JAMA Surgery | Original Investigation | ASSOCIATION OF VA SURGEONS

Association of High Mortality With Postoperative Myocardial Infarction After Major Vascular Surgery Despite Use of Evidence-Based Therapies

Robert J. Beaulieu, MD; Danielle C. Sutzko, MD; Jeremy Albright, PhD; Erin Jeruzal, BA; Nicholas H. Osborne, MD; Peter K. Henke, MD

IMPORTANCE Patients undergoing vascular surgery are at high risk of postoperative myocardial infarction (POMI). Postoperative myocardial infarction is independently associated with significant risk of in-hospital mortality.

OBJECTIVE To examine the association of patient and procedural characteristics with the risk of POMI after vascular surgery and determine the association of evidence-based therapies with longer-term outcomes.

DESIGN, SETTING, AND PARTICIPANTS A retrospective cohort study of prospectively collected data within a statewide quality improvement collaborative database between January 2012 and December 2017. Patient demographics, comorbid conditions, and perioperative medications were captured. Patients were grouped according to occurrence of POMI. Univariate analysis and logistic regression were used to identify factors associated with POMI. The collaborative collects data from private and academic hospitals in Michigan. Patients undergoing major vascular surgery, defined as endovascular aortic aneurysm repair, open abdominal aortic aneurysm, peripheral bypass, carotid endarterectomy, or carotid artery stenting were included. Analysis began December 2018.

MAIN OUTCOMES AND MEASURES The presence of a POMI and 1-year mortality.

RESULTS Of 26 231 patients identified, 16 989 (65.8%) were men and the overall mean (SD) age was 69.35 (9.89) years. A total of 410 individuals (1.6%) experienced a POMI. Factors associated with higher rates of POMI were age (odds ratio [OR], 1.032 [95% CI, 1.019-1.045]; $P < .001$), diabetes (OR, 1.514 [95% CI, 1.201-1.907]; $P < .001$), congestive heart failure (OR, 1.519 [95% CI, 1.163-1.983]; $P = .002$), valvular disease (OR, 1.447 [95% CI, 1.024-2.046]; $P = .04$), coronary artery disease (OR, 1.381 [95% CI, 1.058-1.803]; $P = .02$), and preoperative P2Y12 antagonist use (OR, 1.37 [95% CI, 1.08-1.725]; $P = .009$). Procedurally, open abdominal aortic aneurysm (OR, 4.53 [95% CI, 2.73-7.517]; $P < .001$) and peripheral bypass (OR, 2.375 [95% CI, 1.818-3.102]; $P < .001$) were associated with the highest risk of POMI. After POMI, patients were discharged and received evidence-based therapy with high fidelity, including β-blockade (296 [82.7%]) and antiplatelet therapy (336 [95.7%]). A high portion of patients with POMI were dead at 1 year compared with patients without POMI (113 [37.42%] vs 993 [5.05%]; $\chi^2 = 589.3$; $P < .001$).

CONCLUSIONS AND RELEVANCE Despite high rates of discharge with evidence-based therapies, the long-term burden of POMI is substantial, with a high mortality rate in the following year. Patients with diabetes mellitus, coronary artery disease, congestive heart failure, and valvular disease warrant additional consideration in the preoperative period. Further, aggressive strategies to treat patients who experience a POMI are needed to reduce the risk of postoperative mortality.

Author Affiliations: Section of Vascular Surgery, Department of Surgery, University of Michigan, Ann Arbor (Beaulieu, Sutzko, Osborne, Henke); Division of Cardiology, Department of Medicine, University of Michigan, Ann Arbor (Albright, Jeruzal).

Corresponding Author: Peter K. Henke, MD, Section of Vascular Surgery, 5364 Cardiovascular Center, University of Michigan, 1500 E Medical Center, Ann Arbor, MI 48109 (henke@umich.edu).

JAMA Surg. doi:10.1001/jamasurg.2019.4908
Published online December 4, 2019.

Patients undergoing vascular surgery are at the highest risk among all noncardiac operative patients to experience postoperative cardiac complications.[1] The effect of a postoperative myocardial infarction (POMI) after vascular surgery is substantial, with early mortality ranging between 16.4% and 30.4%.[2] Postoperative myocardial infarction is an independent predictor of increased long-term mortality among patients who have undergone vascular surgery.[3] Further, POMI may have greater effect on mortality after carotid endarterectomy (CEA) than postoperative stroke.[4] While the survival after myocardial infarction has improved among the general population, with a current mortality of 3.8%, mortality following POMI after vascular surgery has remained staggeringly high (more than 20%) and nearly constant since 2009.[2,5] To this end, identification of patients undergoing vascular surgery who are at particular risk for cardiac complications has the potential to affect short- and long-term survival after their operation.

