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Hemodynamic instability predicts in-hospital and 1-year mortality after transcarotid artery revascularization and transfemoral carotid stenting

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ABSTRACT

Objective: Blood pressure fluctuations are a common hemodynamic alteration following carotid artery stenting either with transfemoral (TFCAS) or transcarotid (TCAR) approach and are thought to be related to alteration in baroreceptor function due to angioplasty and stent expansion. These fluctuations are particularly worrisome in the high-risk patient population referred for CAS. This study aims to evaluate the outcomes of patients who required the administration of intravenous blood pressure medication (IVBPmed) for hypotension or hypertension after CAS.

Methods: All patients undergoing carotid revascularization in the Vascular Quality Initiative (VQI) database between 2016 and 2021 were included. We compared outcomes of patients who required postoperative IVBPmed to treat hyper- or hypotension with normotensive patients. In-hospital outcomes were compared using multivariable logistic regression. One-year outcomes were assessed using Kaplan-Meier survival and multivariable Cox proportional hazard regression analyses.

Results: We identified 38,510 patients undergoing CAS (57.7% TCAR and 42.3% TFCAS), of which, 30% received IVBPmed for treatment of either postoperative hypertension (12.6%) or hypotension (16.4%). In multivariable analysis, postoperative hypotension was associated with a higher risk of stroke, death, or myocardial infarction (MI) (odds ratio [OR], 3.1; 95% confidence interval [CI], 2.6-3.6; $P < .001$), stroke or death (OR, 2.9; 95% CI, 2.4-3.5; $P < .001$), stroke (OR, 2.6; 95% CI, 2.1-3.2; $P < .001$), death (OR, 3.5; 95% CI, 2.6-4.8; $P < .001$), MI (OR, 4.7; 95% CI, 3.3-6.7; $P < .001$), and bleeding (OR, 1.96; 95% CI, 1.4-2.7; $P < .001$) compared with normotensive patients. Postoperative hypertension was associated with a higher risk of stroke, death, or MI (OR, 3.6; 95% CI, 3-4.4; $P < .001$), stroke or death (OR, 3.3; 95% CI, 2.7-4.1; $P < .001$), stroke (OR, 3.7; 95% CI, 3-4.7; $P < .001$), death (OR, 2.7; 95% CI, 1.9-3.9; $P < .001$), MI (OR, 5.7; 95% CI, 3.9-8.3; $P < .001$), and bleeding (OR, 1.9; 95% CI, 1.4-2.7; $P < .001$) compared with normotensive patients.

Conclusions: Postoperative hypertension or hypotension requiring IVBPmed after CAS is associated with an increased risk of in-hospital stroke, death, MI, and bleeding. Postoperative hypertension is associated with worse survival at 1 year. This study indicates that the need for IVBPmed after CAS is not benign; therefore, these patients necessitate aggressive perioperative medical management and safe techniques to avoid hypo and hypertension. Close follow-up and continue medical management are needed to maximize these patients' survival. (J Vasc Surg 2023;78:446-53.)

Keywords: Carotid artery stenting; Carotid outcomes; Hemodynamic instability

Treatment of carotid artery stenosis using catheter-based interventions is an important means of stroke prevention, especially in patients that are at high risk for carotid endarterectomy due to medical comorbidities or hostile neck anatomy.[1,2] However, catheter-based interventions, specifically carotid artery stenting (CAS), either via the transfemoral (TFCAS) or transcarotid (TCAR) approach, are not without their own inherent risks.[3-6] One important concern is periprocedural hemodynamic instability (HI), defined as clinically significant changes in blood pressure or heart rate that occur either during the procedure or in the postprocedural period. In CAS, a catheter is advanced into the internal carotid artery, balloon angioplasty is followed by stent

