# Financial Impact of Acute Kidney Injury After Cardiac Operations in the United States

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*Background.* **Acute kidney injury (AKI) after major cardiac operations is a potentially avoidable complication associated with increased morbidity, death, and costly long-term treatment. The financial impact of AKI at the population level has not been well defined. We sought to determine the incremental index hospital cost associated with the development of AKI.**

*Methods.* **All patients undergoing coronary artery bypass grafting (CABG) or valve replacement operations, or both (clinical classification software codes 43 and 44), between 2008 and 2011 were identified from the Nationwide Inpatient Sample. AKI was identified using International Classification of Diseases, 9th Revision, Clinical Modification diagnosis codes (584.xx); patients with chronic renal failure were excluded. Mean total index hospitalization costs were compared between patients with and without AKI.**

*Results.* **At the population level, 1,078,036 individuals underwent major cardiac procedures from 2008 to 2011, with AKI developing in 105,648 (9.8%). Specifically, AKI developed in 8.0% of CABG, 11.4% of valve replacement, and 17.0% of CABG plus valve replacement patients ($p < 0.001$). Death was more common among patients with AKI vs those without (13.9% vs 1.3%, $p < 0.001$). Mean total index hospitalization cost was $77,178 for patients with AKI vs $38,820 for those without ($p < 0.001$). At the national level, the overall incremental annual index hospitalization cost associated with AKI was $1.01 billion.**

*Conclusions.* **AKI developed in 1 in every 10 patients nationwide after a cardiac operation. Achieving a 10% reduction in AKI in this population would likely result in an annual savings of approximately $100,000,000 in index-hospital costs alone. Support for research on mechanisms to detect impending damage and prevent AKI may lead to reduced patient morbidity and death and to substantial health care cost savings.**

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Acute kidney injury (AKI) is a common complication after cardiac operations [1]. Previous studies have reported the AKI incidence ranges from 3% to 30% after operations that require cardiopulmonary bypass, including coronary artery bypass graft (CABG) and valve replacement/repair surgeries (VRS) [1]. Managing this postoperative complication often requires extensive resource utilization, including extended use of intensive care, longer length of stay (LOS), and the use of renal replacement therapy (RRT) [2]. As health care moves into an era of greater accountability, there is increased focus on cost containment by the prevention of costly postoperative complications. As such, data quantifying the increased resource utilization and resulting incremental cost associated with AKI is necessary. Single-center reports have identified an increased total index hospitalization costs of 37% [3] to 104% [2] among patients who developed AKI vs those who did not. However, the financial burden of AKI after cardiac operations has not been well described at the national level. We sought to quantify the incremental index hospitalization cost associated with the development of AKI using a nationally representative sample of patients undergoing cardiac procedures. In addition, we assessed

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AKI-related variability in inpatient death and discharge to additional care.

## Patients and Methods

### *Data Source and Patient Population*

The Johns Hopkins University Institutional Review Board approved this study.

The current cross-sectional analysis was performed using data from the Nationwide Inpatient Sample (NIS) database between 2008 and 2011. The NIS, developed and maintained by the Agency for Healthcare Research and Quality-Healthcare Cost and Utilization Project (AHRQ-HCUP), is the largest in-hospital all-payer database, representing a 20% stratified sample of all inpatient discharge records in the United States [4]. In accordance with HCUP methods, sampling weights were applied to obtain estimates at the level of the United States population [5].

All patients aged 18 years or older undergoing CABG or VRS, or both, were identified using the Clinical Classification Software codes 43 and 44, respectively (Supplemental Table 1). Clinical Classification Software codes were previously validated to enable the accurate identification of patients undergoing CABG or VRS [6]. Patients with a history of chronic kidney disease and patients undergoing RRT without a concurrent diagnosis of AKI were excluded from the study population (Fig 1). Patient comorbidity was classified using the Charlson Comorbidity Index (CCI), and patients were grouped into three categories according to their CCI score: 0, 1, or 2 or higher [7, 8].

