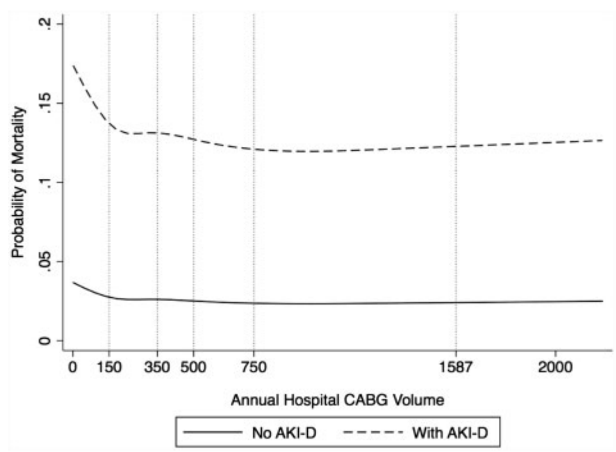

Fig. 3. Impact of annual hospital CABG volume on adjusted probabilities for mortality by AKI-D. Interaction P = 0.5. OR for mortality for AKI-D (in comparison with no AKI-D) is 7.58 (95% CI 6.81–8.44) at all arbitrarily selected reference points.

mortality using the NIS database for the years 1998–2000. They found that in comparison with high-volume hospitals, mortality was progressively higher in medium- and low-volume hospitals. Similarly, using data from California CABG Mortality Report Program, Nallamothu *et al.* [5] found similar results across different categories of expected surgical risk. Both these studies, however, used hospital CABG volume as a categorical variable and divided the hospitals into low, medium and high volume depending on number of annual CABG procedures. Categorizing a continuous variable can, however, lead to loss of information and can greatly influence the results depending on how the categories are chosen [14]. When categorizing a continuous variable, there is an assumption of constant effect within a category, which may lead to loss of information, especially if the relationship with dependent and independent variable is nonlinear. In contrast, splines use all data points and create a functional representation of the shape of the relationship between dependent and independent variables and are, therefore, the preferred method of defining nonlinear relationships [13, 15]. Our results are in contrast to the study by LaPar *et al.*, where they found no relationship of annual CABG volume, when used as a restricted cubic spline, with mortality. However, they had restricted their study to only the year 2008 [16]. The reasons for association between annual CABG procedure volume and mortality are likely multifactorial and include improved patient selection, increased surgeon experience and better postoperative care. The reasons may also include the fact that high-risk patients are more likely to have CABG at relatively lower volume hospitals, as described by Nallamothu *et al.* [5]. We did find that lower volume hospitals had higher proportions of hospitalizations of those with higher comorbidity burden (when hospital volume was divided into tertiles, Charlson's comorbidity index $\geq$4 was seen in 3.9% of admissions in low-volume hospitals in comparison with 5.4% in medium-volume and 10.2% in high-volume hospitals; $P < 0.001$).

Similar to previous literature, we also found AKI-D to be an independent predictor of mortality [3]. The impact on AKI-D on mortality was, however, not dependent on annual hospital CABG volume. Higher volume centers with their increased experience can be presumed to have access to better facilities (for example, access to continuous renal replacement therapy) and better overall processes of care, which could translate into better outcomes. Though we were unable to study the impact of dialysis modalities (continuous versus intermittent) in this study, they have not been shown to influence mortality [17–20]. That may partly explain the lack of effect of annual hospital CABG volume on impact of AKI-D on inpatient mortality. Further studies are needed to explore and understand this relationship.

This study has some important limitations that merit consideration. We have relied on ICD-9-CM codes to identify those with CABG, and our results may, therefore, be susceptible to variation in coding practices between providers and hospitals, and over the years. The NIS database has, however, been validated for identifying CABG procedures using Medicare claims data [21]. Similarly, the ICD-9 codes used have been demonstrated to have excellent positive and negative predictive values to identify patients with AKI-D [11]. Though we have used a large, nationally representative dataset, it lacks the granularity to assess variables such as cardiopulmonary bypass times, bleeding, center experience in using dialysis, and variations in perioperative and dialysis management, which could have impacted our observations. The NIS does not include specific patient identifiers, and therefore it is not possible to accurately identify the impact of readmissions on our results. Another limitation of our study is that the outcomes are only available until the end of each index hospitalization. As NIS provides data only for the duration of the hospitalization and lacks any patient identifiers that can be used to link the data to other registries, it is not possible to comment on the long-term mortality of these patients. The experience and comfort level of each individual provider can impact the timing and reasoning of dialysis initiation. This, in turn, makes the interpretation of the observed practice patterns as an indicator of outcome, rather difficult. In addition, we were unable to assess the reasons for dialysis initiation due to lack of the data granularity. The database has ~20% missing data on patient's race that limits further exploration of the impact of race on outcomes. To ensure that our technique for handling missing data did not significantly impact our results, we performed regression analysis for both AKI-D and mortality as dependent variables while using missing values of race as a separate level of race in the regression model and found similar results. Finally, the time from admission to acute dialysis or CABG was missing in 29.3% of in patients with AKI-D. Our results were, however, consistent despite excluding these patients and restricting our sample to only those who were confirmed not to have received acute dialysis before the day of their CABG.

