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Original Article

A Retrospective Analysis of the Variability in Case Duration for Aortic Valve Replacement and Association With Hospital Facility Types

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Objective: Currently, there are no large-scale studies that compare differences in case duration of aortic valve replacements (AVRs). The primary objective of this study was to determine associations of hospital facility type, geographic location, case volume per year, and time of day with duration of valve replacement surgery.
Design: Retrospective.
Setting: Data from the National Anesthesia Clinical Outcomes Registry.
Participants: National data from university and non-university hospitals.
Interventions: No interventions.
Measurements and Main Results: All AVRs from the National Anesthesia Clinical Outcomes Registry were identified from 2010 to 2014. Mean case duration for all AVRs was 360.8 $\pm$ 95.8 minutes and was presented based on facility type (university hospital, large community hospital, medium-sized community hospital, and other); US geographic region; time of day (cases performed after 5 pm and before 7 am *v* day shift); and case volume per year. A multivariable linear regression model was built to determine the association of various patient, procedural, and facility characteristics with case duration. University hospitals were associated with increased case duration for AVRs ($p < 0.0001$).
Conclusions: With this large national database, the authors demonstrated that academic hospitals, time of day of the surgery, US region, and case volume per year for a facility are related to the case duration of AVRs.

Key Words: aortic valve replacement; efficiency; duration; anesthesia; scheduling

SURGICAL REPLACEMENT of heart valves remains a common and effective procedure for severe valvulopathy.[1] Operating room time for cardiac surgery is an important efficiency metric in any hospital, given that these procedures account for a significant proportion of institutional revenue. Inefficiencies in this metric may incur significant costs.[2–4] Operating room time may be categorized into the following 3 components: anesthesia control, surgical control, and turnover time.[5,6] Anesthesia control time is defined as time from operating room entry until anesthesia induction is complete

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and surgical preparation begins and the time from the end of the surgical procedure until the patient exits the operating room.[7] Surgical control time is defined as the time when surgical preparation begins to when the surgery ends (ie, incision is closed and the dressing is applied).[8]

Developing statistical models aimed at improving the prediction of case duration for cardiac surgeries is essential for optimizing operating room efficiency. A recent study by Wu et al, which used aortic valve replacement (AVR) case data from a single institution, attempted to create a model for estimating surgical time from the historic average of each surgeon's surgical times.[9] However, predictive models developed at single institutions may not translate well to other institutions due to variability in anesthesia, surgical, and institutional practices. Additional variability is introduced by the existence of different types of hospital facilities, including university hospitals, large community hospitals, small community hospitals, and specialty hospitals, each with their own unique workflows, resources, and patient populations. Currently, there are no large-scale studies that compare differences in case duration of AVR surgeries at these different types of hospital facilities. Identifying the variability of case duration for cardiac surgery at different facility types is important to better understand unique financial and resource utilization issues at these locations and to help facilities benchmark their performance against other comparable institutions.

In this retrospective study, the authors investigated AVR case data from the National Anesthesia Clinical Outcomes Registry (NACOR) from 2010 to 2014 and compared case duration at different facility types, US regions, time of day, and case volume per year. The primary objective of this study was to describe variability of case duration of AVRs based on hospital facility types, particularly comparing the duration of surgeries performed at university hospitals versus non-university centers, along with other factors that may affect case duration.

Material and Methods

NACOR is a voluntary submission registry that was created with the goal of sharing anesthesia-related data and outcomes to evaluate the quality of care both nationally and locally.[10] Data for this study were collected from January 1, 2010, to December 31, 2014, from the Participant User File 2010 to 2014. Because the database is deidentified, it meets the criteria of the Health Insurance Portability and Accountability Act to protect personal information and was exempt from the consent requirement by the authors' institutional review board.

All AVRs were identified from the database by using surgical Common Procedural Terminology (CPT) code 33405. For each case, the following data were collected: case duration, the facility type, US region, time of day at case start (7:00-17:00 or 17:01-06:59), number of AVRs performed each year at that facility, American Society of Anesthesiologists physical status (ASA PS) classification score, and patient sex and age (dichotomized to ≥ 65 years old *v* < 65 years old [to characterize older patients]). Facility types included were university hospitals, large community hospitals (consisting of > 500 beds), medium-sized community hospitals (consisting of 100-500 beds), and other facility types. The "other" category consisted mainly of small community hospitals (< 100 beds) and specialty hospitals; this group was consolidated due to the relatively smaller sample size. US regions included the Northeast, Midwest, South, and West. ASA PS was dichotomized to ≥ 4 versus ≤ 3. Case volume per year was categorized into 4 groups based on the interquartile range of that population. Of note, some facilities incorrectly reported the time of day a case started (ie, all cases at this facility were documented to start at 0:00; therefore, these cases were treated as "unknown" start time. Case duration was defined based on the reported billed interval between the anesthesia start and stop times. The case duration therefore represents a composite of the surgical and anesthesia control times.

