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Incidence of Myocardial Infarction After High-Risk Vascular Operations in Adults

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Supplemental content

IMPORTANCE Advances in perioperative cardiac management and an increase in the number of endovascular procedures have made significant contributions to patients and postoperative myocardial infarction (POMI) risk following high-risk vascular procedures. Whether these changes have translated into real-world improvements in POMI incidence remain unknown.

OBJECTIVE To examine the temporal trends of myocardial infarction (MI) following high-risk vascular procedures.

DESIGN, SETTING, AND PARTICIPANTS A retrospective cohort study was performed using data collected from January 1, 2005, to December 31, 2013, in the American College of Surgeons National Surgery Quality Improvement Program database, to which participating hospitals across the United States report their preoperative, operative, and 30-day outcome data. A total of 90 303 adults who underwent a high-risk vascular procedure—open aortic surgery or infrainguinal bypass—during the study period were identified. Patients were divided into cohorts based on their year of operation, and their baseline cardiac risk factors and incidence of POMI were compared. Cases from 2005 to 2014 in the database were eligible for inclusion if one of their *Current Procedural Terminology* codes matched any of the operations identified as a high-risk vascular procedure. Data analysis took place from August 1, 2016, to November 15, 2016.

EXPOSURES The main exposure was the year of the operation. Other variables of interest included demographics, comorbidities, and other risk factors for MI.

MAIN OUTCOMES AND MEASURES Primary outcome of interest was the incidence of POMI.

RESULTS Of the 90 303 patients included in the study, 22 836 (25.3%) had undergone open aortic surgery and 67 467 (74.7%) had had infrainguinal bypass. The open aortic cohort comprised 16 391 men (71.9%), had a mean (SD) age of 69.1 (11.5) years, and was predominantly white (18 440 patients [80.8%] self-identified as white race/ethnicity). The infrainguinal bypass cohort included 41 845 men (62.1%), had a mean (SD) age of 66.7 (11.7) years, and had 51 043 patients (75.7%) who self-identified as white race/ethnicity. During the study period, patients who underwent open aortic procedures were more likely to be classified as American Society of Anesthesiologists class IV (7426 patients [32.6%] vs 15 683 [23.3%] for the infrainguinal bypass cohort) or class V (1131 [5.0%] vs 206 [0.3%]; $P < .001$) and to undergo emergency procedures (4852 [21.3%] vs 4954 [7.3%]; $P < .001$). The open aortic procedure cohort also experienced significantly higher actual incidence of POMI (464 [3.0%] vs 1270 [1.9%]; $P < .001$). From 2009 to 2014, the incidence of POMI demonstrated no substantial temporal change (2.7% in 2009 to 3.1% in 2014; $P = .64$ for trend). Postoperative MI was consistently associated with poor prognosis, with a 3.62-fold (95% CI, 2.25-5.82) to 11.77-fold (95% CI, 6.10-22.72) increased odds of cardiac arrest and a 3.01-fold (95% CI, 2.08-4.36) to 6.66-fold (95% CI, 4.66-9.52) increased odds of mortality.

CONCLUSIONS AND RELEVANCE The incidence of MI did not significantly decrease in the past decade and has been consistently associated with worse clinical outcomes. Further inquiry into why advanced perioperative care did not reduce cardiac complications is important to quality improvement efforts.

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Major surgery is associated with increased myocardial oxygen demand and risk of coronary plaque rupture resulting in myocardial infarction (MI). Postoperative MI (POMI) occurs in 1% of the 230 million patients undergoing major surgery each year[1] and remains the leading cause of mortality and morbidity in patients undergoing vascular surgery,[2,3] with a reported incidence ranging from 5% to 20%.[4,5] Among vascular procedures, infrainguinal arterial bypass and open aortic surgery are categorized as procedures with the highest cardiac risk according to the 2014 American College of Cardiology/American Heart Association guidelines.[6]

The past decade has seen a number of important changes in patient demographics, perioperative cardiac care, and surgical technique for vascular surgery. The efficacy of preoperative statins,[7] β-blockers,[8-10] angiotensin-converting enzyme inhibitors,[11] and antiplatelet agents[11,12] in reducing postoperative cardiac complications remain controversial, but routine use of these agents has gained wide acceptance[13] and has substantially affected the patient cardiac risk profile. Conversely, incorporation of high-sensitivity troponin values into the definition of POMI has resulted in the diagnosis of many more MIs, the importance of which remains controversial.

