Predictors and In-Hospital Outcomes Among Patients Using a Single Versus Bilateral Mammary Arteries in Coronary Artery Bypass Grafting

Sohail Sareh, MD[a,b], Joseph Hadaya, MD[a], Yas Sanaiha, MD[a], Esteban Aguayo, BS[a], Vishal Dobaria, BS[a], Richard J. Shemin, MD[a], Bassam Omari, MD[b], and Peyman Benharash, MD[a,*]

The benefit of bilateral mammary artery (BIMA) use during coronary artery bypass grafting (CABG) continues to be debated. This study examined nationwide trends in BIMA use and factors influencing its utilization. Using the National Inpatient Sample, adults undergoing isolated multivessel CABG between 2005 and 2015 were identified and stratified based on the use of a single mammary artery or BIMA. Regression models were fit to identify patient and hospital level predictors of BIMA use and characterize the association of BIMA on outcomes including sternal infection, mortality, and resource utilization. An estimated 4.5% (n = 60,698) of patients underwent CABG with BIMA, with a steady increase from 3.8% to 5.0% over time (p<0.001). Younger age, male gender, and elective admission, were significant predictors of BIMA use. Moreover, private insurance was associated with higher odds of BIMA use (adjusted odds ratio 1.24) compared with Medicare. BIMA use was not a predictor of postoperative sternal infection, in-hospital mortality, or hospitalization costs. Overall, BIMA use remains uncommon in the United States despite no significant differences in acute postoperative outcomes. Several patient, hospital, and socioeconomic factors appear to be associated with BIMA utilization. **(Am J Cardiol 2020;134:41−47)**

Since the introduction of coronary artery bypass grafting (CABG) over half a century ago, the durability of various vascular conduits has been debated. With the landmark 1986 report by Loop et al on the long-term superiority of arterial conduits compared with saphenous vein grafts,[1] followed by several studies demonstrating the superiority of left internal mammary artery for bypassing lesions in the left anterior descending artery,[2,3] the use of arterial revascularization in surgical management of coronary disease has been solidified. In fact, left internal mammary artery utilization is now considered a quality metric for cardiac surgery programs across the country.[4] Nevertheless, the advantages of multiarterial revascularization remain debated, refueled with the recent publication of the ART trial demonstrating no survival benefit at 10 years with bilateral mammary artery (BIMA) use.[5] In contrast, a number of observational studies including a recent analysis of over 7,000 CABG patients by Chikwe et al, have revealed incremental survival in patients receiving multiple arterial grafts.[6] Currently, less than 15% of CABG patients in the United States receive multiarterial revascularization, with only a subset having BIMA use.[6,7] Factors associated with postoperative sternal wound infection, such as diabetes, obesity and lung disease, appear to play a major role in the decision to utilize BIMA. Although difficult to quantify, adequacy of distal run off and caliber of recipient artery are likely to influence the decision to use BIMA. The present study examined trends in BIMA utilization at the national level, as well as potential nonanatomic factors influencing the utilization of BIMA for isolated CABG in the United States.

Methods

Using the National Inpatient Sample (NIS), we identified all hospitalizations for adults (≥18 years) undergoing multivessel CABG between January 2005 and September 2015. The NIS is an all-payer, inpatient database under the Healthcare Cost and Utilization Project (HCUP) that contains data on more than 7 million hospitalizations annually. National estimates were tabulated using specific institutional trend-weights (prior to 2012) and discharge-weights (2012 to 2015) provided by HCUP.[8] Patient diagnoses and outcomes were identified using the International Classification of Diseases, Ninth Revision, Clinical Modification (ICD-9) diagnostic and procedures codes. Patients undergoing CABG with a single internal mammary artery conduit (ICD-9 code 36.15) or bilateral internal mammary arteries (ICD-9 code 36.16) comprised the *SIMA* and *BIMA* cohorts, respectively. Patients undergoing a concomitant cardiac procedure as well as those with a diagnosis of congenital heart disease, malignancy, or prior cardiac surgery were excluded.