For patients with both endovascular and open options for treatment of vascular disease, an understanding of the particular cardiac risk for that individual may help to drive clinical decision-making. For instance, endovascular aortic aneurysm repair (EVAR) has been demonstrated to have a much lower risk of POMI than open repair of abdominal aortic aneurysm (AAA) (4.3% vs 1.0%, $P < .001$).[6] Alternatively, determination of a patient's cardiac risk is an important component of informed consent even if the operative plan cannot be altered. Multiple risk calculators have been constructed, especially in the general surgery population, with the Revised Cardiac Risk Index being most widely used. The applicability of these models in patients who have undergone vascular surgery remains controversial and, in particular, the Revised Cardiac Risk Index may be less accurate in predicting postoperative complications in patients who have undergone vascular surgery with up to 7.4-fold underestimation of cardiac risk.[7,8] Recent evidence suggests that comorbid conditions have minimal effect compared with procedural characteristics, such as urgency and blood loss.[9] Owing to these variable reports, prediction of POMI among patients who have undergone vascular surgery remains imprecise.

Key Points

Question What is the association of postoperative myocardial infarction with outcomes after vascular surgery and what are contributing factors?

Findings In this cohort study using a large collaborative database that included 26 231 patients undergoing major vascular surgery, factors associated with an increased risk of postoperative myocardial infarction included increased age, diabetes, coronary artery disease, congestive heart failure, cardiac valvular disease, and preoperative use of P2Y12 inhibitors. Patients who experienced a postoperative myocardial infarction had a 37% 1-year mortality rate after their operation.

Meaning Patients with diabetes mellitus, coronary artery disease, congestive heart failure, or valvular disease undergoing major vascular surgery require thorough evaluation to reduce rates of postoperative myocardial infarction, which is associated with a high rate of mortality at 1 year.

Methods

We performed a statewide, retrospective observational cohort study using the Blue Cross Blue Shield of Michigan Cardiovascular Collaborative (BMC2) database. At each participating site, study coordinators are trained to evaluate electronic medical records for specific patient conditions and outcomes and are ultimately responsible for the input and verification of patient variables, including postoperative outcomes. We queried the database for all patients undergoing the following vascular operations: open AAA repair, EVAR, peripheral arterial bypass, CEA, and carotid artery stenting (CAS). Based on this query, we then separated patients into cohorts based on the presence of a POMI. Postoperative myocardial infarction was defined as a myocardial infarction, diagnosed with electrocardiogram (ECG) changes and biomarker changes, occurring in the immediate postoperative setting up to 30 days after the operation.[10] Particularly, study coordinators evaluated ECGs, laboratory values (including troponins), and medical documentation from both surgical and cardiology physicians to detect POMI and ensure patients classified as such meet consensus criteria for the diagnosis. Data were collected from January 2012 to December 2017, and analysis began in December 2018. The BMC2 vascular interventions collaborative has been determined to have a nonregulated status and has been granted an exemption from requirement of patient consent by the University of Michigan Institutional Review Board. All patient records were deidentified prior to analysis.

The BMC2 database collects both patient-specific demographics and comorbid conditions, as well as information regarding the hospital system in which the patient was treated. As such, we collected data regarding the rural population percentage of the hospital region (grouped in tertiles), the number of beds within the hospital (grouped in tertiles), and the percentage of cases listed as urgent. Patient-level demographics included age, body mass index, race, and sex. Comorbid conditions included smoking status (never smoker or past/current smoker), family history of premature coronary artery disease (CAD), hypertension, hyperlipidemia, type 2 diabetes mellitus, congestive heart failure, significant cardiac valvular disease, chronic obstructive pulmonary disease (COPD), CAD, atrial fibrillation, and chronic kidney disease. The BMC2 database was also queried for preoperative and discharge cardiovascular medications.[11] Additionally, BMC2 allowed for the determination of intraoperative and postoperative blood transfusion, which were therefore queried based on previous literature demonstrating the significant effect of this on POMI after vascular surgery.[9] One-year mortality was abstracted with complete follow-up available in approximately 75% of patients.

Univariate analysis was used to identify patient-, hospital-, and procedural-level variables that differed among the group with POMI and those without. Categorical variables were summarized using frequencies and percentages,

and χ^2 or Fisher exact tests were used to identify significant unadjusted differences between POMI and non-POMI cases. Interval variables were summarized with means and standard deviations, and unadjusted differences were tested using *t* tests. Postoperative myocardial infarction was then modeled using logistic regression with patient comorbidities, admission medications, preoperative testing, and hospital-level variables included as factors associated with POMI. The percentage of patients prescribed angiotensin-converting enzyme inhibitors, β-blockers, anticoagulants, warfarin, direct oral anticoagulants, or statins at admission and again at discharge were calculated, and significant changes in medications from admission to discharge were examined using the McNemar test. Statistical significance threshold was .05, and testing was 2-sided.