Moreover, widespread use of endovascular technologies has yielded major changes in the practice of vascular surgery. Most abdominal aortic aneurysms are now treated using endovascular aneurysm repair,[14] although its association with the POMI incidence of open aortic operations remains ill-defined. Conversely, the availability of endovascular procedures and thrombolysis has reduced the need for emergency infrainguinal bypass procedures. One study demonstrated significant reductions in infrainguinal bypasses owing to the decreased incidence of acute limb ischemia and increased use of endovascular interventions.[15] Our present study used the American College of Surgeons National Surgical Quality Improvement Program (ACS NSQIP) database to examine trends in the incidence and prognostic implications of POMI among patients undergoing high-risk vascular operations. Given the aforementioned changes, we hypothesized a shift in aortic surgery toward more emergency and complex cases and a reduction in emergency infrainguinal bypass procedures. In addition, with the broadened definition of POMI, we anticipated an increase in POMI with a reduction in POMI-associated mortality.

Key Points

Question What are the temporal trends of postoperative myocardial infarction incidence following high-risk vascular procedures in the past decade?

Findings In this cohort study of 90 303 adults who underwent either open aortic surgery or infrainguinal bypass, the incidence of postoperative myocardial infarction remained stable following the procedure. However, increasing rates of cardiac arrest and mortality were observed for those who had undergone an open aortic procedure and mortality improved for those who had undergone an infrainguinal bypass.

Meaning Despite major advances in perioperative cardiac care in the past decade and the availability of an endovascular surgical approach, high-risk vascular procedures were not associated with lower rates of postoperative myocardial infarction.

Methods

A retrospective cohort study using data from the ACS NSQIP database was performed of cases collected from January 1, 2005, to December 31, 2013. Patients undergoing a *high-risk vascular procedure*, defined as any open surgery involving the abdominal aorta or an infrainguinal arterial bypass, were divided into cohorts based on their year of operation. Baseline cardiac risk factors and incidence of POMI, cardiac arrest, and mortality were then compared. Because of the deidentified nature of preexisting data, this study was deemed exempt from review by the institutional review board of the UCLA (University of California, Los Angeles). Patient informed consent was deemed unnecessary by the UCLA institutional review board. Data analysis took place from August 1, 2016, to November 15, 2016.

Database and Sample Selection

The ACS NSQIP database contains clinician-collected preoperative, operative, and 30-day outcome variables for sampled cases in participating hospitals throughout the United States. The number of hospitals reporting their data has increased from 121 in 2005 to 517 in 2014.

Cases from January 1, 2005, to December 31, 2014, in the ACS NSQIP database were eligible for inclusion if one of the *Current Procedural Terminology* codes matched any of the operations identified as a high-risk vascular procedure (**Table 1**). The definition of a high-risk procedure was based on the 2014 American College of Cardiology and American Heart Association guidelines.[6]

Variables of Interest

Preoperative patient characteristics of interest included sex, age, body mass index (calculated as weight in kilograms divided by height in meters squared), race/ethnicity, smoking status, presence of diabetes requiring insulin, anemia status (hematocrit reading <37% [to convert to a proportion of 1, multiply by 0.01]), renal insufficiency status (creatinine level >1.5 mg/dL; to convert to millimoles per liter, multiply by 88.4), dialysis status, history of congestive heart failure, history of MI, history of stroke, American Society of Anesthesiologists (ASA) Physical Status classification,[16] and preoperative functional status. Operative variables included procedure type as open aortic surgery or as infrainguinal bypass procedure and case status as emergent or as nonemergent. A cardiac risk summary statistic was calculated using the myocardial infarction and cardiac arrest (MICA) risk estimate.[17] The MICA risk estimate is a validated prediction tool for intraoperative or postoperative MI and cardiac arrest that was developed using data from the 2007 ACS NSQIP database and validated using data from the 2008 ACS NSQIP database and that has performance comparable to the Revised Cardiac Risk Index.[18] The MICA risk estimate uses 5 POMI risk factors: age, ASA classification, creatinine level, functional status, and procedure type. *Functional*

