The decreasing mortality rate of pediatric congenital heart surgery has been paralleled by an ever-increasing number of adult survivors with congenital heart disease. Outnumbering pediatric congenital heart disease patients for the first time, there are an estimated 1.3 million adults with congenital heart disease in the United States.1–4 Likewise, the annual number of hospitalizations of adults with congenital heart disease has more than doubled from approximately 36,000 in 1998 to >72,000 in 2005.5 A significant proportion of these admissions address the late sequelae of previously palliated congenital heart disease, some of which require congenital heart surgery in adulthood.

Congenital heart surgery admissions comprise approximately 20% of all adult congenital heart (ACH) disease hospitalizations.5,6 It is not uncommon for these admissions to occur in pediatric hospitals, where there is surgical expertise in congenital heart disease. Despite the central role pediatric hospitals play in the surgical treatment of congenital heart disease, little is known about the outcomes of adult congenital cardiac surgical care in pediatric hospitals. Risk factors for inpatient death, including adult congenital heart (ACH) surgery admissions, are poorly described.

**Background**—Despite the central role that pediatric hospitals play in the surgical treatment of congenital heart disease, little is known about outcomes of adult congenital cardiac surgical care in pediatric hospitals. Risk factors for inpatient death, including adult congenital heart (ACH) surgery admissions, are poorly described.

**Methods and Results**—We obtained inpatient data from 42 free-standing pediatric hospitals using the Pediatric Health Information System database 2000 to 2008 and selected ACH surgery admissions (ages 18 to 49 years). We examined admission characteristics and hospital surgery volume. Of 97,563 total (pediatric and adult) congenital heart surgery admissions, 3,061 (3.1%) were ACH surgery admissions. Median adult age was 22 years and 39% were between ages 25 to 49 years. Most frequent surgical procedures were pulmonary valve replacement, secundum atrial septal defect repair, and aortic valve replacement. Adult mortality rate was 2.2% at discharge. Multivariable analyses identified the following risk factors for death: age 25 to 34 years (adjusted odds ratio [AOR], 2.1; P=0.009), age 35 to 49 years (AOR, 3.2; P=0.001), male sex (AOR, 1.8; P=0.04), government-sponsored insurance (AOR, 1.8; P=0.03), and higher surgical risk categories 4+ (AOR, 21.5; P=0.001). After adjusting for case mix, pediatric hospitals with high ACH surgery volume had reduced odds for death (AOR, 0.4; P=0.003). There was no relationship between total congenital heart surgery volume and ACH inpatient mortality.

**Conclusions**—Older adults, male sex, government-sponsored insurance, and greater surgical case complexity have the highest likelihood of in-hospital death when adult congenital surgery is performed in free-standing pediatric hospitals. After risk-adjustment, pediatric hospitals with high ACH surgery volume have the lowest inpatient mortality. (Circ Cardiovasc Qual Outcomes. 2011;4:433-439.)

**Key Words:** heart defects • congenital • surgery • risk factors • mortality
The purpose of this study was to (1) characterize ACH surgery admissions in free-standing pediatric hospitals; (2) identify adjusted risk factors associated with inpatient mortality after ACH surgery; and (3) examine the extent to which adult versus total (pediatric and adult) congenital heart surgery volume is associated with adult in-hospital mortality.

WHAT IS KNOWN
- Little is known about outcomes of adult congenital cardiac surgical care in pediatric hospitals.
- Factors associated with inpatient mortality, including adult congenital heart surgery volume, are poorly described.

WHAT THE STUDY ADDS
- Inpatient death after adult congenital heart surgery is lower in free-standing pediatric hospitals with high adult congenital heart surgery volume.
- Risk factors for death after adult congenital heart surgery in pediatric hospitals include older age, male sex, government-sponsored insurance, and greater surgical complexity.

Methods
The study methods were reviewed and approved by the Institutional Review Board of Children’s Hospital Boston.

Data Source
We analyzed data from the Pediatric Health Information System (PHIS) from January 2000 through December 2008. PHIS is an administrative data base containing comprehensive inpatient data from 42 not-for-profit children’s hospitals belonging to an alliance of free-standing pediatric hospitals, the Child Health Corporation of America (Shawnee Mission, KS), which has been previously used to study clinical outcomes.15–17 PHIS contains admission data including age, sex, race, International Classification of Diseases, Ninth Revision, Clinical Modification (ICD-9-CM) diagnosis and procedure codes, insurance type, length of stay, and discharge status (discharged to home, rehabilitation facility, nursing facility, or inpatient death). Data are deidentified and undergo quality and validity checks before inclusion in the data base.

ACH Surgery Admission Selection
To identify ACH surgery admissions, we selected admissions ages 18 to 49 years with ICD-9-CM codes indicating at least 1 congenital heart surgery procedure. We excluded cardiac transplants, transcatheter interventions, and pacemaker placements if it was the sole surgical procedure coded. Our method of congenital heart surgery case selection has been previously described.18 We set our upper age limit to <50 years to minimize inclusion of acquired heart disease.