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deployment, and the carotid artery plaque is remodeled and stabilized in a way such that the stenosis and the risk of embolization are reduced. Intravascular manipulation of the carotid bulb during balloon angioplasty and stent deployment may lead to subsequent hemodynamic alterations. Distention of the bulb may stimulate the baroreceptors, causing reflex inhibition of adrenergic output to the peripheral vasculature and, consequently, increased cardiac parasympathetic stimulation results.[7-9] This results in bradycardia and peripheral vasodilation, leading to profound hypotension. The stent continues to expand in the postoperative period, leading to persistent hypotension. Besides, patients with carotid artery stenosis may have developed altered vascular physiology and impaired autoregulation at baseline, and thus, there may be significant rebound hypertension.[7,10,11]

It is hypothesized that hemodynamic instability after CAS may be linked to poorer postoperative outcomes (for example, increased rates of postprocedural stroke, myocardial infarction [MI], and death).[1,12-15] As such, some patients undergoing CAS are treated with perioperative intravenous antihypertensive, vasopressor, or antiarrhythmic medications (IVBPmed) to prevent or treat HI early in its development.[10] But although many studies have previously evaluated the incidence, predictors, and outcomes of HI following CAS, there remains debate about its true clinical consequences. Furthermore, previous studies were conducted prior to the mainstream adoption of TCAR and thus, the impact of HI on outcomes of TCAR has not yet been fully elucidated. Therefore, it is the aim of this study to investigate the need for IVBPmed for the treatment of either hypotension or hypertension after CAS and its effects on postoperative and long-term outcomes, using real-world data from one of the largest national registries available.

ARTICLE HIGHLIGHTS

- **Type of Research**: Retrospective review of the prospectively collected Vascular Quality Initiative database
- **Key Findings:** In this study of 38,510 patients undergoing carotid artery stenting, 12.6% received intravenous blood pressure medication (IVBPmed) for treatment of postoperative hypertension and 16.4% for hypotension. Patients receiving IVBPmed for either hypotension or hypertension had higher odds of in-hospital stroke, death, myocardial infarction, and bleeding. Postoperative hypertension was associated with worse 1-year survival compared with normotensive patients.
- **Take Home Message:** Postoperative hypotension or hypertension requiring IVBPmed following transcarotid artery revascularization and transfemoral carotid artery stenting is associated with worse postoperative morbidity and mortality. These patients necessitate aggressive perioperative medical management and safe techniques to avoid significant complications.

METHODS

Dataset. We retrospectively reviewed patients undergoing TCAR and TFCAS in the Vascular Quality Initiative (VQI) database from September 2016 to October 2021. The VQI is a prospectively maintained registry of patients undergoing vascular procedures from more than 900 centers in the United States and Canada.[16] It contains data regarding patients' demographics, comorbidities, and procedural factors as well as postoperative and 1-year outcomes. This study was exempt from Institutional Review Board approval and patient consent due to the deidentified nature of the database.

Variables definition. Patients were classified into three groups according to their status of postoperative hemodynamic status: (1) normotensive patients; (2) patients requiring IVBPmed for hypotension; and (3) patients requiring IVBPmed for hypertension. Hypotension and hypertension were defined as the administration of a continuous IV infusion of a vasoactive medication more than 1 hour after the end of the surgery for the treatment of hypotension or hypertension, respectively, for greater than 15 minutes of infusion time or more than one dose of IV push/bolus vasoactive medication required 1 hour after the end of the surgery. We then compared the three groups with normotensive patients as the reference group. Baseline patient characteristics included demographics (age, sex, race, and ethnicity), preoperative symptomatic status, preoperative comorbidities (hypertension, diabetes, congestive heart failure, coronary artery disease [CAD], chronic obstructive pulmonary disease [COPD], chronic kidney disease [CKD], and hemodialysis), smoking history (none, prior, or current), degree of ipsilateral carotid artery stenosis, preoperative medications (aspirin, P2Y12 inhibitors, statins, beta-blockers, and anticoagulants), and prior cardiovascular procedures (major amputations, coronary artery bypass grafting or percutaneous coronary intervention, and prior carotid endarterectomy [CEA] or CAS). Procedure factors included urgency, anesthesia type (general or local/regional), and pre- and post-stent balloon angioplasty. Symptomatic status was defined as any history of ipsilateral amaurosis fugax, transient ischemic attack (TIA), or stroke within the 6 months prior to the procedure. TIA was defined as any focal neurological symptoms lasting no more than 24 hours, and stroke was defined as any focal neurological symptoms lasting more than 24 hours. CKD was defined as a preoperative estimated glomerular filtration rate of less than 60 mL/min, based on the preoperative creatinine level, using the Modification of Diet in Renal Disease study equation. Only patients with atherosclerotic or re-stenotic lesions were included. Patients with dissection, trauma, and unidentified carotid lesions were excluded from the analysis.