Results

A total of 26 231 patients were identified, with 410 patients (1.6%) with a POMI. Patients who experienced POMI had an older mean (SD) age than patients who did not (71.33 [9.2] vs 69.35 [9.89] years; $t = 4.026$; $P < .001$). Otherwise, there were no significant differences between categories of race or sex between those in the POMI cohort and those who were not (**Table 1**). Hospital-level characteristics, such as rural patient distribution, number of beds, and overall burden of urgent caseload, were also similar between patient groups (Table 1).

Based on univariate analysis, patients who experienced POMI were more likely to have hypertension (392 [95.6%] vs 23 024 [89.2%]; $\chi^2 = 16.8$; $P < .001$), hyperlipidemia (378 [92.2%] vs 22 918 [88.8%]; $\chi^2 = 4.45$; $P = .04$), type 2 diabetes mellitus (203 [49.5%] vs 8774 [34.0%]; $\chi^2 = 42.57$; $P < .001$), congestive heart failure (119 [29.0%] vs 3849 [14.9%]; $\chi^2 = 61.52$; $P < .001$), cardiac valvular disease (52 [12.7%] vs 1685 [6.5%]; $\chi^2 = 23.71$; $P < .001$), CAD (288 [70.2%] vs 13 090 [50.7%]; $\chi^2 = 60.91$; $P < .001$), and chronic kidney disease (23 [5.6%] vs 428 [1.7%]; $\chi^2 = 34.91$; $P < .001$) (Table 1). Postoperative myocardial infarction rates varied according to procedure type with patients undergoing peripheral bypass and open AAA having the highest rates (AAA: 26 [3.75%]; peripheral bypass: 185 [2.56%]; EVAR: 45 [0.96%]; CAS: 28 [1.21%]; and CEA: 126 [1.11%]).

A logistic regression was next fit including all of the variables in Table 1 as factors associated with POMI. **Table 2** presents the results that were statistically significant. Variables that remained significantly associated with POMI, according to the logistic regression, were type 2 diabetes mellitus (odds ratio [OR], 1.514; 95% CI, 1.201-1.907; $P < .001$), congestive heart failure (OR, 1.52; 95% CI, 1.163-1.983; $P = .002$), valvular disease (OR, 1.447; 95% CI, 1.024-2.046; $P = .04$), and CAD (OR, 1.381; 95% CI, 1.058-1.803; $P = .02$) (Table 2). Patients who underwent open AAA or peripheral bypass were found to have the highest risk of POMI compared with those undergoing CAS, CEA, or EVAR. Patients undergoing AAA or bypass surgery had higher rates of former/current tobacco abuse (7323 [92.5%] vs 15 171 [82.9%]; $\chi^2 = 415.48$; $P < .001$), diabetes (2965 [37.4%] vs 6012 [32.8%]; $\chi^2 = 51.84$; $P < .001$), COPD (3077 [38.9%] vs 6210 [33.9%]; $\chi^2 = 58.57$; $P < .001$), and chronic kidney disease (243 [3.1%] vs 208 [1.1%]; $\chi^2 = 120.25$; $P < .001$). Patients undergoing lower-risk surgeries had higher rates of hypertension (16 458 [89.9%] vs

Table 1. Patient Demographics and Hospital Characteristics, Univariate Analysis

Comorbidity	No MI (n = 25 821)	MI Within 30 d (n = 410)	*P* Value
Age, mean (SD), y	69.35 (9.89)	71.33 (9.2)	<.001
BMI, mean (SD)	28.67 (9.83)	28.38 (6.04)	.34
Race			
Black	1916 (7.42)	40 (9.76)	.14
White	23 241 (90.0)	357 (87.1)	
Other[a]	664 (2.57)	13 (3.71)	
Sex			
Female	8823 (34.2)	143 (34.9)	.82
Male	16 989 (65.8)	109 (27.4)	
Rural tertile, %			
High	5751 (23.2)	108 (27.1)	.09
Medium	6453 (26.1)	109 (27.4)	
Low	12 542 (50.7)	181 (45.5)	
Beds, No.			
<250	3835 (15.2)	67 (16.5)	.08
250-500	13 645 (54.0)	235 (57.9)	
>500	7799 (30.9)	104 (25.6)	
Urgent cases, %			
<5	634 (2.5)	9 (2.2)	.11
5-20	14 569 (57.6)	255 (62.8)	
>20	10 076 (39.9)	142 (34.89)	
Tobacco use			
Never	3684 (14.3)	53 (12.9)	.48
Past/current	22 137 (85.7)	357 (87.1)	
Family history of CAD	2865 (11.1)	55 (13.4)	.16
Hypertension	23 024 (89.2)	392 (95.6)	<.001
Hyperlipidemia	22 918 (88.8)	378 (92.2)	.04
Diabetes	8774 (34.0)	203 (49.5)	<.001
CHF	3849 (14.9)	119 (29.0)	<.001
Valve disease	1685 (6.5)	52 (12.7)	<.001
COPD	9127 (35.3)	160 (39.0)	.14
CAD	13 090 (50.7)	288 (70.2)	<.001
Atrial fibrillation	3789 (14.7)	64 (15.6)	.65
CKD	428 (1.7)	23 (5.6)	<.001
Procedure type			
CEA	11 189 (43.3)	126 (30.7)	<.001
CAS	2227 (8.8)	28 (6.8)	
EVAR	4645 (18.0)	45 (11.0)	
AAA	667 (2.6)	26 (6.3)	
Peripheral bypass	7043 (27.3)	185 (45.1)	