We defined “total” congenital heart surgery admissions as adult and pediatric congenital heart surgery admissions; that is, all congenital heart surgery admissions from ages 0 to 49 years. To create the total congenital heart surgery population, we selected admissions <18 years of age that were identified from all hospital admissions with ICD-9-CM codes indicating surgical repair of a congenital heart defect as above and added these admissions to the previously identified ACH surgery admissions (ie, ages 18 to 49 years).

Admission Characteristics
Admission characteristics examined included demographics (age, sex, and race), genetic syndrome (Down syndrome and DiGeorge syndrome), comorbidities (complicated diabetes mellitus, uncomplicated hypertension, peripheral vascular disease, chronic lung disease, and depression),19 and admission day of the week (weekend or weekday). Payer status was categorized into government-sponsored (Medicare, Medicaid, Title V, or other government) or non–government-sponsored (private, self pay, or other) insurance.

We used the surgical risk categories of the Risk Adjustment for Congenital Heart Surgery-1 (RACHS-1) method as an exploratory effort to adjust for surgery case complexity. RACHS-1 is a consensus-based risk-adjustment tool developed to compare in-hospital death of pediatric patients undergoing congenital heart surgery20 that has been previously applied to an adult congenital cardiac population.10 This method assigns congenital heart surgery cases to 1 of 6 risk categories, based on the presence or absence of specific diagnosis and procedure codes, whereby category 1 has the lowest risk of death and category 6 the highest. In this study, surgical risk categories 4 through 6 were combined because of the paucity of category 5 and 6 cases; this category was labeled category 4+. Cases with combinations or multiple cardiac surgical procedures were placed in the category corresponding to the single highest-risk procedure.

Adult and Total Congenital Heart Surgery Volume Categories
ACH surgery volume was defined as the mean annual surgery volume; that is, the number of ACH surgery admissions divided by the number of years these surgeries were performed by each hospital over the 9-year period (January 1, 2000, to December 31, 2008). ACH surgery volume was modeled as a categorical variable defined as low (<10 admissions), medium (10 to 19 admissions), or high (≥20 admissions), with cut-points chosen to ensure adequate distribution of admissions in each category.

Total congenital heart surgery volume was defined as the mean annual number of adult and pediatric congenital heart surgery admissions for each institution. Total congenital heart surgery volume was modeled as a categorical variable defined as low (<200 admissions), medium (200 to 399 admissions), or high (≥400 admissions).

Main Exposures
Our main exposures were (1) clinical and demographic admission characteristics and (2) adult and total (adult and pediatric) congenital heart surgery volume in pediatric hospitals.

Main Outcomes
The main outcome of interest was inpatient death during ACH surgery admissions.

Statistical Analysis
We estimated unadjusted in-hospital mortality rates according to baseline admission characteristics (age, sex, race, genetic syndromes, comorbidities, surgical risk category, and insurance status). We calculated 95% confidence intervals (CI), using the exact binomial method. We examined bivariate and multivariate relationships between death and these baseline patient-level admission characteristics using generalized estimating equations models, which account for the correlation among different admissions within the same hospital. Odds ratios and 95% CI were estimated.

We fit a multivariable model (model 1) using forward selection; only admission characteristics found to be significant (P<0.05) by the likelihood ratio test were retained in the final model. A second multivariable model (model 2) explored potential confounding by adult or total congenital hospital surgery volume by including volume in the previously developed model. Binary covariates for medium and high volume were introduced into the model; low volume was used as the reference group. The added discrimination attributed to congenital surgery volume was measured by an increase in the c-statistic.

Results
Admission Characteristics
Among the 42 free-standing pediatric hospitals in the PHIS data base, 39 performed ACH surgery. Between 2000 and...
In our second logistic regression model including ACH surgery volume (model 2, Table 3), we found that pediatric hospitals with high ACH surgery volume had a lower risk for inpatient death (adjusted odds ratio, 0.4; 95% CI, 0.2 to 0.7) compared with pediatric hospitals with low ACH surgery volume. The addition of ACH surgery volume modestly improved the discriminatory power of the multivariable model, with an increase in the c-statistic from 0.749 to 0.769. This indicates that although ACH surgery volume is predictive of adult death in pediatric hospitals, admission-level variables appear to have greater importance. The addition of adult surgery volume to the model also resulted in government insurance becoming nonsignificant and illustrated only a trend toward increased death for patients with government-sponsored insurance. We found no association between total (adult and pediatric) congenital heart surgery volume and risk for death.
and ACH surgery deaths after adjustment for admission-level risk factors (Figure 4).

**Discussion**

In this study of ACH surgery admissions among pediatric hospitals, we identified older adults, male sex, higher surgical complexity, and government-sponsored insurance as risk factors for in-hospital death. Additionally, we demonstrated that although ACH surgeries performed in pediatric institutions have an overall low mortality rate, higher ACH surgery volume was associated with a significantly lower risk for adjusted inpatient mortality rates among these pediatric hospitals. These findings were robust to adjustment for admission-level risk factors including clinical characteristics and surgery case complexity.

