Outcomes of major cardiac operations are not improved for black patients at black-serving institutions

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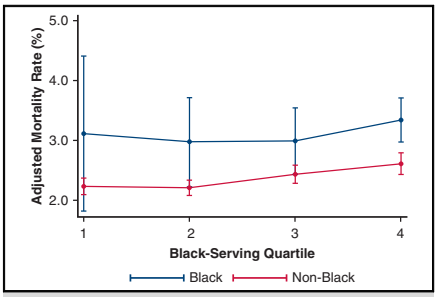
ABSTRACT

Objective: Although provider–patient racial concordance has been associated with improved outcomes among patients of Black race, it is unclear if increased representation at the institutional level is associated with the same benefits.

Methods: Adults undergoing coronary artery bypass grafting and valve operations were tabulated from the 2016-2020 National Inpatient Sample. Black-serving quartiles were generated using the annual proportion of Black patients admitted for all diagnoses. The primary end point was in-hospital mortality with Society of Thoracic Surgeons–defined major complications, postoperative length of stay, and costs as secondary outcomes. Mixed regression models were used to ascertain the association between Black-serving quartile designation and outcomes of interest; an interaction term was used to evaluate the incremental association of race and Black-serving quartiles.

Results: Of an estimated 1,203,120 patients, 7.2% were Black. After adjustment, highest Black-serving quartile hospitals demonstrated higher odds of mortality (adjusted odds ratio, 1.18, 95% CI, 1.06-1.30) and major complications (adjusted odds ratio, 1.19, 95% CI, 1.11-1.28) compared with lowest Black-serving quartile hospitals. Notably, Black patients had significantly higher mortality compared with non-Black patients at highest Black-serving quartile institutions (3.3%, 95% CI, 3.0-3.7 vs 2.6, 95% CI, 2.4-2.8), but not at the lowest (3.1%, 95% CI, 1.8-4.4 vs 2.2, 95% CI, 2.1-2.4). Black patients exhibited a stepwise increase in risk of major complication rates, postoperative length of stay, and costs with higher Black-serving quartiles.

Conclusions: Highest Black-serving quartile hospitals had worse clinical outcomes overall compared with those in the lowest Black-serving quartile. Unfortunately, Black patients had additional increased mortality, complications, postoperative length of stay, and costs at high Black-serving quartile institutions, highlighting the compounding effects of patient and hospital-level racial disparities. (JTCVS Open 2025;24:321-31)



Black patients have higher mortality rates at the highest BSQ hospitals.

CENTRAL MESSAGE

Likely because of compounding individual and systemic factors, Black patients undergoing major cardiac operations had worse outcomes at the highest BSQ institutions compared with the lowest.

PERSPECTIVE

Although provider–patient racial concordance may improve outcomes in Black patients, it is unclear if that can be extrapolated to the hospital level. We found that Black patients undergoing major cardiac operations fared worse at institutions that serve a higher proportion of such patients. Future work to determine prehospital, perioperative, and systemic barriers to healthcare access are necessary.

Prior literature has demonstrated provider–patient racial concordance to be associated with improved patient experience scores, health communication, and reduced hospital expenditures among Black patients in the United States.[1-3] Meanwhile, minority-serving institutions have demonstrated inferior outcomes for sepsis, critical care

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Abbreviations and Acronyms

AOR = adjusted odds ratio
β = beta coefficient
BSQ = Black-serving quartile
CABG = coronary artery bypass grafting
ICD-10 = International Classification of Diseases, 10th Revision
NIS = National Inpatient Sample
pLOS = postoperative length of stay
SNH = safety net hospital

admissions, and failure to rescue after cardiac surgery. Differences in resourcing and advanced patient presentations have been implicated in these inferior outcomes.[4-6] Thus, it is warranted to examine the complex relationship between patient race and minority-serving institution status for Black patients undergoing major cardiac operations.

Racial disparities continue to affect patient outcomes, resource allocation and use, and patient experience.[1,4,7] However, the majority of research examining such disparities has focused on regional or national-level populations.[8] Although these are useful to understand the scope of the issue, they do not facilitate examination of policies, determine lack of access, or incorporate hospital differences into decisions. This lack of understanding has real-world implications. For example, the Hospital Readmissions Reduction Program is meant to encourage hospitals to reduce avoidable readmissions by reducing Medicare-based payouts to poorly performing hospitals.[9] However, minority-serving institutions are nearly twice as likely to be penalized than their counterparts resulting in a tripling of their reimbursement reductions.[10] Compounded with slower than expected improvements, minority-serving institutions consistently face barriers to significant advancement.[5] Unfortunately, these institutions serve as the primary point of access for many Black patients. Therefore, we must quantify the compounding effects of interpersonal, societal, and systemic disparities for such patients at minority-serving institutions.

This was a retrospective study of the largest all-payer inpatient database in the United States and included patients receiving coronary artery bypass grafting (CABG) or cardiac valve operations. Hospitals were grouped into Black-serving quartiles (BSQs) by calculating the overall proportion of Black patients seen at each institution. An interaction term and marginal analysis were then used to determine the interrelated effects of Black race and BSQ. We hypothesized that Black patients have higher adjusted rates of mortality and major complications at both the lowest and highest hospital quartiles of Black-serving status. We also postulate, however, that these differences would be magnified for the highest quartile due to additional systemic disparities.