Once the cases were identified, all cases with missing case duration, facility type, and US region were removed from the analysis. Furthermore, to account for extreme cases, all cases with duration less than the lower 5% and duration greater than the upper 95% were removed. In addition, all cases from facilities that reported < 10 AVRs were removed because the study reports the mean and standard deviation of case duration at each facility. Furthermore, all AVRs that included an additional major cardiac surgery performed during the same encounter were removed by eliminating cases with additional CPT codes associated with coronary artery bypass grafts, aortic root repair/replacement, aortic repair, or other valve surgeries (ie, mitral valve, tricuspid valve, pulmonic valve). Figure 1 illustrates the inclusion and exclusion criteria for the sample population.

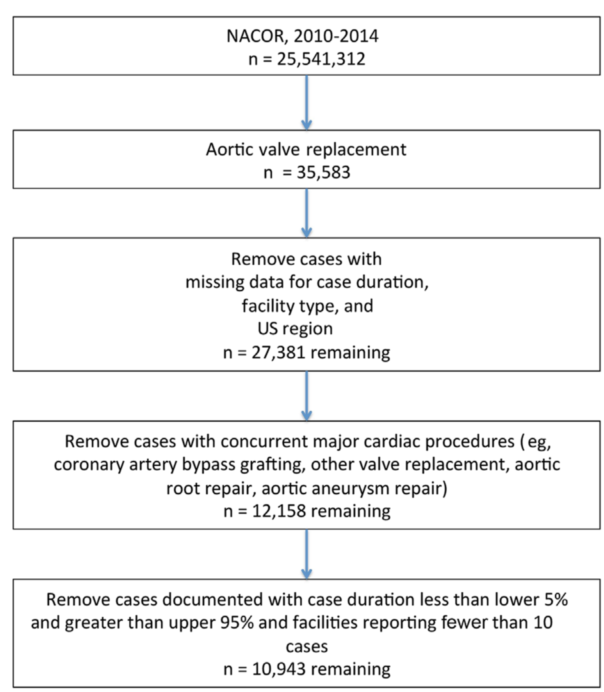

Fig 1. Flow diagram illustrating the methodology of inclusion and exclusion of the final dataset.

The primary objective of this study was to describe the variability of case duration of AVRs based on hospital facility types, particularly comparing the duration of surgeries performed at university hospitals versus non-university centers. Case duration is defined in NACOR as the time from the recorded anesthesia start to the anesthesia stop time. Other important objectives were to compare how case duration varies based on US region, time of day of case start, and hospital case volume.

R, a software environment for statistical computing (R version 3.3.2), was used to perform all statistical analyses. A histogram was created, which illustrated the frequencies of case distribution across the entire sample. In addition, the mean and standard deviation of case duration for each facility were calculated and the results were plotted. The mean and median case duration of AVRs for each variable were illustrated via box plots. Welch's 2-sample *t*-test was calculated to determine statistical significance between one group to the reference group. The reference groups chosen were university hospitals, case volume per year in the first interquartile range, Northeast US region, and cases performed during the day shift. University hospitals were chosen as the reference variable because one of the primary objectives of the study was to compare AVR case duration at academic centers versus nonacademic centers. Multivariable linear regression models were built to calculate case duration for AVR. For these models, case duration (min) was treated as the response variable. Covariates included in the model were facility type, US region, time of day of case start, case volume per year, age, sex, and ASA PS class. These covariates were decided a priori to be important in their association with case duration and therefore were forced into the model. Results are reported as odds ratio and its associated 95% confidence interval. Given the large sample size and multiple comparisons, a p value < 0.0001 was considered to be statistically significant. The adjusted R^2 of the model was calculated to determine the proportion of total variance of case duration explained by the model.