[a]Cardiovascular Outcomes Research Laboratories, Division of Cardiac Surgery, Department of Surgery, University of California, Los Angeles, California; and [b]Department of Surgery, Los Angeles County Harbor-UCLA Medical Center, Torrance, California. Manuscript received May 4, 2020; revised manuscript received and accepted August 4, 2020.

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*Corresponding author. Tel.: (310) 206-6717; fax: (310) 206-5901.

E-mail address: Pbenharash@mednet.ucla.edu (P. Benharash).

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The primary aim of the study was to identify patient- and hospital-level factors associated with BIMA utilization. We further assessed national trends of BIMA use and postoperative outcomes including in-hospital mortality, index length of stay (LOS) and costs, prolonged ventilator requirement (>96 hours), stroke, as well as a composite variable consisting of postoperative sternal wound infection and mediastinitis (ICD-9 codes 998.59 and 519.2). Although a specific ICD-9 code for sternal wound infection is not available, ICD-9 code 998.59 has previously been validated as an appropriate proxy.[9] Patients were labeled as off-pump if there was no indication of cardiopulmonary bypass utilization (ICD-9 procedure codes 39.61 and 39.66). To account for comorbidities, the Elixhauser Comorbidity Index, a validated risk-adjustment score for administrative databases, was derived for each patient using the methodology proposed by van Walraven et al.[10] Obesity was defined via ICD-9 codes (V85.3x, and 278.00, 278.01, 278.03).

Costs were estimated using institution-specific cost-to-charge ratios provided by HCUP, and adjusted for inflation using the 2015 Gross Domestic Product Price Index. Hospitals were stratified into quartiles based on annual CABG volume utilizing at least 1 internal mammary artery conduit, with thresholds set at the 25th, 50th, and 75th percentiles for each year yielding low- *(LV)*, medium- *(MV)*, high- *(HV)*, and very-high volume- *(VHV)* centers. To preserve anonymity, the NIS employs unique hospital identifiers that are not maintained across years. Thus, volume quartiles were tabulated separately for each reporting year.

Temporal trends were analyzed using Cuzick's nonparametric test for trend, an extension of the Wilcoxon rank-sum test that allows for correction for ties.[11] Data from 2015 were not included for trend analysis given the transition of ICD coding to the tenth revision in October 2015, and thus a lack of a complete dataset for that year. Predictors of BIMA utilization were identified using a multivariable logistic regression model accounting for clinically relevant patient-and hospital factors that was optimized via Akaike and Bayesian information criteria. Univariate analysis comparing patient characteristics between the *SIMA* and *BIMA* cohorts were performed using the Adjusted Wald Test or Pearson's chi-square test as appropriate. Adjusted odds ratios with 95% confidence intervals (CI) are reported for dichotomous outcomes, while Beta coefficients are reported for continuous outcomes such as cost and hospital LOS. A p-value less than 0.05 was deemed statistically significant. Data analysis was performed using Stata software (Version 16.0, Stata Corporation, College Station, TX). This study met exemption criteria by the Institutional Review Board at the University of California, Los Angeles.

Results

Of an estimated 1,346,985 hospitalizations for multivessel CABG, 4.5% (n = 60,698) underwent BIMA grafting, with an increasing trend from 3.8% in 2005 to 5.0% in 2014 (NP-trend <0.001) (Figure 1). When clustered by NIS geographic region, the Northeast consistently exhibited a larger proportion of BIMA cases as compared with the other areas of the United States (Figure 2). Similarly, teaching hospitals exhibited the highest proportion of BIMA utilization beginning in 2006 compared with rural and urban nonteaching facilities (Figure 3). Patient and hospital characteristics among *SIMA* and *BIMA* cohorts