Table 1. *CPT* Codes Used for Patient Identification

Procedures	*CPT* Codes
Open aortic	
Suture repair of aorta or great vessels	33320, 33321, 33322
Insertion of graft, aorta or great vessels	33330, 33332, 33335, 33875
Aortic aneurysm repair	33877, 34830, 34831, 34832, 35081, 35082, 35091, 35092, 35102, 35103
Thromboendarterectomy of aorta	35331
Bypass graft with vein involving the aorta	35526, 35531, 35541, 35546, 35548, 35549, 35551, 35560
Bypass graft with conduit other than vein involving the aorta	35626, 35631, 35641, 35646, 35647, 35651
Infrainguinal arterial bypass	
Bypass graft with veins	35521, 35533, 35556, 35558, 35563, 35565, 35571, 35681, 35682, 35683
Bypass graft with conduit other than vein	35621, 35623, 35654, 35656, 35661, 35663, 35665, 35666, 35671

Abbreviation: *CPT, Current Procedural Terminology*.

status, as defined in the ACS NSQIP, was classified as totally independent, partially dependent, and totally dependent. Procedure type was classified into 21 categories (including anorectal, aortic, bariatric, brain, breast, and cardiac, to name a few), and a specific coefficient was assigned for each category.

The primary outcome for this study was POMI. From 2005 to 2011, *POMI* was defined in the ACS NSQIP as a new transmural acute MI occurring during surgery or within 30 days of surgery as manifested by new Q waves on electrocardiogram. Since 2012, this definition has been revised as the documentation of electrocardiogram changes indicative of acute MI and one or more of the following: ST segment elevation greater than 1 mm in 2 or more contiguous leads, new left bundle branch, new Q wave in 2 or more contiguous leads, and new elevation in troponin values greater than 3 times the upper level of the reference range. Secondary outcomes included 30-day mortality and *cardiac arrest*, defined in the ASC NSQIP as the absence of cardiac rhythm or presence of chaotic cardiac rhythm resulting in loss of consciousness and requiring the initiation of any component of basic and/or advanced cardiac life support in accordance with the 2012 ACS NSQIP Participant Use Data File user guide.[19]

Statistical Analysis

Patient characteristics and outcomes were first tabulated after stratification by procedure category and operative year. Each variable was then compared by procedure types using the χ^2 test for categorical variables and unpaired, 2-tailed *t* test for continuous variables. The statistical significance of temporal relationships was examined by use of a modified Wilcoxon rank sum test for trend across ordered groups.[20] To identify important risk factors for cardiac complications and to assess the independent contribution of the operation year in estimating the association with adverse cardiac outcomes, logistic regression models were constructed to adjust for other confounders. A backward stepwise elimination algorithm was adopted for selection of the most parsimonious set of variables by using .01 as the alpha-to-remove value.

Finally, to assess the temporal shift in severity of diagnosed POMI's during the study period, a subgroup analysis was performed using only patients who experienced POMI. Logistic regression analyses were performed for each yearly cohort to quantify the odds of developing cardiac arrest or mortality following POMI after adjusting for other noncardiac complications, including stroke, acute renal failure, thromboembolism, bleeding, and infectious complications. A 2-sided $P < .05$ was considered statistically significant. Statistical analyses were performed using Stata, version 13.0 (StataCorp LLC).

Results

Open Aortic vs Infrainguinal Bypass

From January 1, 2005, to December 31, 2014, a total of 90 303 patients were identified as undergoing high-risk vascular procedures, comprising 22 836 open aortic procedures (25.3%) and 67 467 infrainguinal bypasses (74.7%). The open aortic cohort comprised 16 391 men (71.9%), had a mean (SD) age of 69.1 (11.5) years, and was predominantly white (18 440 patients [80.8%] self-identified as white). The infrainguinal bypass cohort was composed of 41 845 men (62.1%), had a mean (SD) age of 66.7 (11.7) years, and had 51 043 patients (75.7%) who reported white as their race/ethnicity. A gradual decrease in the sampled proportion of open aortic cases was observed across the years (36.2% in 2005 vs 19.9% in 2014; $P < .001$). (Because of the large sample sizes in this study, the *P* values for these comparisons involve multiple digits behind the decimal point. To maintain readability, we simplified the *P* values.)