Results

From January 1, 2010, to December 31, 2014, NACOR contained 25,541,312 cases, of which 37,048 were AVRs, as indicated by the surgical CPT code. After exclusion criteria were met, 10,943 cases were included in the final analysis (most of the cases removed were due to the presence of concurrent major cardiac surgeries during the same encounter). There were 92 different facilities reporting data, in which 15 were university hospitals, 23 were large community hospitals, 49 were medium-sized community hospitals, and 5 were classified as "other." Table 1 lists the patient, case, and facility characteristics of the AVR patients. Most cases represented in NACOR were from medium-sized hospitals (57.3%), from the South (35.6%), were males (62.6%), and were ≥ 65 years old (69.2%). The mean number (standard deviation) of AVR procedures performed among all facilities was 118.9 (167.4). For university hospitals, large community hospitals, medium-sized community hospitals, and other facilities, the mean number (standard deviation) of AVR procedures performed were 140.9 (205.5), 102.5 (123.2), 128.0 (179), and 40.4 (54.2), respectively.

Table 1
Demographics of Cases in Analysis

	AVR	
	n	%
Total	10,943	-
Facility type		
University hospital	2,113	19.31
Large community hospital	2,358	21.55
Medium-sized community hospital	6,270	57.30
Other facility type	202	1.85
US region		
Northeast	2,833	25.89
Midwest	2,318	21.18
South	3,893	35.58
West	1,899	17.35
Time of day		
7:00-17:00	9,200	84.07
17:01-6:59	1,685	15.40
Unknown	58	0.53
Case volume per year*		
1st quartile	2,850	26.04
2nd quartile	2,689	24.57
3rd quartile	2,721	24.87
4th quartile	2,683	24.52
ASA PS classification score		
< IV	2,704	24.71
≥ IV	7,116	65.03
Unknown	1,123	10.26
Sex		
Female	3,736	34.14
Male	6,845	62.55
Unknown	362	3.31
Age group		
< 65 yr	3,232	29.53
≥ 65 yr	7,568	69.16
Unknown	143	1.31

*1st quartile: ≤ 29.8 cases per year, 2nd quartile: > 29.8 and ≤ 60.2 cases per year; 3rd quartile: > 60.2 cases per year and ≤ 97.0 cases per year, 4th quartile: > 97.0 cases per year.

The mean case duration (standard deviation) of all AVRs in the final analysis was 360.8 minutes (95.8). The median case duration was 344.0 minutes (25%-75% interquartile range of 290.0-413.5 min). Figure 2 illustrates the distribution of case duration via a histogram among all cases. The variability of mean case duration differed in each facility participating in NACOR as illustrated in Figure 3. Eleven facilities (73.3%) associated with a university hospital demonstrated a mean case duration above the overall mean. Figure 4 illustrates differences in case duration of AVRs based on facility type, US region, time of day of case start, and facility case volume per year. Compared with all other facility types, university hospitals had the longest case duration (mean 390.3, standard deviation 100.3 min) compared with large community hospitals (mean 362.7, standard deviation 97.6 min), medium-sized community hospitals (mean 351.0, standard deviation 91.6

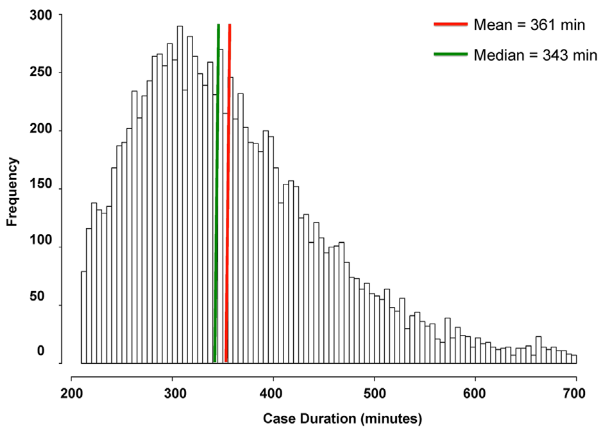

Fig 2. Histogram illustrating the various frequencies of case duration of AVRs in the NACOR dataset.

min), and other facilities (mean 334.2, standard deviation 85.5 min) ($p < 0.0001$ for all comparisons). AVRs performed in the West had the longest mean case duration (mean 376.9, standard deviation 104.5 min). AVRs performed during the time period of 17:01 to 06:59 had a longer mean case duration than those performed during the day (366.5 min [standard deviation 97.2 min] *v* 358.4 min [standard deviation 93.6 min], $p = 0.001$). The mean case duration (standard deviation) for AVRs performed in facilities with case volume per year in the first quartile was 355.4 (98.5) minutes, in the second quartile was 364.6 (101.1) minutes, in the third quartile was 367.8 (85.0) minutes, and in the fourth quartile was 355.7 ± 97.1 minutes.