Outcomes. The primary outcome was the composite endpoint of in-hospital stroke, death, or myocardial infarction (MI). Secondary outcomes included the composite end point of in-hospital stroke or death and in-hospital stroke, death, bleeding requiring intervention, and MI as individual endpoints, and postoperative length of stay (LOS) more than 1 day, as well as 1-year mortality. In-hospital stroke was defined as any ipsilateral or contralateral cortical, retinal, or vertebrobasilar ischemic or hemorrhagic stroke following the index procedure and before hospital discharge. MI was reported by either the presence of electrocardiogram changes indicative of acute ischemia, ischemic symptoms such as angina or shortness of breath, or a rise in cardiac biomarkers, especially troponin.

Statistical analysis. Categorical variables were expressed as numbers and percentages. Continuous variables were conveyed as median with interquartile range or mean ± standard deviation. Baseline patient characteristics, as well as crude outcomes, were compared between normotensive vs hypotensive and normotensive vs hypertensive patients using the Pearson χ^2 and Fisher exact tests for categorical variables and analysis of variance or median test for continuous variables, as appropriate. In-hospital outcomes of hypotensive and hypertensive vs normotensive patients were evaluated using multivariable logistic regression analysis, adjusting for potential confounders such as demographics, comorbidities, preoperative medications, and procedural factors. Variable selection was done using stepwise backward and forward regression with a P value $< .1$. Clinically relevant variables were forced into the final models. Final models were clustered by center identifier to account for intra-group correlation and decrease bias from unmeasurable factors per institutional level. Model fit was evaluated using Hosmer-Lemeshow goodness of fit testing, and model accuracy was evaluated using area under the receiver operator curve. One-year mortality was evaluated using Kaplan-Meier survival analysis and multivariable Cox proportional hazard regression analyses, adjusting for potential confounders.

A P-value of $\leq .05$ was considered statistically significant. The above-mentioned analyses were executed using Stata version 17 SE software (StataCorp LP, College Station, TX).

RESULTS

Baseline characteristics. A total of 38,510 patients underwent TCAR (57.7%) and TFCAS (42.3%) during the study period, of whom 27,327 (71%) were normotensive postoperatively, 6405 (16.6%) required IVBPmed for hypotension postoperatively, and 4778 (12.4%) required IVBPmed for hypertension postoperatively. Compared with normotensive and hypertensive patients, hypotensive patients were more likely to be females (41% vs 35.2% vs 34.8%; $P < .001$), and to have a history of CAD (53% vs 49% vs 48.1%; $P < .001$), congestive heart failure (18.8% vs 16.8% vs 16.5%; $P < .001$), and COPD (27.7% vs 25.7% vs 24.3%; $P < .001$), respectively. Hypotensive patients were also more likely to undergo pre- (82.2% vs 80.6% vs 79.6%; $P = .004$) and post-stent balloon angioplasty (57.8% vs 50.7% vs 46.9%; $P < .001$), respectively. Compared with normotensive or hypotensive patients, hypertensive patients were more likely to be black (7.6% vs 5.2% vs 4.4%; $P < .001$), Hispanic (4.4% vs 3.7% vs 4%; $P = .047$), and symptomatic (39.4% vs 32.5% vs 32.2%; $P < .001$). Hypertensive patients were also more likely to have a history of diabetes (42.8% vs 38.3% vs 38.3%; $P < .001$), hypertension (93.5% vs 89.9% vs 89.6%; $P < .001$), and CKD (39.3% vs 36.6% vs 35.2%; $P < .001$), respectively. A comparison between the three groups' characteristics is detailed in Table I.