Considerable differences in both cardiac risk factor and outcome profile were observed between open aortic and infrainguinal bypass procedures (**Table 2**). Patients undergoing open aortic procedures were less likely than those with infrainguinal bypass to have insulin-dependent diabetes (972 [4.3%] vs 13 445 [19.9%]; $P < .001$), be receiving dialysis (776 [3.4%] vs 3401 [5.0%]; $P < .001$), or have dependent functional status (2192 [9.6%] vs 7770 [11.5%]; $P < .001$). However, patients who had open aortic surgery were more likely to be classified as ASA class IV (7426 [32.6%] vs 15 683 [23.3%] of patients in the infrainguinal bypass cohort) or class V (1131 [5.0%] vs 206 [0.3%]; $P < .001$) and undergo more emergent procedures (4852 [21.3%] vs 4954 [7.3%]; $P < .001$). The mean (SD) MICA risk estimate among open aortic procedures was nearly 3-fold higher than that for infrainguinal bypass procedures (3.8% [4.8%] vs 1.3% [1.3%]; $P < .001$). Compared with the infrainguinal bypass cohort, the open aortic procedure cohort was associated with substantially higher actual incidence of POMI (464 [3.0%] vs 1270 [1.9%]; $P < .001$), cardiac arrest (732 [3.2%] vs 789 [1.2%]; $P < .001$), and mortality (1995 [8.7%] vs 1930 [2.9%]; $P < .001$).

Open Aortic Procedure

The sample size for open aortic procedures displayed a steady growth, from 540 cases in 2005 to 2464 cases in 2014 (eTable

Table 2. Comparison of Preoperative Cardiac Risk Factors and Postoperative Outcomes Between Open Aortic Surgery and Infrainguinal Bypass

Factor	No. (%) Open Aortic Surgery Total (n = 22 836)	No. (%) Infrainguinal Bypass Total (n = 67 467)	P Value
Preoperative characteristics			
Male	16 391 (71.9)	41 845 (62.1)	<.001
Age, mean (SD), y	69.1 (11.5)	66.7 (11.7)	<.001
Race/ethnicity			
White	18 440 (80.8)	51 043 (75.7)	<.001
Black or African American	1701 (7.5)	9503 (14.1)	
Asian or Native American	497 (2.2)	1093 (1.6)	
Others/Unknown	2198 (9.6)	5828 (8.6)	
BMI, mean (SD)	27.6 (5.9)	27.2 (6.2)	<.001
Diabetes requiring insulin	972 (4.3)	13 445 (19.9)	<.001
Hypertension	17 803 (78.0)	55 109 (81.7)	<.001
Anemia	8801 (38.5)	30 381 (45.0)	<.001
Renal insufficiency	5139 (22.5)	12 910 (19.1)	<.001
Dialysis	776 (3.4)	3401 (5.0)	<.001
History of CHF	506 (2.2)	1771 (2.6)	.001
History of MI[a]	354 (2.4)	842 (2.2)	.20
History of stroke[a]	2234 (12.5)	2712 (7.1)	<.001
ASA class[16]			
I	94 (0.4)	186 (0.3)	<.001
II	1665 (7.3)	3858 (5.7)	
III	12 472 (54.7)	47 479 (70.4)	
IV	7426 (32.6)	15 683 (23.3)	
V	1131 (5.0)	206 (0.3)	
Dependent functional status	2192 (9.6)	7770 (11.5)	<.001
MICA risk estimate, mean (SD), %	3.8 (4.8)	1.3 (1.3)	<.001
Emergent procedure	4852 (21.3)	4954 (7.3)	<.001
Postoperative outcomes			
MI	464 (3.0)	1270 (1.9)	<.001
Cardiac arrest	732 (3.2)	789 (1.2)	<.001
Mortality	1995 (8.7)	1930 (2.9)	<.001

Abbreviations: ACS NSQIP, American College of Surgeons National Surgical Quality Improvement Program; ASA, American Society of Anesthesiologists; BMI, body mass index (calculated as weight in kilograms divided by height in meters squared); CHF, congestive heart failure; MI, myocardial infarction; MICA, myocardial infarction and cardiac arrest.

[a] Only containing data from 2005 to 2012. The ACS NSQIP did not collect data on these variables from 2013 onward.

1 in the Supplement). There were significant decrements in renal insufficiency prevalence (157 [29.1%] in 2005 vs 508 [20.6%] in 2014; *P* < .001) and dependent functional status (86 [15.9%] in 2005 vs 70 [2.8%] in 2014; *P* < .001), which were countered by an increase in emergent procedures and ASA class IV or V patients. The mean (SD) MICA risk estimate showed no significant change over the 10-year period (4.3% [6.2%] in 2005 vs 3.6% [3.6%] in 2014; *P* = .14]).