A multivariable linear regression model was built to determine the association of various patient, procedural, and facility characteristics with that of case duration for AVRs (Table 2). In summary, when adjusting for multiple factors, university hospitals, US region, ASA PS class, and time of day of case start were associated with longer case durations for AVRs. The most significant differences were seen with facility type, in which university hospitals were associated with longer case durations. The adjusted R^2 for the linear model was 0.09.

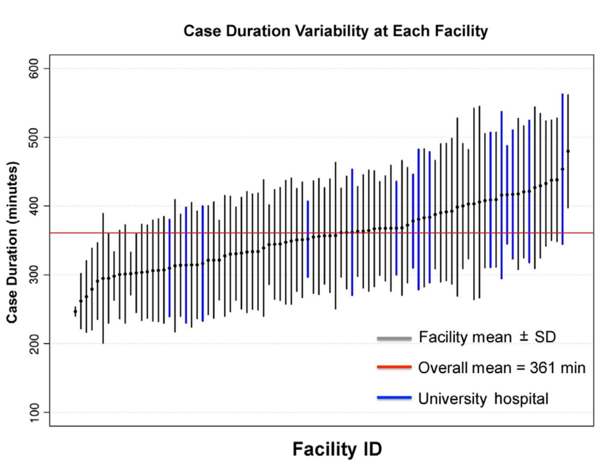

Fig 3. Plot illustrating the mean and standard deviations AVR case duration at each facility in ascending order.

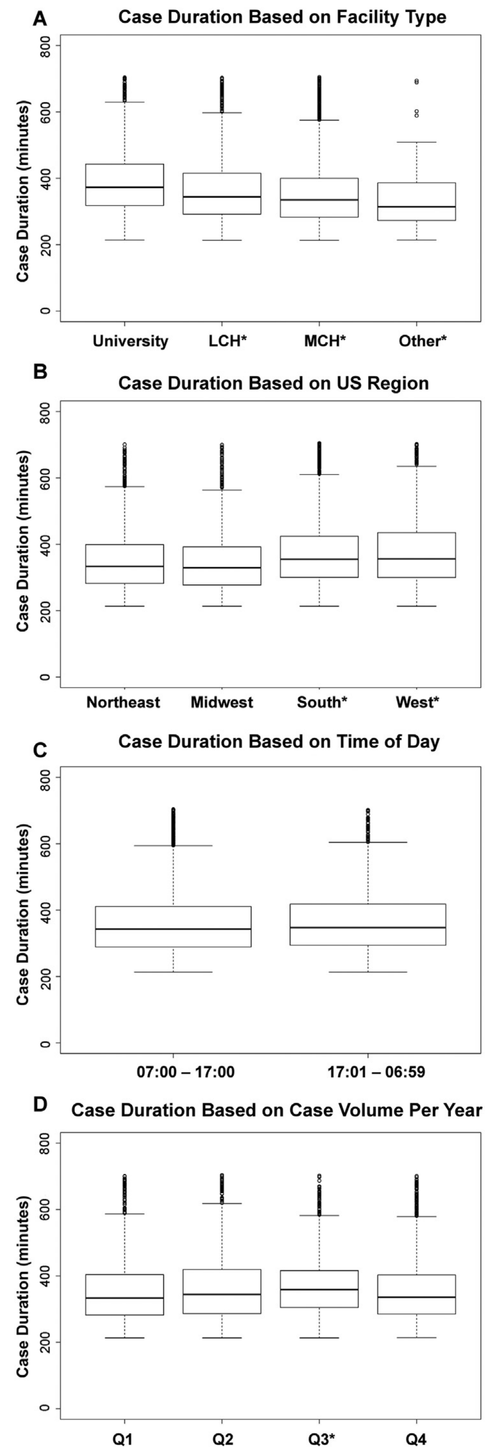

Fig 4. Box plots illustrating the mean/median case duration of AVRs categorized by (A) facility type, (B) US geographic region, (C) time of day of procedure start, and (D) AVR volume per year. *Statistically different from reference group ($p < 0.0001$). LCH, large community hospital; MCH, medium-sized community hospital; Q1-Q4: interquartile ranges 1-4.