Discharge disposition was categorized as routine discharge, discharge against medical advice, or discharge to additional care. Additional care was defined as discharge to hospice, home health care, federal, or skilled nursing facilities, intermediate care, short-term care, or other types of medical facilities. Hospital-level characteristics collected within the data set included hospital geographic location, hospital teaching status, and hospital rural vs urban location (rural, urban nonteaching, or urban teaching).

### *Outcomes: AKI, LOS, In-Hospital Death, and Total Hospitalization Costs*

Patients who developed AKI were identified using the clinically validated International Classification of Disease, 9th Revision, Clinical Modification diagnostic codes (584, 584.5, 584.6, 584.7, 584.8, 584.9) [9]. LOS was calculated from the date of admission to the date of the index hospital discharge. In-hospital death was defined as any death during the index admission. The AHRQ-HCUP provides two cost elements in the NIS: the total hospitalization charges and a hospital- and year-specific cost-to-charge ratio. We used the cost-to-charge ratio to obtain total hospitalization costs from the total hospitalization charges based on the method described by the AHRQ-HCUP [10]. Total index hospitalization costs were inflation adjusted to 2011 dollars using Consumer Price Index values provided by the United States Bureau of Labor Statistics [11].

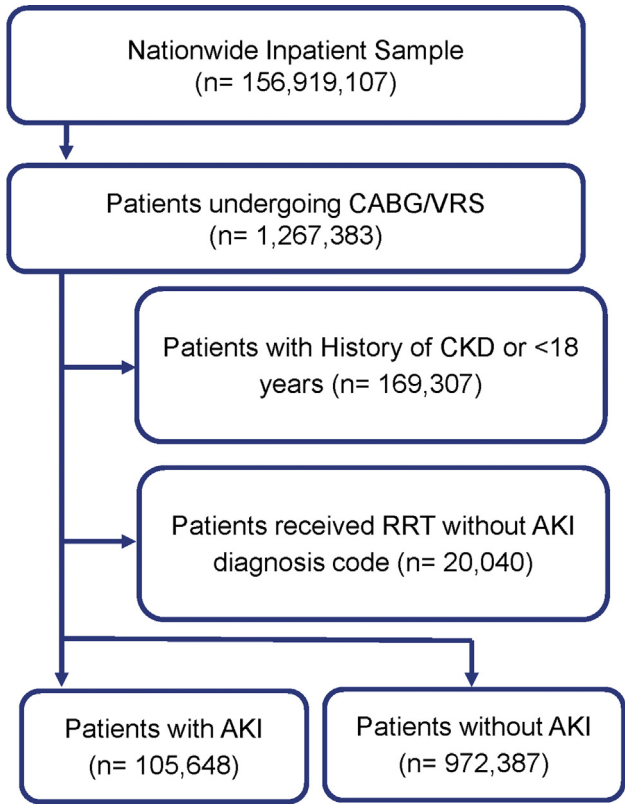


*Fig 1. Derivation of the study cohort: exclusion and inclusion criteria. (AKI = acute kidney injury; CABG = coronary artery bypass graft; CKD = chronic kidney disease; RRT = renal replacement therapy; VRS = valve replacement/repair surgery.)*

### *Statistical Analysis*

Categoric data are reported as whole numbers and proportions, and continuous variables are reported as population means with the SD. Normally distributed continuous data were compared using the Student *t* test and categorical data were compared using the Pearson $\chi^2$ test. LOS and factors associated with an increased LOS were assessed using multivariable Poisson regression adjusting for the type of operation (CABG vs VRS) and patient and hospital characteristics (age, race, comorbidity, type of insurance, discharge disposition, hospital location, and bed size). Coefficients presented in the Poisson regression indicate differences in total length of hospitalization (days) between the level of categoric variables or with each 1-unit increase in the value of continuous variables (age). Because total hospital costs were right skewed, a modified Park test was performed to ascertain the best underlying distribution for analysis [12]. The results of the modified Park test were used to perform a generalized linear model analysis with an underlying gamma distribution to determine factors associated with increased cost. Model selection was based on the Akaike information criterion, and the final model