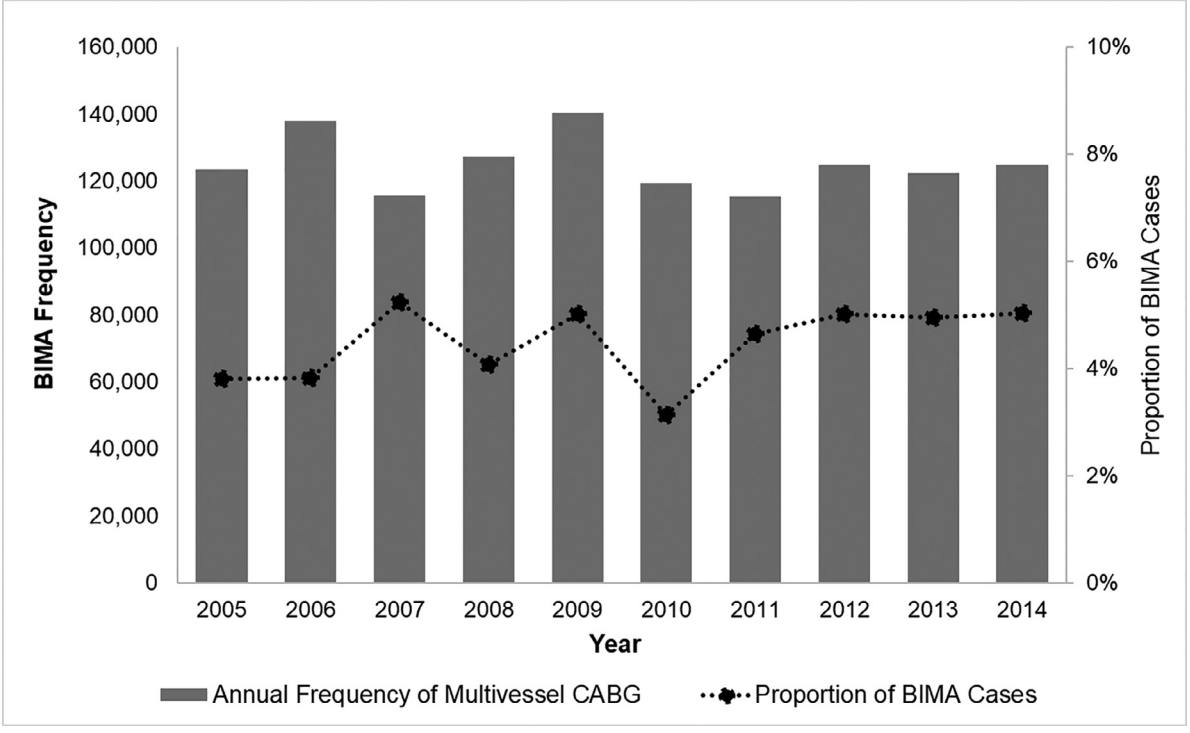

Figure 1. Incidence of bilateral internal mammary artery conduit utilization during multivessel CABG in the United States, 2005 to 2014.