MATERIAL AND METHODS

The 2016-2020 National Inpatient Sample (NIS) was queried for all adult (≥18 years) elective and nonelective admissions for CABG, valve, or CABG/valve operations using International Classification of Diseases, 10th Revision (ICD-10) codes (Table E1).[11] Briefly, the NIS is managed by the Healthcare Cost and Utilization Project and is the largest all-payer nationwide inpatient database.[11] Using unique survey-weights, the NIS provides accurate estimates for approximately 97% of all inpatient admissions in the United States. Patients with a concomitant diagnosis of endocarditis or receiving same-admission heart transplant or left ventricular assist device placement were not included. Patients with missing data for death, age, sex, race, costs, or postoperative length of stay (pLOS; 6.7%) were similarly excluded from analysis (Figure 1).

Additional patient and hospital characteristics were defined per the NIS data dictionary or by relevant ICD-10 codes.[11] The van Walraven modification of the Elixhauser Comorbidity Index was used to incorporate patient comorbidity in our analysis.[12,13] Center-specific cost-to-charge ratios were applied to overall charges to obtain hospitalization costs.[14] These were then inflation adjusted to the 2020 Personal Health Index.[15] BSQs were determined by obtaining the percentage of annual admissions for all diagnoses that involved Black patients. For ease of interpretation, patients at lowest BSQ institutions were classified as *lowest*, and those managed at the highest BSQ hospitals were categorized as *highest*. Safety net burden was defined as the proportion of patients who had Medicaid insurance or were otherwise uninsured. Safety net hospital (SNH) status was subsequently assigned if an institution was in the top quartile of safety net burden.[16] Finally, the annual volume of major cardiac operations was tabulated and incorporated into analyses as a continuous variable.

The primary outcome of interest was in-hospital mortality. Secondary end points included major complication, pLOS, and costs. Major complications were defined according to current Society of Thoracic Surgeons guidelines and comprised perioperative stroke, prolonged mechanical ventilation (>96 hours), acute renal failure requiring dialysis, and reoperation.[17]

Continuous variables are presented as means with SD, or as medians with interquartile ranges if not normally distributed. Categorical variables are reported as frequencies (%). The adjusted Wald and Pearson chi-square tests were used to determine the significance of intergroup differences for continuous and categorical variables, respectively. Mixed regression models were used to determine the association of BSQ with the outcomes of interest. An interaction term incorporating BSQ and Black race was used to evaluate the marginal effects of Black race and increasing BSQ. In addition to Black race and BSQ, all regression models were adjusted for annual cardiac surgery volume, type of operation, elective case status, age, sex, primary payer, income quartile, hospital setting, hospital size, hospital region, SNH status, and Elixhauser Comorbidity Index. Regression outputs are reported as adjusted odds ratios (AORs) or beta coefficients (β) for logistic and linear regression, respectively, with 95% CIs. All statistical analyses were performed using Stata 16.1 (StataCorp). This study was deemed exempt from Institutional Review Board review by the University of California Los Angeles Institutional Review Board (IRB#17-001112 on July 26, 2017) due to use of deidentified data.

RESULTS

Of an estimated 1,203,120 patients meeting inclusion criteria, 86,900 (7.2%) were Black. A total of 1279 and 1672 hospitals were categorized as highest and lowest, respectively (Table 1). A full comparison of all BSQ quartiles is shown in Table E2. A total of 17.2% of patients were Black at highest hospitals compared with 1.2% at lowest hospitals. Patients treated at highest hospitals were younger (65 [58-72] vs 67 years [60-74], $P < .001$) and