Predictors of postoperative hypotension. In a multivariable setting, female gender, age, history of CAD, contralateral occlusion, and post-stent balloon angioplasty were all predictive of postoperative hypotension requiring IVBPmed. Patients with preoperative hypertension, symptomatic presentation, preoperative beta-blocker use, prior ipsilateral CEA, prior ipsilateral CAS, and CKD had lower odds of experiencing postoperative hypotension requiring IVBPmed (Fig 1).

Predictors of postoperative hypertension. In a multivariable setting, African Americans, history of diabetes, hypertension, CKD, prior ipsilateral CEA, symptomatic presentation, beta-blocker use, American Society of Anesthesiologists class IV/V, and general anesthesia were all predictive of postoperative hypertension requiring IVBPmed. Patients with a history of COPD, preoperative statin or anticoagulant use, prior coronary artery bypass grafting/percutaneous coronary intervention, elective status, and post-stent balloon angioplasty had lower odds of experiencing postoperative hypertension requiring IVBPmed (Fig 2).

In-hospital outcomes. Major complications (stroke, MI, or bleeding requiring intervention) occurred in 1.6% of normotensive patients, 4.4% of hypotensive patients, and 5.8% of hypertensive patients. Postoperative hypotension requiring IVBPmed was associated with a higher risk of stroke, death, or MI (odds ratio [OR], 3.1; 95% confidence interval [CI], 2.6-3.6; $P < .001$), stroke or death (OR, 2.9; 95% CI, 2.4-3.5; $P < .001$), stroke (OR, 2.6; 95% CI, 2.1-3.2; $P < .001$), death (OR, 3.5; 95% CI, 2.6-4.8; $P < .001$), MI (OR, 4.7; 95% CI, 3.3-6.7; $P < .001$), and bleeding (OR, 1.96; 95% CI, 1.4-2.7; $P < .001$), and LOS >1 day (OR, 5.6; 95% CI, 5.0-6.2; $P < .001$) compared with normotensive patients on both univariable and multivariable analysis.

Table I. Baseline characteristics of normotensive vs hypotensive vs hypertensive patients

	Normotensive (n = 27,327)	Hypotensive (n = 6405)	Hypertensive (n = 4778)	*P* value
Age, years	72 (66-79)	73 (66-79)	73 (66-79)	<.001
Sex				
Female	9631 (35.2)	2634 (41.1)	1665 (34.8)	<.001
Race				
Black	1410 (5.2)	280 (4.4)	365 (7.6)	<.001
Hispanic or Latino	1003 (3.7)	255 (4)	209 (4.4)	.047
Symptomatic stenosis	8885 (32.5)	2068 (32.3)	1881 (39.4)	<.001
Diabetes	10,462 (38.3)	2453 (38.3)	2043 (42.8)	<.001
Hypertension	24,502 (89.9)	5719 (89.6)	4448 (93.5)	<.001
CAD	13,351 (49)	3389 (53)	2289 (48.1)	<.001
CHF	4592 (16.8)	1202 (18.8)	788 (16.5)	<.001
COPD	7029 (25.7)	1776 (27.7)	1161 (24.3)	<.001
CKD	9777 (36.6)	2209 (35.2)	1828 (39.3)	<.001
Dialysis	353 (1.3)	93 (1.4)	96 (2)	.001
Preoperative medications				
Aspirin	24,020 (87.9)	5637 (88)	4177 (87.4)	.583
Anticoagulant	3857 (14.1)	887 (13.9)	623 (13)	.138
Beta blocker	14,941 (54.7)	3464 (54.1)	2796 (58.5)	<.001
Statin	23,710 (86.8)	5602 (87.5)	4087 (85.6)	.012
Angiotensin-converting enzyme inhibitors	13,979 (51.2)	3414 (53.3)	2565 (53.7)	<.001
P2Y12 antagonists	22,709 (83.1)	5329 (83.2)	3962 (83)	.936
ASA class (IV-V)	6156 (23.3)	1520 (24.6)	1394 (30)	<.001
Current smoker	6575 (24.1)	1492 (23.3)	1140 (23.9)	.451
Prior CABG/PCI	10,578 (38.7)	2567 (40.1)	1767 (37)	.004
Prior ipsilateral CEA	4564 (16.7)	345 (5.4)	956 (20)	<.001
Prior ipsilateral CAS	795 (2.9)	113 (1.8)	143 (3)	<.001
Prior contralateral CEA/CAS	4467 (16.4)	1002 (15.7)	831 (17.4)	.047
Contralateral occlusion	2584 (10.1)	688 (11.5)	457 (10.1)	.006
Ipsilateral stenosis ≥80%	13,517 (52.1)	3109 (51.2)	2434 (53.1)	.140
Elective	22,931 (83.9)	5248 (82)	3624 (75.9)	<.001
Anesthesia				
General/converted to general	15,030 (55.1)	3555 (55.6)	3045 (63.8)	<.001
Post-stent balloon angioplasty	13,688 (50.7)	3665 (57.8)	2214 (46.9)	<.001
Pre-stent balloon angioplasty	19,173 (80.6)	4757 (82.2)	3331 (79.6)	.004