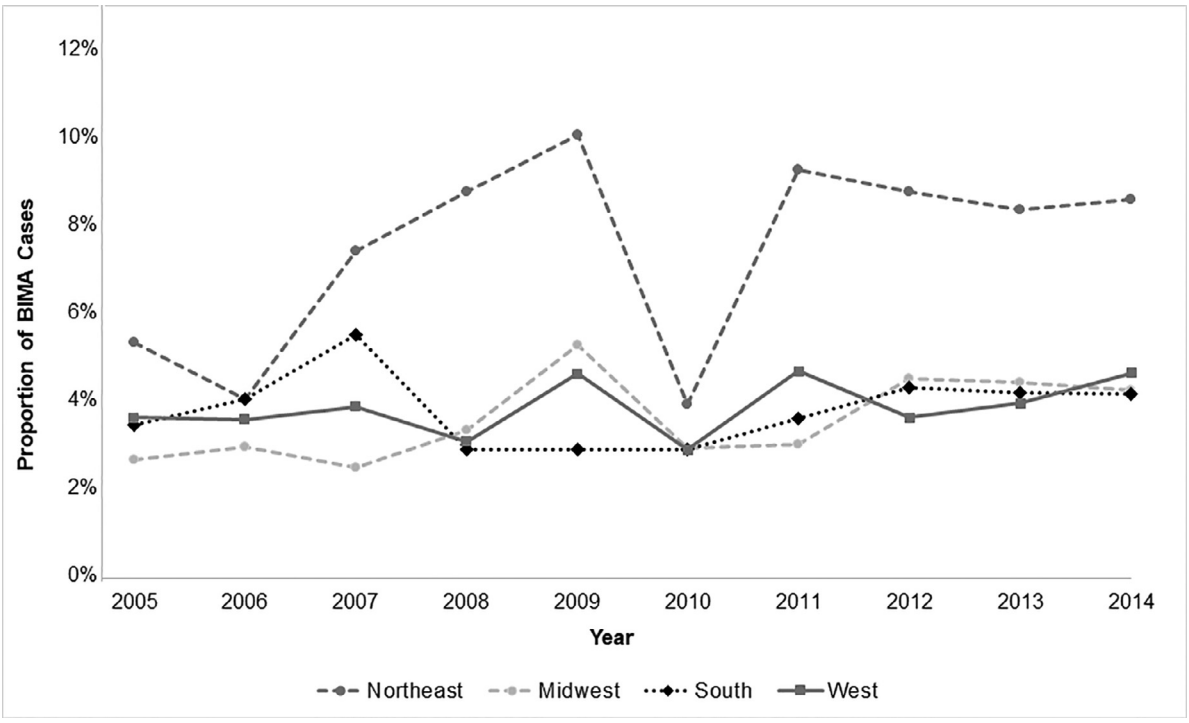

Figure 2. Incidence of bilateral internal mammary artery conduit utilization during multivessel CABG in the United States stratified by geographic region, 2005 to 2014.

are shown in Table 1. *BIMA* patients were younger, less likely to be female, and suffered from fewer comorbidities. Moreover, there were significant differences in the distribution of race, household income, and insurance status between the 2 cohorts. As displayed in Table 2, a number of predictors of BIMA utilization were identified on multivariable regression, including younger age, male gender, white race, and freedom from comorbidities such as diabetes and obesity. Furthermore, markers of low socioeconomic status, such as low-income quartile or