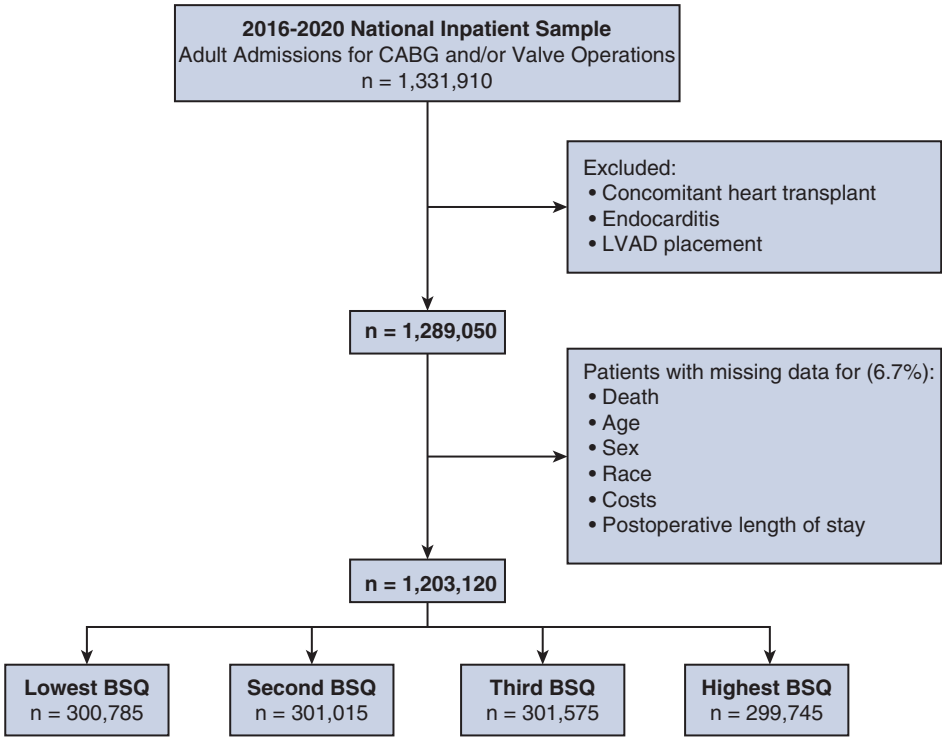

FIGURE 1. Exclusion criteria. *CABG*, Coronary artery bypass grafting; *LVAD*, left ventricular assist device; *BSQ*, black-serving quartile.

more frequently female (30.3% vs 27.3%, $P < .001$) compared with those at lowest hospitals. Patients at highest hospitals had higher rates of both private insurance (32.8% vs 29.3%) and uninsured status (7.2% vs 5.6%, both $P < .001$), but were more frequently in the bottom income quartile (34.1% vs 24.7%, $P < .001$) compared with lowest hospitals. Those at highest hospitals more frequently underwent nonelective operations (45.6% vs 43.3%, $P = .002$). At the hospital level, highest BSQ institutions were more frequently large (52.9% vs 47.9%, $P < .001$), urban teaching institutions (82.3% vs 62.1%, $P < .001$). Finally, highest BSQ institutions were more frequently in the South (64.4% vs 21.4%) and SNH (38.2 vs 16.2%, both $P < .001$). On unadjusted bivariate comparison, highest institutions had higher rates of both in-hospital mortality (2.7% vs 2.4%, $P = .003$) and major complications (6.9% vs 5.8%, $P < .001$), compared with lowest. Highest BSQ institutions had higher mean pLOS (8.0 ± 7.4 vs 7.1 days ± 5.4, $P < .001$), but lower mean costs ($53,600 ± $39,100 vs $55,500 ± $38,200, $P = .014$).

A brief comparison of Black and non-Black patients revealed Black patients to be younger (62 [55-69] vs 67 years [59-73], $P < .001$) and more frequently female (42.1% vs 27.8%, $P < .001$). They less commonly had private insurance (28.3% vs 31.8%, $P < .001$) or were otherwise uninsured (8.4% vs 5.5%, $P < .001$) compared with others (Table 2). Black patients had higher rates of in-hospital mortality (3.2% vs 2.4%, $P < .001$) and major complications (8.6% vs 6.2%, $P < .001$) on unadjusted analysis compared with their non-Black counterparts. They additionally experienced longer pLOS (8.9 ± 8.4 days vs 7.4 ± 6.3 days, $P < .001$) and incurred higher hospitalization costs ($60,600 ± $48,900 vs $54,800 ± $40,500, $P < .001$).

After adjustment with lowest BSQ status as reference, treatment at the highest BSQ institutions was associated with significantly increased odds of mortality (AOR, 1.18, 95% CI, 1.06-1.30) and major complications (AOR, 1.19, 95% CI, 1.11-1.28). Highest BSQ status was associated with increased pLOS (β +0.61 days, 95% CI, 0.46-0.76) and hospitalization costs (β +$2700, 95% CI, 1200-4100). Analysis by race, with non-Black as reference, demonstrated that Black patients had similar odds of death (AOR, 1.28, 95% CI, 0.82-2.00) and major complications (AOR, 1.05, 95% CI, 0.77-1.44). Black patients additionally incurred a similar adjusted pLOS (β +0.59 days, 95% CI, <−0.01 to +1.18) and hospitalization costs (β +$2300, 95% CI, −1300 to +5800).

Marginal analysis was then conducted using an interaction term for Black race and BSQ quartile to elucidate the combined effects of race and BSQ status. Black race was not associated with any significant differences in mortality (Black: 3.1%, 95% CI, 1.8-4.4 vs non-Black: 2.2%, 95% CI, 2.1-2.4) or major complication (Black: 6.5%, 95%

TABLE 1. Patient and hospital characteristics of adults undergoing major cardiac operation at lowest and highest Black-serving quartile institutions