A dramatic increase in the incidence of POMI, from 1.2% to 3.5%, was observed from the fourth quarter of 2008 to the first quarter of 2009. The abrupt nature of the increase and the steady POMI incidence both before and after this junction led us to hypothesize that the observed increase was likely associated with a change in the data sampling algorithm rather than a disruptive epidemiological change in POMI incidence. Thus, we performed subsequent analyses involving POMI incidence using only data after 2008. The observed POMI incidence from 2009 to 2014 demonstrated no significant temporal change (*P* = .64 for trend), ranging from 2.7% to 3.1%. However, the rates of cardiac arrest and mortality increased, from 2.3% in 2009 to 4.7% in 2014 and from 8.4% in 2009 to 10.2% in 2014, respectively (eFigure in the Supplement).

A logistic regression model was created to identify POMI risk factors. After adjustment for known risk factors, no significant association was found between temporal year and MI (odds ratio [OR], 0.99; 95% CI; 0.95-1.02; *P* = .36 [not shown in **Table 3**]). The most significant risk factors were emergent case status, ASA class, renal insufficiency, and age greater than 75 years (Table 3).

Infrainguinal Bypass Procedure

The sample number for the infrainguinal bypass procedure has been steadily growing, from 952 cases in 2005 to 9921 cases in 2014 (eTable 2 in the Supplement). However, a smaller percentage of patients in 2014 had anemia (446 [46.9%] in 2005 vs 4191 [42.2%] in 2014; *P* < .001), had renal insufficiency (230 [24.2%] vs 1662 [18.8%]; *P* < .001), were undergoing dialysis (52 [5.5%] vs 405 [4.1%]; *P* < .001), had dependent functional status (174 [18.3%] vs 613 [6.2%]; *P* < .001), and underwent emergent procedures (93 [9.8%] vs 634 [6.4%]; *P* = .005). On

Table 3. Risk Factors for Postoperative Myocardial Infarction, 2009-2014

	Open Aortic Surgery		Infrainguinal Bypass	
Risk Factor	Odds Ratio (95% CI)	P Value[a]	Odds Ratio (95% CI)	P Value[a]
Age >75 y	1.32 (1.15-1.78)	<.001	1.36 (1.18-1.56)	<.001
Diabetes requiring insulin	NA		1.43 (1.25-1.64)	<.001
Hypertension			1.79 (1.45-2.21)	<.001
Renal insufficiency	1.43 (1.15-1.78)	<.001	1.47 (1.28-1.68)	<.001
Emergent case status	1.67 (1.32-2.12)	<.001	1.48 (1.21-1.80)	<.001
Anemia	NA		1.28 (1.12-1.45)	<.001
ASA class	1.44 (1.23-1.69)	<.001	1.53 (1.36-1.72)	<.001

Abbreviations: ASA, American Society of Anesthesiologists; NA, not applicable.

[a] Because of the large sample sizes in this study, the *P* values for these comparisons involve multiple digits behind the decimal point. To maintain readability, we simplified the *P* values.

Table 4. Association of Myocardial Infarction With Cardiac Arrest and Mortality

Year of Operation	Incidence, %	Odds Ratio (95% CI)	P Value[a]
Cardiac Arrest			
2005	11.1	8.11 (0.77-85.86)	.08
2006	17.5	6.45 (2.56-16.24)	<.001
2007	23.2	11.77 (6.10-22.72)	<.001
2008	12.3	3.78 (1.74-8.20)	<.001
2009	8.9	3.62 (2.25-5.82)	<.001
2010	10.8	5.52 (3.23-8.87)	<.001
2011	12.7	5.81 (3.76-8.98)	<.001
2012	10.3	3.84 (2.43-6.07)	<.001
2013	11.1	5.59 (3.58-8.72)	<.001
2014	11.3	6.15 (4.07-9.29)	<.001
Mortality			
2005	22.2	2.54 (0.25-25.46)	.43
2006	30.0	5.78 (2.46-13.60)	<.001
2007	30.4	4.99 (2.68-9.28)	<.001
2008	24.7	3.52 (1.87-6.63)	<.001
2009	19.7	3.01 (2.08-4.36)	<.001
2010	23.1	5.03 (3.44-7.34)	<.001
2011	25.0	6.66 (4.66-9.52)	<.001
2012	16.4	3.14 (2.13-4.63)	<.001
2013	22.5	5.68 (4.00-8.07)	<.001
2014	20.2	5.68 (4.04-7.98)	<.001

[a] Because of the large sample sizes in this study, the *P* values for these comparisons involve multiple digits behind the decimal point. To maintain readability, we simplified the *P* values.

the other hand, diabetes prevalence has increased from 2005 to 2014 (174 [18.3%] vs 2118 [21.4%]; $P < .001$), and a steady shift of patients from ASA class II and III into ASA class IV was observed. The mean (SD) MICA risk estimate during the study period remained unchanged (1.3% [1.4%] in 2005 vs 1.2% [1.1%] in 2014; $P = .07$ for trend).