ASA, American Society of Anesthesiologists; *CABG*, coronary artery bypass graft; *CAD*, coronary artery disease; *CAS*, coronary artery stenting; *CEA*, carotid endarterectomy; *CHF*, congestive heart failure; *CKD*, chronic kidney disease; *COPD*, chronic obstructive pulmonary disease; *PCI*, percutaneous coronary intervention.
Data are presented as number (%) or median (interquartile range).

Postoperative hypertension requiring IVBPmed was associated with a higher risk of stroke, death, or MI (OR, 3.6; 95% CI, 3-4.4; $P < .001$), stroke or death (OR, 3.3; 95% CI, 2.7-4.1; $P < .001$), stroke (OR, 3.7; 95% CI, 3-4.7; $P < .001$), death (OR, 2.7; 95% CI, 1.9-3.9; $P < .001$), MI (OR, 5.7; 95% CI, 3.9-8.3; $P < .001$), bleeding (OR, 1.9; 95% CI, 1.4-2.7; $P < .001$), and LOS >1 day (OR, 2.3; 95% CI, 2.1-2.6; $P < .001$) compared with normotensive patients on both univariable and multivariable analysis (Tables II and III).

One-year survival for all patients. One-year survival for the whole cohort is 94.8% vs 92.0% vs 92.0% ($P < .001$) for normotensive vs hypotensive vs normotensive patients (Supplementary Fig, online only). On multivariate analysis, both hypotension and hypertension were associated with higher mortality (Table IV).

DISCUSSION

Since the advent of CAS as a treatment option for carotid artery disease, there has been much interest in

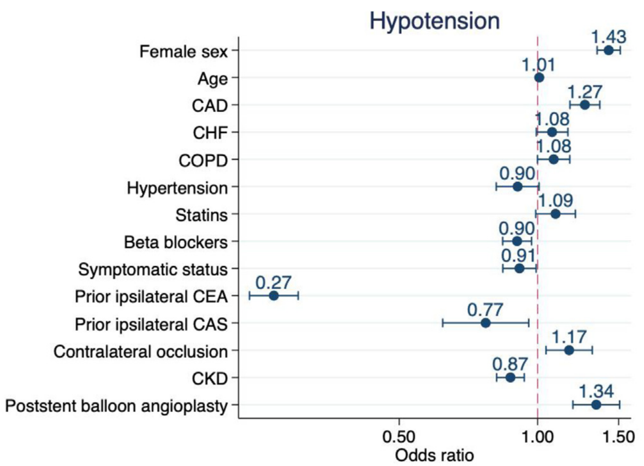

Fig 1. Predictors of postoperative hypotension requiring intravenous blood pressure medications (IVBPmed). *CAD*, Coronary artery disease; *CAS*, carotid artery stenting; *CEA*, carotid endarterectomy; *CHF*, congestive heart failure; *CKD*, chronic kidney disease; *COPD*, chronic obstructive pulmonary disease.