Characteristics	Lowest BSQ (n = 300,785)	Highest BSQ (n = 299,745)	*P* value
Patient characteristics			
Age (y, median [IQR])	67 [60-74]	65 [58-72]	<.001
Female (%)	82,130 (27.3)	90,720 (30.3)	<.001
Elixhauser Index (median [IQR])	4 [3-5]	4 [3-5]	<.001
Race (%)			<.001
White	246,040 (81.8)	217,415 (72.5)	
Black	3685 (1.2)	51,550 (17.2)	
Hispanic	29,290 (9.7)	16,125 (5.4)	
Asian/Pacific Islander/Other	21,770 (7.2)	14,655 (4.9)	
Income quartile (%)			<.001
76th-100th	58,820 (19.6)	52,760 (17.6)	
51st-75th	76,060 (25.3)	66,050 (22.0)	
26th-50th	85,340 (28.4)	74,360 (24.8)	
0-25th	74,275 (24.7)	102,175 (34.1)	
Primary payer (%)			<.001
Private	88,175 (29.3)	98,335 (32.8)	
Medicare	172,275 (57.3)	155,865 (52.0)	
Medicaid	22,970 (7.6)	23,250 (7.8)	
Uninsured/other	16,750 (5.6)	21,725 (7.2)	
Elective case status (%)	170,415 (56.7)	163,020 (54.4)	.002
Operation (%)			.001
Isolated CABG	200,875 (66.8)	196,680 (65.6)	
Single valve	59,915 (19.9)	63,365 (21.1)	
CABG + valve	32,280 (10.7)	29,415 (9.8)	
Multivalve	7715 (2.6)	10,285 (3.4)	
Hospital characteristics	n = 1672	n = 1279	
Hospital setting (%)			<.001
Urban teaching	1038 (62.1)	1056 (82.3)	
Urban nonteaching	501 (30.0)	171 (13.4)	
Rural	133 (8.0)	52 (4.1)	
Hospital region (%)			<.001
Northeast	175 (10.5)	145 (11.3)	
Midwest	425 (25.4)	273 (21.3)	
South	357 (21.4)	823 (64.4)	
West	715 (42.8)	38 (3.0)	
Bed size (%)			.001
Large	800 (47.9)	676 (52.9)	
Medium	536 (32.1)	416 (32.5)	
Small	336 (20.1)	187 (14.6)	
SNH status (%)	270 (16.2)	489 (38.2)	<.001

IQR, Interquartile range; *CABG*, coronary artery bypass grafting; *SNH*, safety net hospital.

CI, 4.6-8.3 vs non-Black: 5.6%, 95% CI, 5.4-5.9) at lowest BSQ institutions. At highest BSQ institutions, conversely, Black race was associated with significantly higher adjusted rates of mortality (Black: 3.3%, 95% CI, 3.0-3.7 vs non-Black: 2.6%, 95% CI, 2.4-2.8) and major complication (Black: 8.9%, 95% CI, 8.3-9.5 vs non-Black: 6.6%, 95% CI, 6.3-6.9) compared with non-Black race (Figure 2, *A* and *B*). Black race was associated with increased marginal pLOS and costs at all BSQ statuses. However, the differences in pLOS (Black: 9.1 days, 95% CI, 8.9-9.3 vs non-Black: 7.8 days, 95% CI, 7.7-7.9) and costs (Black: $60,800, 95% CI, 59,800-61,800 vs non-Black: $59,400, 95% CI, 54,600-56,900) were most pronounced at the highest BSQ (Figure 2, *C* and *D*).

TABLE 2. Patient characteristics of Black and non-Black adults undergoing major cardiac operations

Characteristics	Black (n = 300,785)	Non-Black (n = 299,745)	*P* value
Patient characteristics			
Age (y, median [IQR])	62 [55-69]	67 [59-73]	<.001
Female (%)	36,560 (42.1)	309,995 (27.8)	<.001
Elixhauser Index (median [IQR])	5 [3-6]	4 [3-5]	<.001
Income quartile (%)			<.001
76th-100th	8925 (10.3)	249,200 (22.3)	
51st-75th	13,695 (15.8)	282,645 (25.3)	
26th-50th	19,535 (22.5)	298,365 (26.7)	
0-25th	43,125 (49.6)	267,590 (24.0)	
Primary payer (%)			<.001
Private	24,600 (28.3)	354,680 (31.8)	
Medicare	41,980 (48.3)	619,895 (55.5)	
Medicaid	12,770 (14.7)	78,950 (7.1)	
Uninsured/other	7340 (8.4)	61,330 (5.5)	
Elective case status (%)	39,890 (45.9)	630,595 (56.5)	<.001
Operation (%)			<.001
Isolated CABG	56,625 (65.2)	719,770 (64.5)	
Single valve	18,515 (21.3)	238,940 (21.4)	
CABG + valve	7010 (8.1)	121,360 (10.9)	
Multivalve	4750 (5.5)	36,150 (3.2)	

CABG, Coronary artery bypass grafting; *IQR*, interquartile range.

DISCUSSION

Research of race-based healthcare disparities can be challenging because of the inability to adequately deconstruct patient and hospital factors.[18] To address this, we assessed outcomes and resource use of Black and non-Black patients receiving major cardiac operations at institutions at multiple BSQs. Although highest BSQ institutions had worse outcomes and higher resource use, Black race was not independently associated with any changes in these metrics. However, we found that highest BSQ institutions were associated with higher adjusted rates of mortality and postoperative complication for Black patients compared with their non-Black counterparts. This difference was notably not seen at lowest BSQ hospitals (Figure 3). Black patients likewise had incrementally longer pLOS and higher hospitalization costs at each progressive BSQ status. These results point to a negative synergistic relationship between individual and systemic disparities that warrants further discussion.