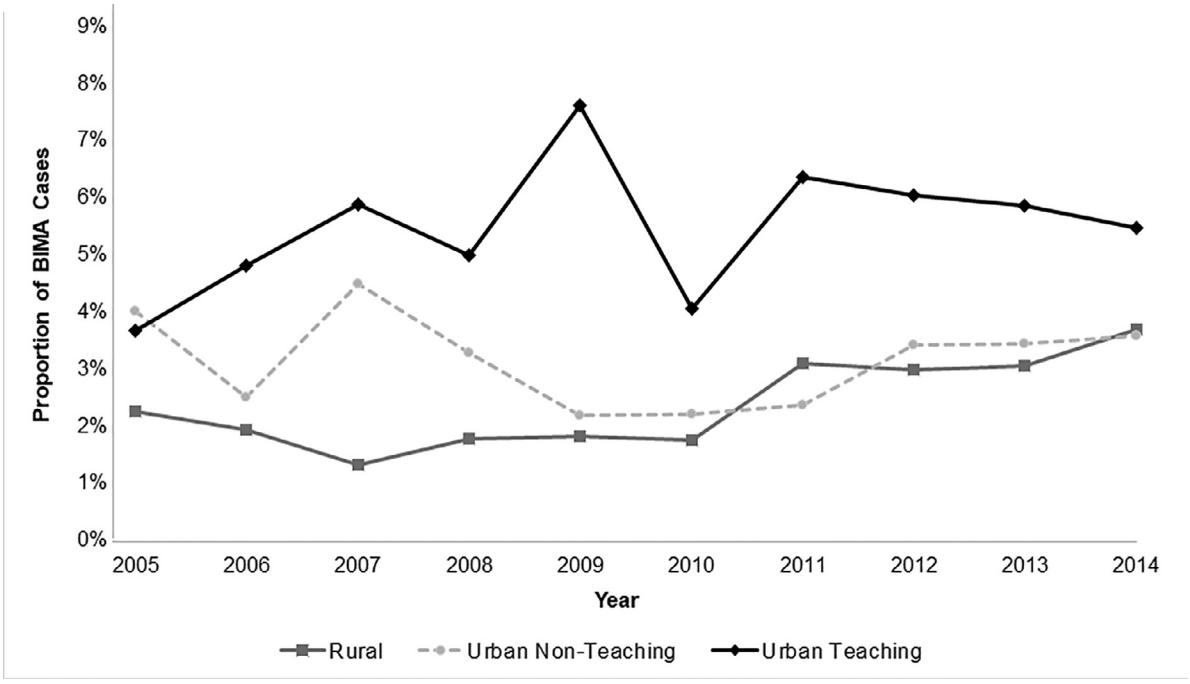

Figure 3. Incidence of bilateral internal mammary artery conduit utilization during multivessel CABG in the Unites States stratified by hospital teaching status, 2005 to 2014.

Table 1
Patient and hospital characteristics among patients undergoing multivessel coronary revascularization in the United States

Variable	*SIMA* (N=1,385,568)	*BIMA* (N=53,853)	P-Value
Age, (mean years ± SD)	65.1 ± 10.4	60.4 ± 10.5	<0.001
Women	25.9%	16.9%	<0.001
Elixhauser Comorbidity Index, (mean ± SD)	3.2 ± 1.6	2.7 ± 1.6	<0.001
Heart Failure	19.6%	12.9%	<0.001
Hypertension	77.6%	75.1%	<0.001
Peripheral Vascular Disease	10.0%	8.2%	<0.001
Chronic Obstructive Pulmonary Disease	16.6%	12.5%	<0.001
Cerebrovascular Disease	10.2%	7.7%	<0.001
Diabetes mellitus	41.1%	30.2%	<0.001
Obesity	18.2%	15.4%	<0.001
Chronic Kidney Disease 1-4	9.2%	6.4%	<0.001
End Stage Renal Disease	3.4%	1.8%	<0.001
Smoker	18.6%	20.2%	<0.001
Elective Admission	44.9%	49.5%	<0.001
Bypassed Vessels, (n)	3.4	3.7	<0.001
Cardiopulmonary Bypass Utilization	77.3%	72.6%	<0.05
Race			<0.001
White	79.2%	81.0%	
Black	6.6%	5.6%	
Hispanic	7.4%	5.8%	
Asian or Pacific Islander	2.6%	2.4%	
Native American	0.6%	0.5%	
Other	3.5%	4.7%	
Median Household Income Quartiles			<0.001
0-25th	28.0%	22.2%	
26-50th	26.9%	24.0%	
51-75th	24.2%	25.6%	
76-100th	20.8%	28.2%	
Primary Payer			<0.001
Medicare	52.1%	34.0%	
Medicaid	6.0%	5.6%	
Private Insurance	34.5%	52.3%	
Self-Pay	4.1%	4.4%	
No Charge	0.5%	0.4%	
Other	2.8%	3.2%	
Hospital Teaching Status			<0.001
Rural	3.9%	2.1%	
Urban Nonteaching	37.6%	25.7%	
Urban Teaching	58.5%	72.2%	
NIS Geographic Region			<0.001
Northeast	17.9%	30.4%	
Midwest	18.9%	15.8%	
South	46.1%	39.0%	
West	17.1%	14.9%	

BIMA = bilateral internal mammary artery; SIMA = single internal mammary artery.

Medicaid insurance status were associated with reduced BIMA utilization. Urban teaching hospitals and those in the Northeast region were also associated with BIMA use on multivariable regression.