Our study findings are consistent with and extend the current literature regarding ACH surgery admissions and suggest that death rates might be altered by specific patient-level admission characteristics. To our knowledge, this is the first study to relate ACH surgery volume to inpatient mortality and suggests that this systems-level characteristic is an important risk factor for death after ACH surgery in pediatric hospitals. Our unadjusted mortality rate of 2.2% is comparable to mortality rates reported in other studies on ACH surgery (1.5% to 7.6%)\(^{13,14,20–26}\) and ACH surgery specifically performed in pediatric institutions (1.5% to 6%).\(^{8–12,27}\)

**Risk Factors for Inpatient Death Among ACH Surgery Admissions**

Admission characteristics that were predictive of in-hospital death were older adults, male sex, and surgical complexity.
Previous studies have also found older adults to be an independent risk factor for surgical death in the ACH population.\textsuperscript{23,26} We found that male sex confers an 80\% increased likelihood of death compared with women after ACH surgery. In contrast, female sex has been associated with increased risk of death after cardiac surgery and worse perioperative morbidity in the pediatric congenital and adult cardiology literature.\textsuperscript{28–32} The adverse effect of male sex on ACH surgical death may reflect sex differences in ACH disease that modify traditional risk factors for perioperative death\textsuperscript{33} or sex-related referral bias. We showed that greater-complexity congenital surgeries are associated with higher rates of inpatient death, similar to pediatric congenital heart surgery.\textsuperscript{18,34–36}"

**ACH Surgery Volume in Pediatric Hospitals**

Pediatric hospitals with high adult volume had the lowest mortality rate after adjusting for case mix. Interestingly, we found that an institution’s ACH surgery volume was predictive of adult mortality rate in pediatric hospitals but not the total congenital heart surgery volume (ie, pediatric and ACH surgery volumes). Improved outcomes may be the result of greater clinical familiarity and experience in the care of the ACH patient rather than with congenital heart disease in general. Our study focusing on pediatric hospitals appears to be one of the first to specify surgery volume as ACH volume rather than an institution’s overall congenital heart surgery volume as a clinically relevant predictor of inpatient death in pediatric hospitals.

**Insurance Status, Referral Patterns, and Inpatient Death**

Our finding that government-sponsored insurance is a risk factor for death after ACH surgery is consistent with existing data in the pediatric congenital cardiac literature.\textsuperscript{37} In the final multivariable model that included ACH surgery volume, government-sponsored insurance was no longer a significant risk factor for death, indicating that government insurance was confounded by low hospital volume. Closer examination revealed that the low volume/high mortality pediatric hospitals had a larger proportion of adult patients with government insurance compared with high volume/low mortality pediatric hospitals. This finding reinforces existing data on health care disparities showing decreased use of high volume/low mortality hospitals by patients who lack private or fee-for-service insurance for a variety of procedures including cardiac surgery.\textsuperscript{38–40}
Limitations
Despite the strengths of our methodology and the consistency of our findings, our study also had limitations. Administrative data provide limited clinical information and may not have captured other important risk factors for death. Despite the limitations inherent to administrative data, our findings are consistent with prior studies; for example, our case mix is consistent with descriptive studies characterizing the frequency of adult congenital cardiac surgery case mix, and our mortality rate was also consistent with prior reports.8–12,27 It is also important to note this was a study of free-standing pediatric hospitals and outcomes of ACH surgery admissions in these pediatric hospitals cannot be generalized outside of this hospital setting or other data bases. Despite the relatively small numbers studied in this report, we were able to establish statistical significance of our findings.

Different authors have used various strategies to examine case complexity, including the RACHS-1 method used in this study.10,26,35,41–47 Although the RACHS-1 risk categories performed well in its discriminatory ability with regard to mortality rates among ACH surgical admissions, these categories were not specifically designed for ACH surgery admissions. As mentioned, this risk-adjustment method groups many types of diagnoses and procedures into these categories according to case complexity, and this categorization should be revisited in future work. At present, however, there is no universally agreed-on method of risk adjustment for surgical case complexity in the ACH surgery population. Although this method was effective and instructive, a specific risk adjustment tool for ACH surgery is needed.

Future Directions
The association between ACH surgery volume and inpatient death is a starting point for further research on potential regionalization of ACH surgical care. Future comparative studies could involve analyses of adult versus pediatric hospitals focusing on systems-level processes that could account for institutional differences in outcome. Both types of these studies, however, would benefit from a congenital heart surgical risk adjustment method specific for ACH surgery admissions. Last, inpatient death represents only one, somewhat crude, measure of quality of care, and future outcomes to consider should include complications and resource utilization.

Conclusion
The mortality rate for adults undergoing congenital heart surgery in pediatric hospitals is low. Within these studied pediatric hospitals, older ACH patients, male sex, government-sponsored insurance, and higher surgical case complexity categories have the highest likelihood for inpatient death. After risk adjustment, pediatric hospitals with high ACH surgery volume have the lowest inpatient mortality rates compared with pediatric hospitals with low adult volume. These findings may have implications on patient referral patterns and suggest that mortality rates after ACH surgery possibly could be reduced among pediatric hospitals by mandated referral to high-volume centers.

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Disclosures
None.

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