Minority-serving institutions have been associated with poorer outcomes after critical care admission and various operations, including cardiac surgery.[4,6,18,19] It is no surprise that we found increased odds of mortality and postoperative complications for patients undergoing CABG or valve operations at the highest BSQ institutions. However, we found that for Black patients specifically, care at high BSQ institutions was associated with increases in adjusted rates of mortality and perioperative complication that were not observed at lowest BSQ hospitals. A recent study by Himmelstein and colleagues[7] found Black-serving hospitals to generate a mean loss of $17/patient/day compared with a mean profit of $126/patient/day for other institutions. To account for this deficit, per the authors, Black-serving hospitals would require an additional $14 billion in additional payments. This significant difference in hospital profit underscores the ability for these institutions to finance themselves and is likely a significant factor in their poorer outcomes. A deeper examination of institutions deemed to be high BSQ may reveal additional explanations for these results. Within our cohort, high BSQ institutions were more frequently SNH status and located in the Southern region. SNHs have been associated with higher odds of mortality and perioperative complications in type B aortic dissection, extracorporeal membrane oxygenation, and surgical aortic valve replacement.[20-22] Issues relating to inadequate resourcing and barriers to adequate pre- and posthospitalization care are often cited as reasons for these worsened outcomes.[23,24] Regrettably, patients receiving care at SNH in the South may further be affected by a lack of Medicaid expansion.[25] By having a larger proportion of uninsured patients, SNHs in these areas may bear an additional financial burden, thereby reducing the quality of care for their entire inpatient population.

As noted, provider–patient racial concordance has been associated with improved health communication and patient experience scores for Black patients.[1-3] It may be

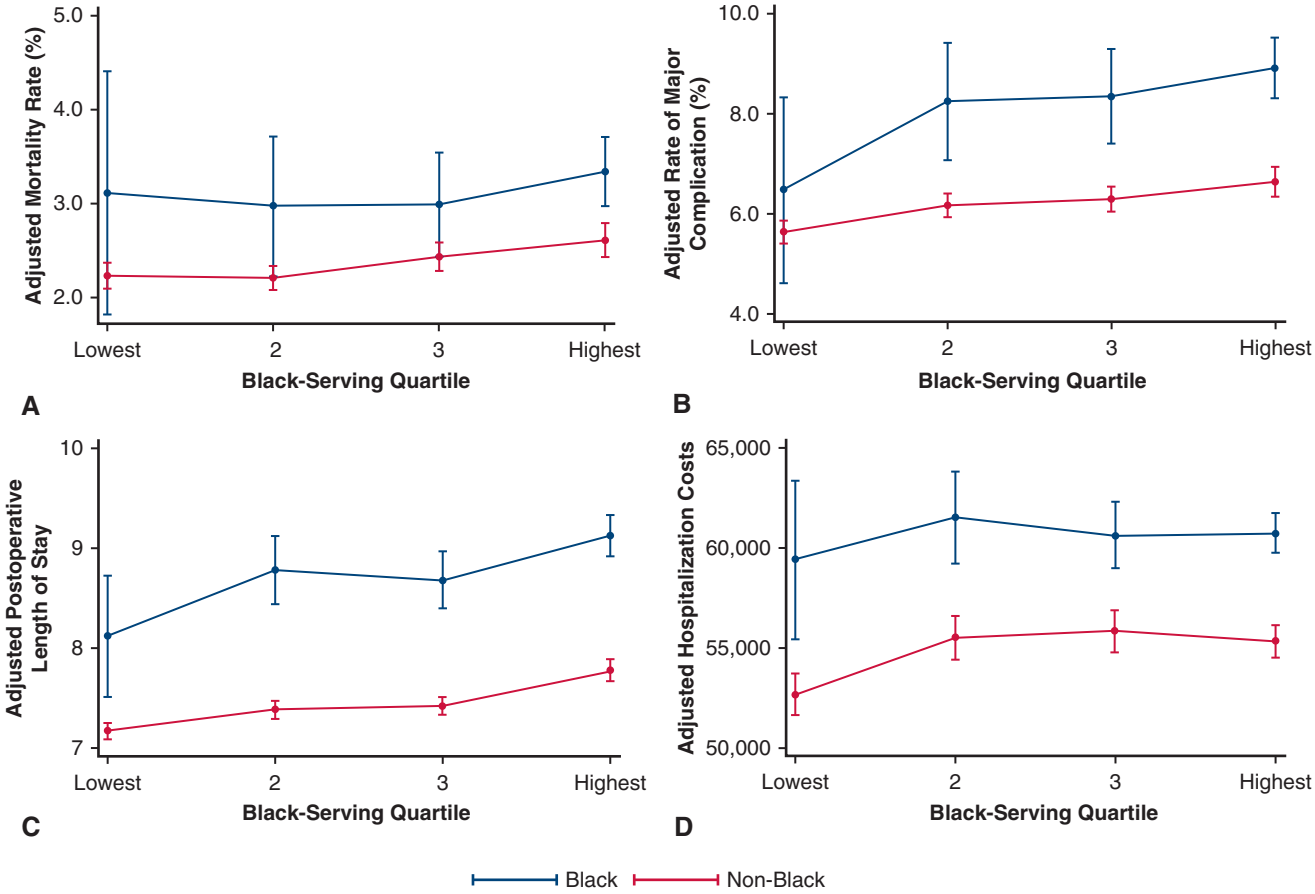

FIGURE 2. Risk-adjusted (A) mortality rate, (B) major complication rate, (C) pLOS, and (D) hospitalization costs of Black (*blue*) and non-Black (*red*) patients receiving care at hospitals in different BSQs.