Similar to open aortic cases, POMI incidence increased from 2008 to 2009, with a jump from 1.02% to 2.72% over a single quarter. For reasons explained earlier, we performed the following analyses using data from 2009 and later and found no consistent temporal shifts in the incidence of POMI ($P = .52$ for trend) or cardiac arrest ($P = .64$ for trend). Of interest, the MICA risk estimate remained consistently below the actual MICA incidence after 2008. However, a gradual decrease in 30-day mortality was observed ($P < .001$ for trend) (eFigure in the Supplement).

The logistic regression model identified the most significant risk factors associated with MI following infrainguinal bypass procedures as hypertension, ASA class, emergent case, renal insufficiency, diabetes, age greater than 75 years, and preoperative hematocrit level less than 37%.

POMI Prognosis

A subgroup analysis was performed that included only patients who experienced POMI. The incidence of cardiac arrest ranged from 8.9% (OR, 3.62; 95% CI, 2.25-5.82) to 23.2% (OR, 11.77; 95% CI, 6.10-22.72) and mortality ranged from 16.4% (OR, 3.14; 95% CI, 2.13-4.63) to 30.4% (OR, 4.99; 95% CI, 2.68-9.28) (**Table 4**). No consistent trend was observed in cardiac arrest or mortality among POMI patients. In addition, logistic regression models were constructed to quantify the association of POMI with subsequent cardiac arrest and death using the entire study population. Postoperative MI was consistently associated with poor prognosis, with a 3.62-fold (95% CI, 2.25-5.82) to 11.77-fold (95% CI, 6.10-22.72) increased odds of cardiac arrest and a 3.01-fold (95% CI, 2.08-4.36) to 6.66-fold (95% CI, 4.66-9.52) increased odds of mortality.

Discussion

The past 2 decades have seen substantial improvements in the perioperative care of patients undergoing major surgery. Nonetheless, cardiovascular complications remain a major cause of mortality following vascular operations. In the present study, we evaluated the temporal changes in the incidence of cardiac complications in high-risk cardiac procedures.[6] Of note, our study results showed that patients undergoing infrainguinal bypass procedures often had severe chronic conditions while those undergoing open aortic procedure were healthier at baseline but had surgery under more emergent conditions. Consequently, open aortic procedures were associated with a higher incidence of POMI, cardiac arrest, and mortality in more recent years, whereas the opposite was noted in the infrainguinal bypass cohort.

On the surface the incidence of POMI for either procedure has remained stable since 2009, but a gradual shift in the patient population and their implied cardiac risk has occurred. Patients who underwent open aortic procedures appeared to have fewer measurable baseline comorbidities but a higher incidence of emergent procedures, which likely resulted from the availability of endovascular procedures.[21] This trend was most evident as the persistent increase in patients belonging to ASA class IV or V (eg, those with severe systemic conditions posing a constant threat to life or moribund patients). The cumulative effect of such opposing trends was no change in the MICA risk estimate or incidence of POMI. However, substantial increases in cardiac arrest incidence and mortality were found. Even after adjusting for all known cardiac risk factors, ASA classification was still independently associated with increased odds of POMI. Simply, there was a discrepancy between illness severity as subjectively perceived by the anesthesiologists rather than objectively quantified by predetermined cardiac risk factors. The causes of such a discrepancy and the association of factors, including frailty as a potential risk factor, with cardiac events deserve further investigation.

We found a more encouraging trend in infrainguinal bypass procedures. A persistent decrease in most baseline comorbidities, except diabetes, and fewer emergency operations led to the decline of overall mortality during the study period. Similar trends have been previously ascribed to the availability of percutaneous interventions for acute limb ischemia.[15] However, there was an increase in patients with ASA class IV status. Shifts in patient and operative risk profiles resulted in a stable incidence for POMI and cardiac arrest.