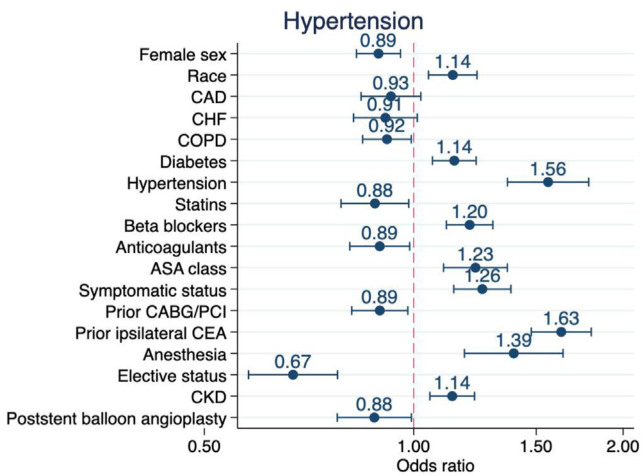

Fig 2. Predictors of postoperative hypertension requiring intravenous blood pressure medications (IVBPmed). *ASA*, American Society of Anesthesiologists; *CABG*, coronary artery bypass graft; *CAD*, coronary artery disease; *CEA*, carotid endarterectomy; *CHF*, congestive heart failure; *CKD*, chronic kidney disease; *COPD*, chronic obstructive pulmonary disease; *PCI*, percutaneous coronary intervention.

the refinement of the procedure as it can potentially be applied to a wider array of patients.[17,18] Ensuring that poor outcomes are prevented is exceedingly important for a procedure that is frequently performed for preventative reasons. Known complications after CAS include postprocedural stroke, MI, and death.[9,15,19-21]

In this study, it was revealed that there was a significantly increased risk of in-hospital stroke, death, MI, and bleeding as well as the composite endpoints of combined in-hospital stroke and death and combined in-hospital stroke, death and MI for patients that required intravenous medications for postprocedural blood pressure alterations, regardless of whether it was for hypertension or hypotension. The risk of in-hospital complications for the patients that experienced HI was several orders of magnitude greater than for patients that did not require IVBPmed. Post-procedural hypotension and hypertension in the postoperative period were significantly associated with slightly increased 1-year mortality relative to normotensive patients. It is difficult to infer as to why this was the result. It is also important to interpret these outcomes in the context of the preoperative status of these patients. Because hypotensive and hypertensive patients had relatively higher comorbidities compared with normotensive patients, this might have slightly contributed to their worse postoperative outcomes.

A previous similar study was performed by Arhuidese et al and demonstrated that periprocedural hemodynamic events are associated with an increase in the periprocedural stroke of up to four times the risk, as well as an increased risk of MI, death, and LOS. They advised that there is a critical need to anticipate and address these hemodynamic events during and after CAS to improve the outcomes of this procedure.[22] The results of this current study are consistent with this previous study and concur with the recommendation of prevention and early treatment of HI to ensure that patients do not require IVBPmed.

Understanding the association of HI and its relationship to postprocedural complications after CAS has been one area of focus in optimizing the CAS technique. It is hypothesized that HI occurs after CAS because there is a manipulation of the carotid baroreceptors during the procedure. Consequently, there is a rise in parasympathetic response leading to decreased vascular tone and resultant bradycardia and hypotension. Many patients with carotid artery stenosis also have developed altered vascular physiology and impaired autoregulation at baseline, and thus, there may be significant rebound hypertension.[7,10,11] These effects may persist into the postoperative period, and additionally, the coronary and cerebral vascular beds may be affected. Hence, patients experiencing HI are at risk for postoperative stroke, MI, and death, and many who perform carotid artery intervention have suspected that control of HI after CAS may result in improved outcomes for the patient. To combat this, parasympatholytic drugs can be administered intraoperatively during CAS and in the postoperative period. However, although IVBPmed after CAS have been a therapeutic consideration, there remains some debate regarding their true benefit. Many studies have demonstrated that the majority of incidents of HI after CAS are benign,[9,11,12,15,19] and opponents of IVBPmed use after CAS have postulated that prophylactic use of these medications may result in unnecessary hemodynamic strain, leading to increased cardiac or neurologic