reasonable, then, to assume that institutions that serve a higher proportion of Black patients may be associated with improved outcomes. However, our results confirm that this extrapolation cannot be made. First, minority-serving institutions are not necessarily those with the highest provider-patient racial concordance. Although increasing physician workforce diversity may be associated with increasing concordance, these studies represent a small proportion of the literature on overall disparities.[26] This is likely due to difficulties in obtaining race data for both providers and patients. In addition, racial self-identity and perceived racial identity are not always aligned because race is a social construct.[27] Variations in physical characteristics and racial expression, as well as the inappropriate application of culture and ethnicity to definitions of race, further complicate these studies, ours included.[28,29] Moreover, studies that examine provider–patient racial concordance are often limited to outpatient settings or when patients may otherwise have the decision-making capability to choose their provider.[2] This differs from in-hospital medicine, where emergency care necessitates the most easily available provider to care for patients. In our cohort, the operating surgeon may not be directly involved in most patient–healthcare interactions. Nursing, care extenders, physical/occupational therapists, and case management may spend more time with inpatients and further affect care disparities. Although provider diversity is necessary to improve patient well-being and representation, our results show that it alone cannot be considered adequate in fully addressing disparate outcomes among Black patients.

Finally, the relationship among patient demographics, hospital resourcing and location, and socioeconomic factors is not simple. In a significant manner, our results show that Black race was not associated with poorer outcomes independent of hospital BSQ status. A large proportion of healthcare disparities work is focused on provider racism or failures in cultural competence.[27,30] Although these issues certainly must be addressed, reframing the discussion to fully accept structural or systemic racism may improve future policy decisions.[27,31] This includes more optimal allocation of inpatient and outpatient resources; a more complete understanding of access to healthy food and

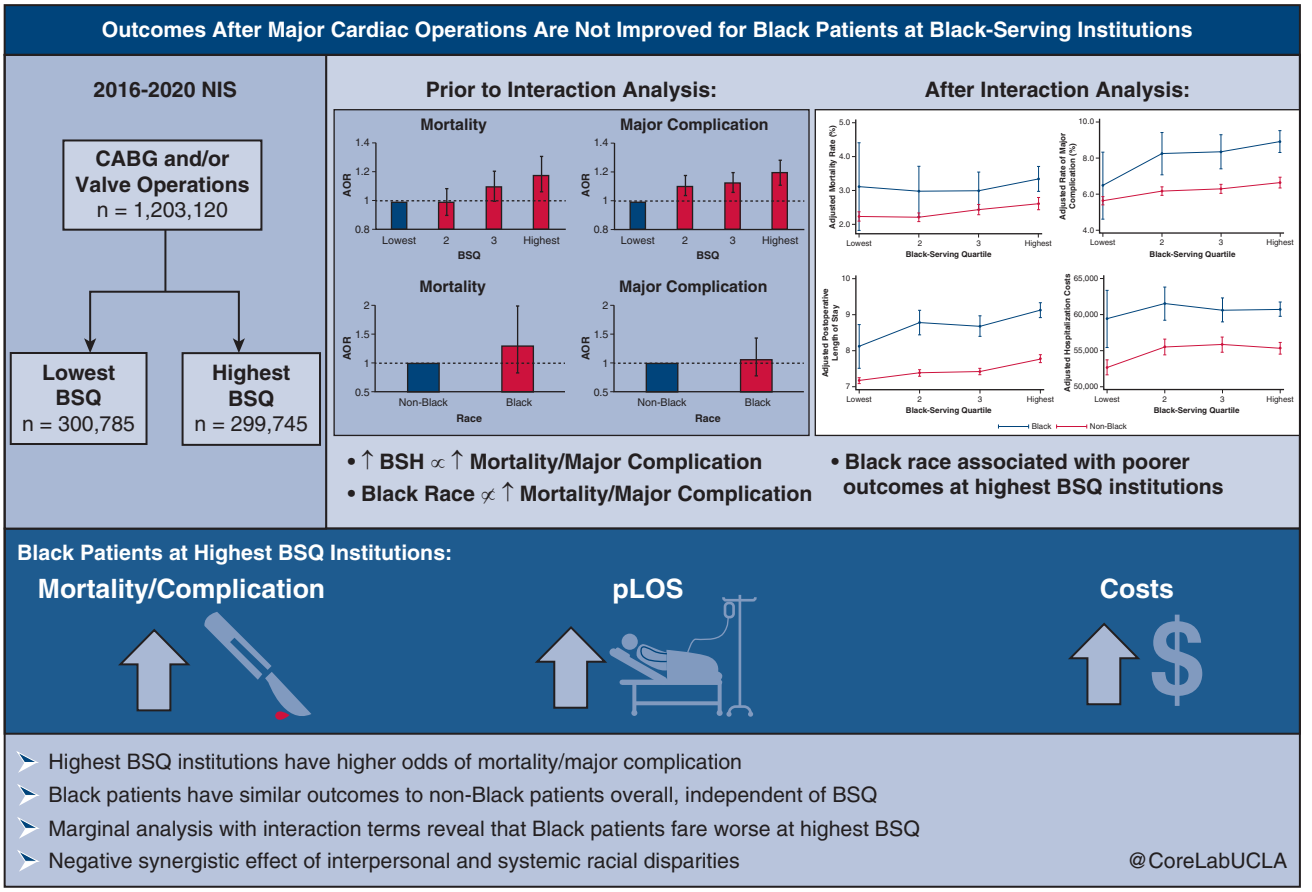

FIGURE 3. Highest BSQ institutions are associated with inferior clinical and financial outcomes compared with lowest BSQ. Conversely, Black patients have similar adjusted outcomes overall compared with non-Black patients. However, Black patients at highest BSQs have higher adjusted mortality rates than non-Black patients. This is not the case at lowest BSQs. *CABG*, Coronary artery bypass grafting; *BSQ*, black-serving quartile; *AOR*, adjusted odds ratio; *pLOS*, postoperative length of stay; *BSH*, black-serving hospitals.