After adjusting for various characteristics, we identified several independent risk factors associated with POMI (which are in agreement with those in previous reports), including advanced age,[22] obesity,[23] renal insufficiency,[24] diabetes,[25,26] anemia,[27] and underlying cardiac diseases.[28-30] Several risk estimate models attempted to summarize these variables into a single risk statistic, including the Revised Cardiac Risk Index,[31] Vascular Study Group of New England Cardiac Risk Index,[32] and the MICA Risk Calculator.[17] However, much controversy exists regarding the applicability of such models to patients undergoing high-risk vascular operations.[31-34] The MICA risk estimate correlates with the occurrence of POMI, but it consistently underestimates absolute incidence of these cardiac complications in data year 2009 and later. Likely reasons for the increase in the incidence of POMI in 2009 were the methodological changes in ACS NSQIP sampling and documentation, but we believe that a revised MICA score using more recent data will update this parsimonious cardiac risk prediction model.

The definition of POMI, both in clinical practice and ACS NSQIP data, has undergone a major revision since the introduction of high-sensitivity troponin assay. Its heightened sensitivity led to an increase in the incidence of diagnosed POMI.[35,36] A systematic review[37] demonstrated that elevated troponin T or I level was consistently associated with elevated hazards for mortality following vascular surgery. However, in our study, we found that diagnosed POMI severity did not significantly decrease with liberalization of diagnostic criteria. In fact, the occurrence of POMI was consistently associated with elevated odds for subsequent cardiac arrest or mortality after adjustment for all other postoperative complications.

There are several practical and clinical implications to our findings. First, the stable rate of POMI with improving patient baseline risk should further stimulate strategies to reduce the chance of myocardial events in both emergency and elective settings. No particular interventions have been shown to reduce POMI in randomized trials, but several measures, including invasive hemodynamic monitoring and continuous telemetry, have been suggested as potential strategies.[38-40] Second, accurate determination of the absolute risk of POMI and cardiac arrest may be helpful in patient counseling and deployment of resource-intensive measures. Limited data are available on the efficacy of preoperative coronary revascularization in reducing cardiovascular events after major surgery.[41] Given significant improvements in the short- and long-term outcomes of surgical and percutaneous coronary interventions, revascularization of hemodynamically significant coronary lesion may prove beneficial.

Limitations

We acknowledge several limitations including those inherent to the data's retrospective nature. The NSQIP database was designed for quality improvement rather than survey purposes, and our conclusions may not be nationally representative. Discrepancy in outcomes has been reported for vascular procedures between the ACS NSQIP and Vascular Quality Initiative.[42,43] In addition, the ACS NSQIP made several revisions to the cardiac-related variable definition over the years, including the 2013 change in the POMI definition and elimination of the history of MI and stroke variables. The combination of these factors led to a limited sample size during certain analyses and may have introduced sampling error. Furthermore, the ACS NSQIP did not consistently collect information on perioperative medical management, such as preoperative revascularization; statin or β-blocker usage; and potentially relevant intraoperative anatomic information, such as the use of suprarenal cross-clamping during open aortic procedures. These factors could be candidate confounders affecting cardiac outcomes.

Conclusions

Over the past decade, the cumulative sea changes in patient selection criteria and perioperative cardiac care have resulted in no significant improvement in the incidence of POMI among patients undergoing high-risk vascular procedures. For open aortic surgery, an increase in postoperative cardiac arrest and mortality was observed in parallel with a higher proportion of patients with ASA class IV or V status and emergent cases. For infrainguinal bypass, there was a decline in mortality associated with improved patient baseline health and decreasing emergent cases. Despite changes in postoperative care, POMI was consistently associated with significantly elevated odds of cardiac arrest and mortality after adjusting for other confounders. Postoperative MI following these high-risk vascular procedures represents a high-value target for quality improvement efforts not only because of its costly sequelae but also because of the anticipated growth in such cases in the aging US population. Strategies to reduce MIs, such as preoperative coronary revascularization and intensive hemodynamic monitoring, deserve further evaluation.

ARTICLE INFORMATION

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Study concept and design: Juo, Ebrahimi, Benharash.
Acquisition, analysis, or interpretation of data: All authors.
Drafting of the manuscript: Juo, Ebrahimi, Ziaeian, Benharash.
Critical revision of the manuscript for important intellectual content: All authors.
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Administrative, technical, or material support: Juo, Mantha, Ziaeian.
Study supervision: Ebrahimi, Ziaeian, Benharash.

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