Our study using nationally representative data of those undergoing CABG shows that progressive increase annual hospital CABG volume is not associated with risk of developing AKI-D but is significantly associated with risk of decline in mortality, though the relationship is not linear. AKI-D is an important predictor of mortality in those undergoing CABG and the impact of AKI-D on mortality is not dependent on a hospital's annual CABG procedure volume.

Supplementary data

Supplementary data are available online at http://ckj.oxfordjournals.org.

Conflict of interest statement

None declared.

References

1. Conlon PJ, Stafford-Smith M, White WD *et al.* Acute renal failure following cardiac surgery. *Nephrol Dial Transplant* 1999; 14: 1158–1162
2. Mangano CM, Diamondstone LS, Ramsay JG *et al.* Renal dysfunction after myocardial revascularization: risk factors, adverse outcomes, and hospital resource utilization. The Multicenter Study of Perioperative Ischemia Research Group. *Ann Intern Med* 1998; 128: 194–203
3. Lenihan CR, Montez-Rath ME, Mora Mangano CT *et al.* Trends in acute kidney injury, associated use of dialysis, and mortality after cardiac surgery, 1999 to 2008. *Ann Thorac Surg* 2013; 95: 20–28
4. Birkmeyer JD, Siewers AE, Finlayson EV *et al.* Hospital volume and surgical mortality in the United States. *N Engl J Med* 2002; 346: 1128–1137
5. Nallamothu BK, Saint S, Hofer TP *et al.* Impact of patient risk on the hospital volume-outcome relationship in coronary artery bypass grafting. *Arch Intern Med* 2005; 165: 333–337
6. Rathore SS, Epstein AJ, Volpp KG *et al.* Hospital coronary artery bypass graft surgery volume and patient mortality, 1998-2000. *Ann Surg* 2004; 239: 110–117
7. Reames BN, Ghaferi AA, Birkmeyer JD *et al.* Hospital volume and operative mortality in the modern era. *Ann Surg* 2014; 260: 244–251
8. Nallamothu BK, Saint S, Ramsey SD *et al.* The role of hospital volume in coronary artery bypass grafting: is more always better? *J Am Coll Cardiol* 2001; 38: 1923–1930
9. Sternberg S. *Hospitals Move to Limit Low-Volume Surgeries*. https://www.usnews.com/news/articles/2015/05/19/hospitals-move-to-limit-low-volume-surgeries (6 April 2017, date last accessed)

10. *Introduction to the HCUP Nationwide Inpatient Sample 2009*. http://www.hcup-us.ahrq.gov/db/nation/nis/NIS_2009_INTRODUCTION.pdf (18 January 2015, date last accessed)
11. Waikar SS, Wald R, Chertow GM *et al*. Validity of international classification of diseases, ninth revision, clinical modification codes for acute renal failure. *J Am Soc Nephrol* 2006; 17: 1688–1694
12. Deyo RA, Cherkin DC, Ciol MA. Adapting a clinical comorbidity index for use with ICD-9-CM administrative databases. *J Clin Epidemiol* 1992; 45: 613–619
13. Greenland S. Avoiding power loss associated with categorization and ordinal scores in dose-response and trend analysis. *Epidemiology* 1995; 6: 450–454
14. Filardo G, Hamilton C, Hamman B *et al*. Categorizing BMI may lead to biased results in studies investigating in-hospital mortality after isolated CABG. *J Clin Epidemiol* 2007; 60: 1132–1139
15. Kozower BD, Stukenborg GJ. The relationship between hospital lung cancer resection volume and patient mortality risk. *Ann Surg* 2011; 254: 1032–1037
16. LaPar DJ, Kron IL, Jones DR *et al*. Hospital procedure volume should not be used as a measure of surgical quality. *Ann Surg* 2012; 256: 606–615
17. Lins RL, Elseviers MM, Van der Niepen P *et al*. Intermittent versus continuous renal replacement therapy for acute kidney injury patients admitted to the intensive care unit: results of a randomized clinical trial. *Nephrol Dial Transplant* 2009; 24: 512–518
18. Vinsonneau C, Camus C, Combes A *et al*. Continuous venovenous haemodiafiltration versus intermittent haemodialysis for acute renal failure in patients with multiple-organ dysfunction syndrome: a multicentre randomised trial. *Lancet* 2006; 368: 379–385
19. Schefold JC, von Haehling S, Pschowski R *et al*. The effect of continuous versus intermittent renal replacement therapy on the outcome of critically ill patients with acute renal failure (CONVINT): a prospective randomized controlled trial. *Crit Care* 2014; 18: R11
20. Rauf AA, Long KH, Gajic O *et al*. Intermittent hemodialysis versus continuous renal replacement therapy for acute renal failure in the intensive care unit: an observational outcomes analysis. *J Intensive Care Med* 2008; 23: 195–203
21. Epstein AJ, Polsky D, Yang F *et al*. Coronary revascularization trends in the United States, 2001–2008. *JAMA* 2011; 305: 1769–1776