Table II. Univariable analysis of in-hospital outcomes of hypotensive and hypertensive vs normotensive patients

	Normotensive, No. (%)	Hypotensive, No. (%)	Hypertensive, No. (%)	*P* value
Stroke/death	337 (1.2)	244 (3.8)	215 (4.5)	<.001
Stroke	253 (0.96)	162 (2.6)	175 (3.8)	<.001
Death	107 (0.4)	102 (1.6)	68 (1.4)	<.001
MI	61 (0.2)	72 (1.1)	62 (1.3)	<.001
Stroke/death/MI	392 (1.4)	300 (4.7)	267 (5.6)	<.001
Bleeding	129 (0.5)	58 (0.9)	45 (0.97)	<.001
LOS >1 day	6359 (23.3)	3813 (59.5)	2057 (43.1)	<.001

LOS, Length of stay; *MI*, myocardial infarction.

Table III. Multivariable analysis of in-hospital outcomes of hypotensive and hypertensive vs normotensive patients

	Stroke/death[a]		Stroke[b]		Death[c]		MI[d]		Stroke/death/MI[e]		Bleeding[f]	
	OR (95% CI)	*P*	OR (95% CI)	*P*	OR (95% CI)	*P*	OR (95% CI)	*P*	OR (95% CI)	*P*	OR (95% CI)	*P*
Normotensive	Reference											
Hypotensive	2.9 (2.4-3.5)	<.001	2.6 (2.1-3.2)	<.001	3.5 (2.6-4.8)	<.001	4.7 (3.3-6.7)	<.001	3.1 (2.6-3.6)	<.001	1.96 (1.4-2.7)	<.001
Hypertensive	3.3 (2.7-4.1)	<.001	3.7 (3-4.7)	<.001	2.7 (1.9-3.9)	<.001	5.7 (3.9-8.3)	<.001	3.6 (3-4.4)	<.001	1.9 (1.4-2.7)	<.001

CI, Confidence interval; *MI*, myocardial infarction; *OR*, odds ratio.
[a]Adjusting for gender, procedure type, age, coronary artery disease, diabetes, prior major amputation, preoperative P2Y12 inhibitors, smoking status, American Society of Anesthesiologists classification, symptomatic status, prior ipsilateral carotid stenting, contralateral occlusion, anesthesia, chronic kidney disease, and urgency.
[b]Adjusting for gender, procedure type, age, race, diabetes, preoperative P2Y12 inhibitors, preoperative aspirin, American Society of Anesthesiologists classification, symptomatic status, prior contralateral carotid stenting or endarterectomy, contralateral occlusion, chronic kidney disease, and urgency.
[c]Adjusting for gender, procedure type, age, coronary artery disease, congestive heart failure, hypertension, prior major amputation, preoperative P2Y12 inhibitors, smoking status, American Society of Anesthesiologists classification, symptomatic status, prior ipsilateral carotid stenting, prior contralateral carotid stenting or endarterectomy, anesthesia, chronic kidney disease, and urgency.
[d]Adjusting for age, coronary artery disease, diabetes, American Society of Anesthesiologists classification, symptomatic status, and chronic kidney disease.
[e]Adjusting for gender, procedure type, age, coronary artery disease, diabetes, prior major amputation, preoperative P2Y12 inhibitors, smoking status, American Society of Anesthesiologists classification, symptomatic status, contralateral occlusion, anesthesia, chronic kidney disease, and urgency.
[f]Adjusting for procedure type, age, diabetes, hypertension, preoperative P2Y12 inhibitors, preoperative aspirin, smoking status, preoperative anticoagulants, symptomatic status, prior contralateral carotid stenting or endarterectomy, contralateral occlusion, and urgency.