Discussion

In this retrospective analysis of AVRs from the NACOR dataset, variability of case duration based on facility type (ie, university hospitals or community hospitals); US region; time

Table 2
Results of Multivariable Linear Regression Model for Estimation of Case Duration for AVR

	Multivariable Linear Regression			
	Estimate	95% CI		p Value
(Intercept)	356.00	348.06	363.93	< 0.0001
Facility type				
University hospital	Reference			
Large community hospital	–30.58	–36.76	–24.41	< 0.0001
Medium-sized community hospital	–34.94	–40.15	–29.73	< 0.0001
Other facility type	–58.36	–72.48	–44.25	< 0.0001
US region				
Northeast	Reference			
Midwest	–2.69	–8.19	2.80	0.34
South	24.41	19.70	29.11	< 0.0001
West	18.82	13.29	24.35	< 0.0001
Time of day				
7:00-17:00	Reference			
17:01-6:59	19.52	14.53	24.52	< 0.0001
Case volume per year*				
1st quartile	Reference			
2nd quartile	3.40	–1.84	8.64	0.20
3rd quartile	10.95	5.93	15.96	< 0.0001
4th quartile	–14.93	–20.30	–9.56	< 0.0001
ASA PS classification score				
< IV	Reference			
≥ IV	10.29	6.05	14.53	< 0.0001
Sex				
Female	Reference			
Male	17.97	14.31	21.62	< 0.0001
Age group				
< 65 yr	Reference			
≥ 65 yr	–2.40	–6.21	1.41	0.22

*1st quartile: ≤ 29.8 cases per year, 2nd quartile: > 29.8 and ≤ 60.2 cases per year; 3rd quartile: > 60.2 cases per year and ≤ 97.0 cases per year, 4th quartile: > 97.0 cases per year.

of day of case start; and case volume per year was characterized. The mean and median case duration for all AVRs was 360.8 minutes and 344 minutes, respectively. The multivariable regression analysis demonstrated that university hospitals, males, ASA PS class, and time of day surgery was performed were associated with longer case durations. However, the adjusted R^2 of the multivariable model was only 0.09, suggesting that the model only explained 9% of the variance. This finding indicates that additional factors not included in the model are associated with case duration. Despite this finding, the authors believe it is important to characterize the differences in case duration based on hospital types because this may have important implications in terms of resource and financial utilization.

An interesting finding was that university hospitals had the longest case duration compared with other facility types. There are many differences between teaching and nonteaching hospitals that may account for these findings because university hospitals tend to have a larger volume, higher acuity patients, trainees in different stages of training, and greater focus on research. Regression analysis demonstrated that the difference in case duration could be more than approximately 1 hour longer in the university hospital setting. There are many possible reasons for this association, including longer anesthesia and surgical times related to the presence of surgical and anesthesia trainees,[11–14] more complicated technical aspects of the surgical procedure at academic centers, use of newer surgical equipment, and higher patient comorbidity burden. However, previous work by Vinden et al demonstrated that even after adjusting for patient-, surgeon-, and procedural-related variables, surgeries performed at university hospitals compared with nonacademic centers demonstrated increased case duration for a variety of surgeries.[11] Due to the limited period of data incorporated into NACOR, encompassing outcomes limited to the operating room and postanesthesia care unit, the authors are unable to comment on associations between increased case duration seen in university hospitals and postoperative outcomes. However, recent work by Burke et al and others has suggested that teaching hospital status is associated with decreased mortality in a cohort of all hospitalized patients.[15–17] Additional work is needed to explore whether this association holds true for patients undergoing aortic valve surgery.

The increased duration of aortic valve surgeries in the university hospital setting may result in a challenging fiscal environment for anesthesia departments. Reimbursement for cardiac surgery cases frequently is lower than that for other surgical procedures due to the payer mix, with a predominance of Medicare patients resulting in low conversion factors. The longer case duration in the university hospital setting is unlikely to offset the decreased base units obtained from performing additional surgeries. This finding necessitates careful consideration in ongoing negotiations between anesthesia departments and hospitals regarding appropriate financial support for cardiac anesthesia coverage.[18]

In this study, significant regional differences in case duration were demonstrated when comparing the Northeast, South, West, and Midwest regions of the United States. The specific source of this variability is unclear from the data; however, the authors hypothesize that this finding could be due to cultural and regional differences in anesthetic and surgical practices.