Abbreviations: AAA, abdominal aortic aneurysm; BMI, body mass index (calculated as weight in kilograms divided by height in meters squared); CAD, coronary artery disease; CAS, carotid artery stenting; CEA, carotid endarterectomy; CHF, congestive heart failure; CKD, chronic kidney disease; COPD, chronic obstructive pulmonary disease; EVAR, endovascular aortic aneurysm repair; MI, myocardial infarction.

[a] The other category includes American Indian, Asian, Pacific Islander, and other races.

Table 2. Logistic Regression for Postoperative Myocardial Infarction Following Major Vascular Surgery[a]

Term	Results From Logistic Regression, Odds Ratio (95% CI)	*P* Value
Age	1.032 (1.019-1.045)	<.001
Rural, %		
<25	1 [Reference]	NA
25-75	1.351 (1.021-1.788)	.04
>75	1.365 (1.023-1.821)	.04
Income quartile		
First	1 [Reference]	NA
Third	0.694 (0.501-0.962)	.03
Diabetes mellitus	1.514 (1.201-1.907)	<.001
Congestive heart failure	1.519 (1.163-1.983)	.002
Significant valve disease	1.447 (1.024-2.046)	.04
Coronary artery disease	1.381 (1.058-1.803)	.02
Preoperative medication: P2Y12 antagonist	1.365 (1.08-1.725)	.009
Electrocardiogram		
No test	1 [Reference]	NA
Normal results	0.515 (0.333-0.797)	.003
Open		
Abdominal aortic aneurysm	4.53 (2.73-7.517)	<.001
Bypass	2.375 (1.818-3.102)	<.001

Abbreviation: NA, not applicable.

[a] All variables from univariate analysis included in model; only significant estimates are shown. Carotid endarterectomy was used as the reference procedure for comparisons with logistic regression.

6958 [87.8%]; χ^2 = 23.99; *P* < .001), hyperlipidemia (16 539 [90.3%] vs 6757 [85.3%]; χ^2 = 139.87; *P* < .001), CAD (9462 [51.7%] vs 3916 [49.4%]; χ^2 = 11.02; *P* < .001), and atrial fibrillation (2823 [15.4%] vs 1030 [13.0%]; χ^2 = 34.91; *P* < .001).

Patients who had a normal ECG preoperatively were less likely to have a POMI (OR, 0.515; 95% CI, 0.33-0.797; *P* = .003). However, abnormal ECGs were common, with 13 700 patients (53.06%) without POMI having an abnormal ECG prior to the operation. Patients in the POMI cohort were also more likely to have an abnormal cardiac stress test result preoperatively (65 [15.9%] vs 2376 [9.2%]; χ^2 = 17.46; *P* < .001) and less likely to have a normal cardiac stress test (64 [15.6%] vs 5921 [19.1%]; χ^2 = 17.46; *P* < .001); however, 18 805 patients (71.7%) within this study did not undergo cardiac stress testing prior to their operation, which limited the ability to make meaningful assertions about the role of this potentially useful evaluation of cardiac reserve.

Mortality differed significantly between the 2 groups with a significant increase at 1 year among patients who experienced a POMI compared with those who did not (113 [37.4%] vs 993 [5.1%]; χ^2 = 589.3; *P* < .001). Among patients in the POMI cohort with data available for 1-year follow-up (n = 302), 1-year mortality based on procedure type was highest for open peripheral bypass (63 [45.32%]), EVAR (14 [41.18%]), and CAS (7 [33.33%]). In pairwise comparisons, only patients with POMI following open peripheral bypass had higher mortality at 1 year (63 [45.32%] vs 23 [26.44%]; χ^2 = 7.32; *P* = .049). Multiple-variable regression analysis demonstrated several comorbid conditions independently associated with mortality at 1 year including diabetes (OR, 1.35; 95% CI, 1.15-1.60; *P* < .001), congestive heart failure (OR, 1.93; 95% CI, 1.61-2.3; *P* < .001), and COPD (OR, 1.73; 95% CI, 1.48-2.02; *P* < .001). Postoperative myocardial infarction had the strongest association with death at 1 year of any variables test (OR, 5.62; 95% CI, 4.04-7.84; *P* < .001).