Table 3 compares in-hospital outcomes between the *SIMA* and *BIMA* cohorts. On univariate analysis, *BIMA* patients had a significantly lower rate of in-hospital mortality, stroke, and prolonged ventilation, but no difference in rate of sternal infection/mediastinitis. Similarly, *BIMA* patients incurred a lower hospital LOS and cost. However, on multivariable regression, *BIMA* utilization only remained a predictor of stroke and prolonged ventilation (Table 4).

Discussion

The early risk and long-term value of multiarterial coronary revascularization remains a topic of ongoing deliberation. In this modern nationwide analysis, we found only a small proportion of patients receive BIMA conduits. Further, we found patient characteristics such as gender, race, and socioeconomic status to influence BIMA utilization. Importantly, our study found no significant difference in early postoperative outcomes between the 2 cohorts, inferring that BIMA use is safe during cardiac surgery. Our findings highlight variations in surgical practice that deserve further discussion.

Table 2
Predictors of bilateral mammary artery utilization during multivessel CABG in the United States

Variable	Adjusted Odds Ratio	95% Confidence Interval	P-value
Age, (per year)	0.96	0.96-0.96	<0.001
Women	0.73	0.70-0.78	<0.001
Elixhauser Comorbidity Index	0.98	0.95-1	0.10
Heart Failure	0.78	0.72-0.84	<0.001
Peripheral Vascular Disease	1.06	0.98-1.15	0.16
Chronic Obstructive Pulmonary Disease	0.89	0.82-0.95	<0.05
Cerebrovascular Disease	0.93	0.85-1.01	0.08
Diabetes Mellitus	0.66	0.63-0.70	<0.001
Obesity	0.81	0.76-0.87	<0.001
End Stage Renal Disease	0.64	0.55-0.75	<0.001
Smoker	0.86	0.81-0.90	<0.001
Elective Admission	1.24	1.16-1.32	<0.001
Cardiopulmonary Bypass Utilization	0.77	0.66-0.89	<0.001
Race			
White	1.0 (REF)		REF
Black	0.89	0.79-1.00	<0.05
Hispanic	0.84	0.72-0.98	<0.05
Asian or Pacific Islander	0.79	0.68-0.93	<0.05
Native American	0.84	0.64-1.12	0.24
Other	1.17	0.94-1.45	0.16
Median Income Quartile			
0-25th	1.0 (REF)		REF
26-50th	1.05	0.97-1.13	0.24
51-75th	1.14	1.03-1.26	<0.05
76-100th	1.28	1.11-1.46	<0.001
Payer			
Medicare	1.0 (REF)		REF
Medicaid	0.86	0.77-0.96	<0.05
Private Insurance	1.24	1.17-1.32	<0.001
Self-pay	0.97	0.85-1.10	0.62
No Charge	0.62	0.45-0.85	<0.05
Other	1.14	0.96-1.35	0.13
Hospital Teaching Status			
Rural	1.0 (REF)		REF
Urban Nonteaching	1.25	0.96-1.63	0.10
Urban Teaching	2.05	1.59-2.64	<0.001
NIS Geographic Region			
Northeast	1.0 (REF)		REF
Midwest	0.56	0.44-0.71	<0.001
South	0.56	0.44-0.73	<0.001
West	0.63	0.46-0.84	<0.05

In this study, BIMA conduits were utilized in 4.5% of patients, consistent with prior reports.[7,12] In a survey of Canadian cardiac surgeons, Mastrobuoni et al identified several barriers to BIMA use, with sternal wound infection being the strongest deterrent.[13] A number of studies have raised concerns for sternal wound infections among BIMA patients,[14,15] however more recent analyses have refuted this dogma by identifying factors such as harvesting technique—namely skeletonized arterial conduits—as eliminating the perceived infection risk associated with BIMA

Table 3
Postoperative outcomes among patients undergoing multivessel coronary revascularization in the United States

Outcome	*SIMA*	*BIMA*	P-Value
In-Hospital Mortality	1.5%	1.0%	<0.001
Sternal Infection or Mediastinitis	0.9%	0.8%	0.40
Stroke	2.0%	1.3%	<0.001
Prolonged Ventilation	2.5%	1.8%	<0.001
Hospitalization Cost	$41,214	$39,909	<0.05
Length of Stay, (Days)	9.2	8.3	<0.001

BIMA = bilateral internal mammary artery; SIMA = single internal mammary artery.