Interestingly, there was not a linear relationship between case volume per year at a facility and case duration of AVRs. Facilities with case volume per year in the third quartile had the longest duration. It is unclear why this is occurred, although it may be related to some interaction between case volume and case complexity. Unfortunately, due to the limitations of the patient and surgical variables recorded in NACOR, the authors were unable to assess the technical complexity of the surgery or the comorbidity of patients. These data variable limitations restrict the authors' ability to better explain this association. In addition, university hospitals had the greatest overall volume of AVRs despite the longest mean surgical time. The limitations of NACOR restrict the authors' ability to explain this finding; however, the authors hypothesize that this may reflect a greater number of available cardiac operating rooms or utilization in off hours, allowing for a greater net number of cases despite longer surgical times.

Time of day the procedure was performed demonstrated a significant association with case duration. Possible explanations for this slight increase include fewer resources to aid in efficiency during after-hours, provider fatigue, complexity of cases occurring in the evening, or more medically complex patients undergoing AVR during after-hours. Previous studies have demonstrated that sleep-deprived providers, defined as those operating during after-hours, did not affect surgical efficiency, morbidity, or mortality in cardiac surgies.[19–21] Considering the potential hourly cost of operating room time and the yearly caseload, even this small increase in case duration can amount to an increase in cost of hundreds of thousands of dollars per year.[4]

Whether sex is an independent risk factor for adverse outcomes after AVR remains controversial. Several retrospective studies have noted sex discrepancies in surgical outcomes after AVR, mitral valve replacement, and coronary artery bypass grafting.[22–24] However, others have failed to find similar associations.[25–27] Multiple etiologies for these sex-specific outcomes have been hypothesized, including smaller target vessels in coronary bypass grafting and the use of smaller valve prostheses in aortic valve surgery, along with female AVR patients having a worse preoperative risk profile. In this study, the authors noted that male patients had longer case duration than did females. Due to the limitations of the NACOR data, the authors are unable to comment on the specific factors that resulted in this finding, such as a longer time on cardiopulmonary bypass, intraoperative complications, or cross-clamp time.

Even though the authors note major differences in facility types in terms of case duration for AVR, the linear model only explained a small portion of the variance. This indicates that there is a multitude of other factors not captured in this database that can explain the differences. For example, a previous sternotomy or alternative chest incisions may affect surgical time.[28] At this point, with the limitations of the NACOR dataset, the authors are only able to speculate on why certain facilities, specifically university hospitals, have longer case duration. Future studies are needed to assess for the specific factors that influence case duration at different institutions.[29,30]

There are several limitations to this study, mainly related to the retrospective design. With this large amount of national data, inevitably there are some missing or incorrectly inputted data. For example, some cases had to be removed for missing or nonsensical case duration data. Nonetheless, this is the largest anesthesia database in the United States and there are no obvious systematic errors in which facilities had more missing or invalid data. Participation in NACOR is voluntary and may represent a biased sample of facilities or practices. Because this was a descriptive case study, the authors were unable to determine cause and effect nor could they draw inferences from the presented results. Lack of data regarding case complexity, patient comorbidity burden (other than ASA PS class), and hospital efficiency variables does not allow for a more in-depth analysis. In addition, data on hospital type are defined based on the Centers for Medicare and Medicaid Services facility type and a pre-specified variable based on the total number of hospital beds. This definition precludes analysis of hospitals based solely on the number of beds dedicated to cardiac surgery patients or the total volume of cardiac surgery cases at a facility. Furthermore, the details of specific surgical techniques used at each facility are not provided, which likely also play an important role in case duration.[28] Nonetheless, this is the only study comparing differences in duration of AVRs at a national level. Regardless of the limitations, this first-of-its-kind study can be used to establish national efficiency benchmarks for AVRs that take into account a variety of facility, patient, and regional factors.

In conclusion, with this large national database, the present study demonstrates that the academic status of a hospital, time of day of the surgery, US region, and case volume per year for a facility are associated with the case duration of AVR but the cause is unknown. This is useful information for generating meaningful hypotheses in research studies and quality improvement projects investigating institutional efficiency of cardiac surgery.

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