Univariate analysis of medications demonstrated that patients who experienced a POMI were more likely to be discharged while receiving statin therapy (318 [90.9%] vs 21 539 [86.9%]; χ^2 = 4.5; *P* = .034), warfarin (40 [12.7%] vs 1885 [8.1%]; χ^2 = 8.23; *P* = .004), and β-blockade (396 [82.7%] vs 14 774 [58.2%]; χ^2 = 86.23; *P* < .001). Patients who experienced POMI were more likely to be taking a P2Y12 antagonist preoperatively (169 [45.92%] vs 8398 [32.78%]; χ^2 = 27.77; *P* < .001). Patients who were taking P2Y12 therapy were found to have higher rates of transfusion both intraoperatively (443 [13.3%] vs 753 [8.2%]; χ^2 = 71.93; *P* < .001) and total during stay (874 [26.2%] vs 1505 [16.4%]; χ^2 = 150.79; *P* < .001). Regardless of therapy, transfusion (161 [62.9%] vs 2264 [18.3%]; χ^2 = 317.98; *P* < .001) occurred in a higher frequency at any time during the stay of patients who experienced a POMI, including a higher rate of intraoperative transfusion (80 [31.3%] vs 1138 [9.2%]; χ^2 = 137.12; *P* < .001).

We examined the POMI cohort for changes in medication regimens from admission to discharge to assess adherence to best medical practices. According to the 2014 American Heart Association/American College of Cardiology Guideline for the Management of Patients with Non-ST-Elevation Acute Coronary Syndromes, patients should be considered for antiplatelet therapy and statin therapy after a coronary event.[11] Additionally, β-blockade and angiotensin-converting enzyme inhibitor/angiotensin-receptor blocker therapy should be prescribed in patients with preserved left ventricular function after their event. Our analyses demonstrated significant increases in the use of β-blockers (255 [70.1%] to 296 [82.7%]; χ^2 = 12.97; *P* = .001), any anticoagulation (35 [8.5%] to 59 [14.4%]; χ^2 = 8.26; *P* = .004), warfarin (25 [6.1%] to 40 [12.7%]; χ^2 = 12.5; *P* < .001), and statin therapy (327 [83.6%] to 318 [90.9%]; χ^2 = 15.04; *P* < .001). A similar number of patients in the 2 cohorts were receiving antiplatelet therapy at discharge (335 [95.73%] vs 23 975 [93.6%]; χ^2 = 2.28; *P* = .13). A similar number of patients in each cohort were taking an angiotensin-converting enzyme inhibitor/angiotensin-receptor blocker at discharge (203 [56.39%] vs 13 697 [53.33%]; χ^2 = 1.21; *P* = .27).

Discussion

The rate of POMI seen in this study was 1.6% and was comparable with rates reported in recent literature.[6,9] However, the burden is not equally distributed among all vascular surgical procedures, with the highest incidence of POMI occurring in patients undergoing open AAA repair (3.75%) and peripheral arterial bypass (2.56%). This study identified several demographic and comorbid conditions that are different

between the cohorts of patients undergoing the lower-risk surgeries (EVAR, CAS, or CEA) and those undergoing high-risk surgeries (AAA, peripheral bypass). This included a heterogenous mixture of comorbidities. Namely, the low-risk group had a higher rate of hypertension, hyperlipidemia, valvular disease, CAD, and atrial fibrillation but lower rates of former/current tobacco abuse, diabetes, COPD, and chronic kidney disease. Of these listed, CAD, valvular disease, and diabetes were considered to be independent risk factors. Therefore, while the cohorts may be different in terms of comorbid status, the association of these differences with outcomes does not clearly benefit 1 cohort. Instead, the higher POMI rate is likely driven by the physiologic derangements associated with the procedure and recovery rather than completely reliant on comorbid status. As such, patients in this high-risk population may warrant a more aggressive preoperative evaluation and preparation.

Preoperative cardiac evaluation, and ensuing revascularization, remains a varied practice, as was recapitulated here. The CARP (Coronary-Artery Revascularization before Elective Major Surgery) trial demonstrated no survival benefit for patients who had undergone revascularization vs those who progressed straight to their vascular surgery.[12] However, this trial excluded many patients with left main disease, a factor that has been shown to be independently predictive of POMI.[13]

In our study groups, preoperative use of ECG was very common. Consistent with our findings, previous research has demonstrated a higher rate of POMI among patients with abnormal ECG, but ECG alone may lack specificity for predicting POMI as many patients with POMI had abnormal ECGs.[14] Cardiac stress testing may be a more efficient method to delineate the functional effect of any coronary lesion, presumably assessing the patient's response to the physiologic stresses of intraoperative physiologic swings that may increase POMI risk.[9] For example, after major aortic surgery, patients with an abnormal stress test result are 3.7-times more likely to have a postoperative coronary event.[13] However, nearly 70% of patients overall did not undergo any preoperative stress testing. Current data are conflicted regarding the utility of stress echocardiography in isolation to predict postoperative cardiac complications.[15,16] While routine preoperative cardiology consultation does not reduce the risk of POMI, the value of pursuing consultation in the setting of an abnormal stress test may be a prudent strategy to manage risks.[14]