Table 4
Impact of bilateral mammary artery use on postoperative outcomes on multivariable regression

Outcome	*AOR/β**	95% Confidence Interval	P-Value
In-Hospital Mortality	1.0	0.83-1.20	0.99
Sternal Infection or Mediastinitis	0.96	0.78-1.18	0.67
Stroke	0.78	0.67-0.92	<0.05
Prolonged Ventilation	0.84	0.73-0.97	<0.05
Hospitalization Cost, ($)	702	−176 - 1,579	0.11
Length of Stay, (Days)	−0.1	−0.3 - 0.0	0.15

* AOR-*Adjusted Odds Ratio, β-* Beta coefficient. Factors included in regression models: age, gender, Elixhauser Comorbidity Index, heart failure, peripheral vascular disease, chronic obstructive pulmonary disease, cerebrovascular disease, diabetes, obesity, renal disease, tobacco use, elective admission status, race, income quartile, insurance status, hospital teaching status, NIS geographic region, and annual institutional volume quartile.

use.[6,16] In our study, postoperative sternal infection rates were not impacted by BIMA use, providing further support of the safety of BMA use.

In agreement with the existing body of literature in other operative categories, we identified significant racial and socioeconomic disparities in the utilization of BIMA across the United States. Patients identifying as Black or Hispanic were significantly less likely to undergo BIMA use compared with those identifying as White. Furthermore, patients in the highest income quartile were significantly more likely to undergo BIMA use. Rangrass et al attributed race-based differences in outcomes to a lack of access to high quality hospitals,[17] while Popescu et al noted White patients to utilize high quality hospitals more commonly irrespective of geographic proximity.[18] Increasing access to high-quality hospitals may be an opportunity to reduce healthcare expenditures and improve quality,[19] a goal that is shared among policy makers, clinicians, and patients alike.

As the largest, all-payer inpatient database, the NIS allows for assessment of practice patterns across the United States. Nevertheless, administrative databases have inherent limitations that are well established in the literature. Specific to this study, we are unable to capture preoperative coronary disease burden or the bypass target locations. As Maniar et al noted in an analysis of postoperative angiographies, target location and level of stenosis was a significant predictor of conduit patency.[20] Moreover, the NIS lacks the granular information needed to ascertain surgeon-level decision-making, and with outcomes limited to in-hospital events, we are unable to make conclusions about the long-term benefits of BIMA utilization.

In conclusion, BIMA utilization remains uncommon in the United States, despite no significant differences in acute postoperative outcomes. While it is plausible that the disparities noted in the present study stem from anatomic considerations, our findings raise concern for socioeconomic inequalities in the choice of CABG grafts that should be investigated as potential targets in improving quality and access in vulnerable patient cohorts.

Authors' Contributions

Sohail Sareh: Conceptualization, Methodology, Software, Formal Analysis, Writing-Original Draft, Visualization; ***Joseph Hadaya:*** Conceptualization, Software, Writing - Review & Editing; ***Yas Sanaiha:*** Methodology, Software, Data Curation, Writing - Review & Editing; ***Esteban Aguayo:*** Methodology, Data Curation, Writing- Original Draft; ***Vishal Dobaria:*** Methodology, Data Curation, Formal Analysis, Visualization; ***Richard Shemin:*** Conceptualization, Writing - Review & Editing, Supervision; ***Bassam Omari:*** Conceptualization, Writing - Review & Editing, Supervision; ***Peyman Benharash:*** Conceptualization, Methodology, Writing - Review & Editing, Supervision.

Disclosures

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