non–healthcare-related services, such as gyms and parks; and incorporation of concepts such as counter-framing described in sociology.[31] From a health services standpoint, scores such as the Area Deprivation Index and the Social Vulnerability Index have been developed to more adequately incorporate systemic barriers to paid work, food, transportation, education, and healthcare.[32,33] These indices, although promising, still may not fully address the intersection of these systemic issues and patient disparities at the time of interaction with the healthcare system. As we strive for more nuanced racial disparities research, we must find ways to incorporate factors such as workforce diversity, local and federal policies, and complex racial trauma into databases or other data-collection tools.[34]

Limitations

This study has several limitations that must be discussed. The NIS is an administrative database that uses ICD-10 codes coded primarily for billing purposes. These ICD-10 codes are often imputed by medical billing specialists and may be subject to some inaccuracy. Furthermore, limited granular clinical data are present, including, but not limited to, laboratory results, vital signs, and intraoperative events. We are also not able to determine workplace diversity, hospital or governmental policy, and hospital resource allocation, which may otherwise provide context for our results. Future work incorporating State Inpatient Database data could assist with these limitations because they contain patient zip code and hospital identifiers.[35] As a result, characteristics such as area deprivation index and hospital resource allocation could be more accurately estimated. Limitations on patient and provider perceptions of race as well as measurements of explicit or implicit bias likewise could be improved by collaboration with researchers within anthropology, sociology, and other relevant social sciences. Because this is a retrospective study, we cannot determine any causal relationships. However, the use of advanced statistical techniques, such as instrumental variables, may be used in future work to strengthen causal inference.[36]

CONCLUSIONS

We found that highest BSQ institutions were associated with increased odds of mortality and perioperative complication, as well as longer adjusted pLOS and increased hospitalization costs after major cardiac operations. Although Black patients had similar mortality and perioperative complication rates as their non-Black counterparts at lowest BSQ institutions, this was not the case at highest BSQ hospitals. This increased adjusted rate of mortality and perioperative complication points to a likely compounding negative effect for such patients based on point-of-care, regional, and systemic racism. Future work to identify local or hospital-wide policies that may negatively affect Black or other patient cohorts must be conducted to ensure high-quality, equitable care.

Audio

Audio Recording: You can listen to the audio recording of the presentation and discussion associated with this paper: https://doi.org/10.1016/j.xjon.2024.11.021.

Conflict of Interest Statement

P.B. received fees from AtriCure as a surgical proctor. All other authors reported no conflicts of interest.

The *Journal* policy requires editors and reviewers to disclose conflicts of interest and to decline handling or reviewing manuscripts for which they may have a conflict of interest. The editors and reviewers of this article have no conflicts of interest.

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Key Words: cardiac surgery, health disparities, minority-serving institutions, systemic racism

TABLE E1. International Classification of Diseases, 10th Revision procedure codes of operations included for analysis

Operation	ICD-10 codes
Coronary artery bypass graft	02100*, 02110*, 02120*, 02130*
Aortic valve repair/replacement	02QF0JZ, 02QF0ZZ, 02QF4JZ, 02QF4ZZ, 02UF07J, 02UF07Z, 02UF08J, 02UF08Z, 02UF0JJ, 02UF0JZ, 02UF0KJ, 02UF0KZ, 02UF47J, 02UF47Z, 02UF48J, 02UF48Z, 02UF4JJ, 02UF4JZ, 02UF4KJ, 02UF4KZ, 02RF07Z, 02RF08Z, 02RF0JZ, 02RF0KZ, 02RF47Z, 02RF48Z, 02RF4JZ, 02RF4KZ
Mitral valve repair/replacement	02QG0JZ, 02QG0ZZ, 02QG4JZ, 02QG4ZZ, 02UG07J, 02UG07Z, 02UG08J, 02UG08Z, 02UG0JJ, 02UG0JZ, 02UG0KJ, 02UG0KZ, 02UG47J, 02UG47Z, 02UG48J, 02UG48Z, 02UG4JJ, 02UG4JZ, 02UG4KJ, 02UG4KZ, 02RG07Z, 02RG08Z, 02RG0JZ, 02RG0KZ, 02RG47Z, 02RG48Z, 02RG4JZ, 02RG4KZ
Tricuspid valve repair/replacement	02QJ0JZ, 02QJ0ZZ, 02QJ4JZ, 02QJ4ZZ, 02UJ07J, 02UJ07Z, 02UJ08J, 02UJ08Z, 02UJ0JJ, 02UJ0JZ, 02UJ0KJ, 02UJ0KZ, 02UJ47J, 02UJ47Z, 02UJ48J, 02UJ48Z, 02UJ4JJ, 02UJ4JZ, 02UJ4KJ, 02UJ4KZ, 02RJ07Z, 02RJ08Z, 02RJ0JZ, 02RJ0KZ, 02RJ47Z, 02RJ48Z, 02RJ4JZ, 02RJ4KZ
Pulmonary valve repair/replacement	02QH0JZ, 02QH0ZZ, 02QH4JZ, 02QH4ZZ, 02UH07J, 02UH07Z, 02UH08J, 02UH08Z, 02UH0JJ, 02UH0JZ, 02UH0KJ, 02UH0KZ, 02UH47J, 02UH47Z, 02UH48J, 02UH48Z, 02UH4JJ, 02UH4JZ, 02UH4KJ, 02UH4KZ, 02RH07Z, 02RH08Z, 02RH0JZ, 02RH0KZ, 02RH47Z, 02RH48Z, 02RH4JZ, 02RH4KZ