Here, we found that among anticoagulants, statin therapy, and antiplatelet agents, only P2Y12 inhibitors taken in the preoperative setting were associated with POMI. The reason for this is not immediately clear but may be a surrogate for greater coronary atherosclerosis risk burden or use in those with drug-eluting stents. Unfortunately, the BMC2 database does not allow for determination of the indications for anti-platelet therapy. Nonetheless, with controlling for CAD, P2Y12 therapy remained independently associated with POMI. Interestingly, previous literature has demonstrated resistance of platelets to antiplatelet therapy with aspirin following intravenous heparin administration during vascular surgery.[17] When taken together with our data, this may suggest resistance to dual antiplatelet therapy as conferring increased risk for POMI among some patients thought to be protected by these therapies. Further, our study demonstrated that patients receiving P2Y12 therapy have higher rates of transfusions both in the operating room and total for their stay, which was also associated with an increased rate of POMI. Patients who experienced a POMI had a much higher rate of transfusion both in the operating room and during the total stay. These data are consistent with previous evidence regarding the effect of intraoperative characteristics such as blood loss on POMI rates.[9,18] However, within this study, intraoperative characteristics, such as hypotension or anemia, that may contribute to the decision to transfuse were not reliably captured. Further, we do not have data regarding transfusion threshold within these 2 groups. To that end, the association with postoperative transfusions may actually be that patients with POMI typically have a more liberal transfusion threshold, leading to increased rates of transfusion, a relative reversal of the suggested relationship.

One of the most important findings of this study is the late high mortality associated with POMI. In this study, POMI had the strongest independent association of all comorbid conditions tested. The mortality rate at 1 year for patients who experienced a POMI was nearly 40%, dramatically higher than the mortality rate after either uncomplicated vascular surgery or even acute coronary syndrome in the general population.[5] To highlight the severity of this effect, recent estimates from high-volume aortic centers show that there is a 23% mortality rate for open aortic surgery even in the highest-risk patients; namely, those with advanced age, elevated creatinine levels, and COPD in cases in which suprarenal clamping is used.[19] Mortality rates remained high for those who experienced a POMI despite the index vascular procedure, suggestive that the myocardial infarction itself may contribute more to mortality than procedure type. Further, those who experience a POMI, either associated with ECG changes or troponin elevation only, continue to have elevated risk of mortality even as long as 5 years after their operation.[3]

Current American Heart Association/American College of Cardiology guidelines for patients following non-ST-elevation myocardial infarction recommends continued therapy with β-blockade (level of evidence: A), aspirin (level of evidence: A), and P2Y12 inhibition (level of evidence: B).[11] Here, we demonstrated preoperative β-blockade was not associated with a protective effect for POMI after vascular surgery. In fact, more than 70% of patients who experience a POMI were already receiving preoperative β-blockade, compared with 57% of patients without myocardial infarction ($P < .001$). These results corroborate previous findings demonstrating minimal effect of β-blockers to lower cardiac complication rates and highlight the shortcoming of relying on these mediations for cardiovascular protection.[20,21] Conversely, β-blockade after POMI decreases mortality rates among patients who have undergonevascular surgery.[21] However, its effects may be limited, as 83% of patients who

experienced a POMI were discharged while taking β-blockade, yet the mortality rate remained very high at 1 year.

The potential cardio-protective benefit of oral anticoagulants, especially of direct oral anticoagulants, has garnered recent interest. In the MANAGE trial, patients with myocardial injury after noncardiac surgery benefitted from the addition of dabigatran to their discharge regimen, measured by a composite outcome rate including major vascular complications, myocardial infarction, or mortality.[22] In our data set, there was an overall low use of direct oral anticoagulants (approximately 5%), so we could not evaluate the potential effect. However, patients with POMI were more likely to be discharged while taking warfarin, even when not taking this medication at admission, suggesting it is potentially being used to reduce ongoing risk after POMI in the community setting. Appropriately, there was a high rate of discharge while taking statin and antiplatelet therapy after POMI, the absence of which has been shown to negatively affect long-term survival in this population.[23] The persistently high rates of mortality after POMI, even when receiving appropriate medical therapy, demonstrate the need for intense cardiovascular follow-up after discharge for these patients and the need for novel therapies. Moreover, there are no evidence-based guidelines for use of cardiac catherization after POMI, although retrospective reviews have found intervention in this setting to have limited effectiveness.[21]

Limitations

This study has several limitations. The effect of regional variability, which has been associated with changes in POMI rates, could not be evaluated here.[24] Given that the BMC2 database captures data within only 1 state (Michigan), we were unable to assess the potential effect this may have had. We were also unable to assess adherence to the prescribed medical regimens, which may affect the accuracy of assertions regarding their effect on POMI mortality rates especially. We were not able to capture any postoperative coronary revascularization for patients who experienced a POMI, although previous literature has not found it to be beneficial.[21] Finally, one limitation that warrants particular consideration is that we were unable to determine the cause of death at 1 year among the patients who died. Therefore, strict assertions as to the causal role of POMI in patients' mortality cannot be made and instead the relationship of POMI to death at 1 year is associative only.

Conclusions

The rate of POMI among patients undergoing open AAA repair or peripheral bypass is high. Patients with diabetes, CAD, or congestive heart failure appear to be at the highest risk. Preoperative stress testing may be beneficial in predicting POMI but is not often used. Despite high rates of discharge with cardioprotective medications, the long-term burden is substantial, with a mortality rate of 37% in the following year for this cohort, highlighting the need for more efforts to prevent POMI occurrence.

ARTICLE INFORMATION

Accepted for Publication: September 21, 2019.

Published Online: December 4, 2019. doi:10.1001/jamasurg.2019.4908

Author Contributions: Dr Henke had full access to all of the data in the study and takes responsibility for the integrity of the data and the accuracy of the data analysis.
Concept and design: Beaulieu, Sutzko, Osborne, Henke.
Acquisition, analysis, or interpretation of data: All authors.
Drafting of the manuscript: Beaulieu, Albright, Henke.
Critical revision of the manuscript for important intellectual content: Beaulieu, Sutzko, Jeruzal, Osborne, Henke.
Statistical analysis: Beaulieu, Albright, Osborne.
Administrative, technical, or material support: Beaulieu, Sutzko, Jeruzal, Henke.
Supervision: Henke.

Conflict of Interest Disclosures: None reported.

Disclaimer: Although Blue Cross Blue Shield of Michigan and the University of Michigan work collaboratively, the opinions, beliefs, and viewpoints expressed by the author do not necessarily reflect the opinions, beliefs, and viewpoints of Blue Cross Blue Shield of Michigan or any of its employees.

Meeting Presentation: This article was presented at the 43rd Annual Meeting of the Association of VA Surgeons Surgical Symposium; April 30, 2019; Seattle, Washington.

Additional Contributions: Support for Blue Cross Blue Shield of Michigan Cardiovascular Collaborative is provided by the Blue Cross Blue Shield of Michigan and Blue Care Network as part of the BCBSM Value Partnerships program.

REFERENCES

1. Eagle KA, Rihal CS, Mickel MC, Holmes DR, Foster ED, Gersh BJ. Cardiac risk of noncardiac surgery: influence of coronary disease and type of surgery in 3368 operations: CASS Investigators and University of Michigan Heart Care Program: Coronary Artery Surgery Study. *Circulation*. 1997;96(6):1882-1887. doi:10.1161/01.CIR.96.6.1882

2. Juo Y-Y, Mantha A, Ebrahimi R, Ziaeian B, Benharash P. Incidence of myocardial infarction after high-risk vascular operations in adults. *JAMA Surg*. 2017;152(11):e173360. doi:10.1001/jamasurg.2017.3360

3. Simons JP, Baril DT, Goodney PP, et al; Vascular Study Group of New England. The effect of postoperative myocardial ischemia on long-term survival after vascular surgery. *J Vasc Surg*. 2013;58(6):1600-1608. doi:10.1016/j.jvs.2013.06.062

4. Jones MR, Howard G, Roubin GS, et al; CREST Investigators. Periprocedural stroke and myocardial infarction as risks for long-term mortality in CREST. *Circ Cardiovasc Qual Outcomes*. 2018;11(11):e004663. doi:10.1161/CIRCOUTCOMES.117.004663

5. Myerson M, Coady S, Taylor H, Rosamond WD, Goff DC Jr; ARIC Investigators. Declining severity of myocardial infarction from 1987 to 2002: the Atherosclerosis Risk in Communities (ARIC) Study. *Circulation*. 2009;119(4):503-514. doi:10.1161/CIRCULATIONAHA.107.693879

6. Bertges DJ, Neal D, Schanzer A, et al; Vascular Quality Initiative. The Vascular Quality Initiative Cardiac Risk Index for prediction of myocardial infarction after vascular surgery. *J Vasc Surg*. 2016;64(5):1411-1421.e4. doi:10.1016/j.jvs.2016.04.045

7. Ford MK, Beattie WS, Wijeysundera DN. Systematic review: prediction of perioperative cardiac complications and mortality by the Revised Cardiac Risk Index. *Ann Intern Med*. 2010;152(1):26-35. doi:10.7326/0003-4819-152-1-201001050-00007