ICD-10, International Classification of Diseases, 10th Revision.

TABLE E2. Clinical Classifications Software Refined codes with associated International Classification of Disease, 10th Revision diagnosis codes used as initial model covariates for machine learning algorithms

Patient characteristics	Lowest n = 300,785	Second n = 301,015	Third n = 301,575	Highest n = 299,745	*P* value
Age (y, mean ± SD)	67 [60-74]	67 [59-74]	67 [59-73]	65 [58-72]	<.001
Female (%)	82,130 (27.3)	85,620 (28.4)	88,085 (29.2)	90,720 (30.3)	<.001
Elixhauser Index (median [IQR])	4 [3-5]	4 [3-5]	4 [3-5]	4 [3-5]	.058
Race (%)					<.001
White	246,040 (81.8)	244,715 (81.3)	237,750 (78.8)	217,415 (72.5)	
Black	3685 (1.2)	10,780 (3.6)	20,885 (6.9)	51,550 (17.2)	
Hispanic	29,290 (9.7)	25,380 (8.4)	21,570 (7.2)	16,125 (5.4)	
Asian/Pacific Islander/Other	21,770 (7.2)	20,140 (6.7)	21,370 (7.1)	14,655 (4.9)	
Income quartile (%)					<.001
76th-100th	58,820 (19.6)	76,850 (25.5)	69,785 (23.1)	52,760 (17.6)	
51st-75th	76,060 (25.3)	77,340 (25.7)	76,890 (25.5)	66,050 (22.0)	
26th-50th	85,340 (28.4)	78,850 (26.1)	79,290 (26.3)	74,360 (24.8)	
0-25th	74,275 (24.7)	63,390 (21.1)	70,875 (23.5)	102,175 (34.1)	
Primary payer (%)					<.001
Private	88,175 (29.3)	95,380 (31.7)	97,390 (32.3)	98,335 (32.8)	
Medicare	172,275 (57.3)	166,750 (55.4)	166,985 (55.4)	155,865 (52.0)	
Medicaid	22,970 (7.6)	23,385 (7.8)	22,115 (7.3)	23,250 (7.8)	
Uninsured/other	16,750 (5.6)	15,300 (5.1)	14,895 (4.9)	21,725 (7.2)	
Elective case status (%)	170,415 (56.7)	167,445 (55.6)	169,605 (56.2)	163,020 (54.4)	.018
Operation (%)					<.001
Isolated CABG	200,875 (66.8)	190,170 (63.2)	188,670 (62.6)	196,680 (65.6)	
Single valve	59,915 (19.9)	67,360 (22.4)	66,815 (22.2)	63,365 (21.1)	
CABG + valve	32,280 (10.7)	32,940 (10.9)	33,735 (11.2)	29,415 (9.8)	
Multiple valve	7715 (2.6)	10,545 (3.5)	12,355 (4.1)	10,285 (3.4)	
Hospital characteristics	n = 1672	n = 1232	n = 1197	n = 1279	
Hospital setting (%)					<.001
Urban teaching	1038 (62.1)	915 (74.3)	939 (78.5)	1056 (82.3)	
Urban nonteaching	501 (30.0)	290 (23.5)	238 (19.9)	171 (13.4)	
Rural	133 (8.0)	28 (2.2)	20 (1.7)	52 (4.1)	
Hospital region (%)					<.001
Northeas	175 (10.5)	217 (17.6)	181 (15.1)	145 (11.3)	
Midwest	425 (25.4)	369 (30.0)	351 (29.3)	273 (21.3)	
South	357 (21.4)	380 (30.8)	515 (43.0)	823 (64.4)	
West	715 (42.8)	266 (21.6)	150 (12.5)	38 (3.0)	
Bed size (%)					<.001
Large	800 (47.9)	672 (54.6)	614 (51.3)	676 (52.9)	
Medium	536 (32.1)	336 (27.3)	365 (30.5)	416 (32.5)	
Small	336 (20.1)	224 (18.2)	218 (18.2)	187 (14.6)	
SNH status (%)	270 (16.2)	214 (17.4)	230 (19.2)	489 (38.2)	<.001

IQR, Interquartile range; *CABG*, coronary artery bypass grafting; *SNH*, safety net hospital.