8. Bertges DJ, Goodney PP, Zhao Y, et al; Vascular Study Group of New England. The Vascular Study Group of New England Cardiac Risk Index (VSG-CRI) predicts cardiac complications more accurately than the Revised Cardiac Risk Index in vascular surgery patients. *J Vasc Surg*. 2010;52(3):674-683. doi:10.1016/j.jvs.2010.03.031

9. Sutzko DC, Andraska EA, Obi AT, Henke PK, Osborne NH. Risk factors associated with perioperative myocardial infarction in major open vascular surgery. *Ann Vasc Surg*. 2018;47:24-30. doi:10.1016/j.avsg.2017.08.030

10. Thygesen K, Alpert JS, Jaffe AS, et al; Joint ESC/ACCF/AHA/WHF Task Force for the Universal Definition of Myocardial Infarction. Third universal definition of myocardial infarction. *Circulation*. 2012;126(16):2020-2035. doi:10.1161/CIR.0b013e31826e1058

11. Amsterdam EA, Wenger NK, Brindis RG, et al; ACC/AHA Task Force Members. 2014 AHA/ACC

guideline for the management of patients with non-ST-elevation acute coronary syndromes: a report of the American College of Cardiology/American Heart Association Task Force on Practice Guidelines. *Circulation*. 2014;130(25):e344-e426. doi:10.1161/CIR.0000000000000134

12. McFalls EO, Ward HB, Moritz TE, et al. Coronary-artery revascularization before elective major vascular surgery. *N Engl J Med*. 2004;351(27):2795-2804. doi:10.1056/NEJMoa041905

13. Han SR, Kim Y-W, Heo S-H, et al. Frequency of concomitant ischemic heart disease and risk factor analysis for an early postoperative myocardial infarction after elective abdominal aortic aneurysm repair. *Ann Surg Treat Res*. 2016;90(3):171-178. doi:10.4174/astr.2016.90.3.171

14. Davis FM, Park YJ, Grey SF, et al. The clinical impact of cardiology consultation prior to major vascular surgery. *Ann Surg*. 2018;267(1):189-195. doi:10.1097/SLA.0000000000002014

15. Matyal R, Mahmood F, Park KW, Hess P. Preoperative stress testing in high-risk vascular surgery and its association with gender. *Gend Med*. 2010;7(6):584-592. doi:10.1016/j.genm.2010.11.002

16. Park KWT, Subramaniam K, Mahmood F, Shapiro F, Long S, Napoli D. Patients with positive preoperative stress tests undergoing vascular surgery. *J Cardiothorac Vasc Anesth*. 2005;19(4):494-498. doi:10.1053/j.jvca.2005.05.008

17. Webster SE, Payne DA, Jones CI, et al. Anti-platelet effect of aspirin is substantially reduced after administration of heparin during carotid endarterectomy. *J Vasc Surg*. 2004;40(3):463-468. doi:10.1016/j.jvs.2004.06.022

18. Obi AT, Park YJ, Bove P, et al. The association of perioperative transfusion with 30-day morbidity and mortality in patients undergoing major vascular surgery. *J Vasc Surg*. 2015;61(4):1000-9.e1. doi:10.1016/j.jvs.2014.10.106

19. Beck AW, Goodney PP, Nolan BW, Likosky DS, Eldrup-Jorgensen J, Cronenwett JL; Vascular Study Group of Northern New England. Predicting 1-year mortality after elective abdominal aortic aneurysm repair. *J Vasc Surg*. 2009;49(4):838-843. doi:10.1016/j.jvs.2008.10.067

20. Scali S, Patel V, Neal D, et al. Preoperative β-blockers do not improve cardiac outcomes after major elective vascular surgery and may be harmful. *J Vasc Surg*. 2015;62(1):166-176. doi:10.1016/j.jvs.2015.01.053

21. Henke PK, Zamora-Berridi G, Englesbe MJ, et al. A case-cohort study of postoperative myocardial infarction: impact of anemia and cardioprotective medications. *Surgery*. 2014;156(4):1018-1026, 1029. doi:10.1016/j.surg.2014.06.055

22. Devereaux PJ, Duceppe E, Guyatt G, et al; MANAGE Investigators. Dabigatran in patients with myocardial injury after non-cardiac surgery (MANAGE): an international, randomised, placebo-controlled trial. *Lancet*. 2018;391(10137):2325-2334. doi:10.1016/S0140-6736(18)30832-8

23. Steely AM, Callas PW, Hohl PK, Schneider DJ, De Martino RR, Bertges DJ. Underutilization of antiplatelet and statin therapy after postoperative myocardial infarction following vascular surgery. *J Vasc Surg*. 2018;67(1):279-286.e2. doi:10.1016/j.jvs.2017.06.093

24. Steely AM, Callas PW, Neal D, et al; Vascular Quality Initiative. Regional variation in postoperative myocardial infarction in patients undergoing vascular surgery in the United States. *Ann Vasc Surg*. 2017;40:63-73. doi:10.1016/j.avsg.2016.07.099