Table IV. One-year survival of hypotensive and hypertensive vs normotensive patients

	One-year survival	
	aHR[a] (95% CI)	*P* value
Normotensive	Reference	
Hypotensive	1.3 (1.2-1.5)	<.001
Hypertensive	1.3 (1.1-1.5)	<.001

aHR, Adjusted hazard ratio; *CI*, Confidence interval.
[a]Adjusting for procedure type, age, coronary artery disease, congestive heart failure, chronic obstructive pulmonary disease, diabetes, preoperative aspirin, American Society of Anesthesiologists classification, symptomatic status, contralateral occlusion, anesthesia, and urgency.

stress.[14] Still, other studies have shown that there is a decreased incidence of postoperative complications with prophylactic and early treatment of HI.[22] In a single institution study performed by Ullery et al, although patients with clinically significant hemodynamic instability were more likely to experience a periprocedural stroke compared with other patients, there were no significant differences in the incidence of mortality or other major complications.[14]

Other studies have demonstrated that post-stent ballooning increases the risk of HI and is associated with a significant increase in the risk of stroke or death following TFCAS.[23,24] Thus, the recommendation to avoid post-stent ballooning was first advocated in these studies. On the other hand, post-stent ballooning did not increase the risk of stroke but was associated with an increased risk of HI and TIA following TCAR in large multi-institutional analysis.[25] It is a standard practice to prophylactically use atropine or other equivalent medications just prior to angioplasty and stenting to reduce the risk of hypotension and bradycardia.

In our current analysis, we have identified that preoperative beta blocker use is associated with reduced risk of hypotension. Prior study has demonstrated that beta blockers are protective against stroke and death following TFCAS specifically in patients who developed postoperative hypertension.[26] However, we found that preoperative beta blocker use is associated with a higher risk of postoperative hypertension. A possible explanation for that is that hypertensive patients, who are at increased risk of postoperative hypertension, are more likely to be on preoperative beta blockers. So, it can be referred to as association, but not causation. We have also identified general anesthesia as a predictor of postoperative hypertension. Prior studies have also demonstrated performing TFCAS under general anesthesia is associated with 43% increased odds of postoperative hypertension.[27] Our study findings confirm these prior analyses and identify few modifiable risk factors to reduce the risk of HI following CAS. These recommendations include avoiding poststent ballooning, performing the procedure under local/regional anesthesia, and maximizing perioperative medication such as beta blockers and statins. In addition, a prior study of 878 patients undergoing CEA showed that routine cardiology consultation before elective CEA in patients with asymptomatic carotid stenosis reduced perioperative cardiac complications and 5-year fatal cardiovascular events compared with a group of patients who received a preoperative cardiology consultation only in selected cases.[28] Therefore, patient referral to a cardiologist to maximize blood pressure 3 to 4 weeks before elective carotid artery stenting may result in a lower incidence of blood pressure changes following carotid interventions.

Two additional considerations are that, first, the frequency of HI has varied greatly in several large series studies, with one range being between 42% and 84%.[12,14] HI was noted to be present in 30% of all patients in this study, although the definition of HI in this study only included patients that were treated with IVBPmed. The definition of HI in other studies may be different; for example, some included patients with alterations in heart rate, specifically bradycardia,[22] and others did not include hypertension in their definition.[19,29] Additionally, TCAR has emerged in recent years as an important advancement of TFCAS, utilizing dynamic flow reversal to protect against distal embolization without needing to traverse the arch and lesion. This technique is fundamentally different from TFCAS, and there has previously not been a study that evaluates the impact of IVBPmed for the treatment of postoperative hypotension or hypertension in the context of TCAR.

LIMITATIONS

Limitations of this study include its retrospective design with follow-up data only being available for only up to 1 year. Data on the types of antihypertensives or vasopressors administered was unavailable, as well as the exact nature of the hemodynamic event which prompted the use of IVBPmed. Similarly, knowledge of outpatient medical regimens was not available, and this information may illustrate more clearly why 1-year survival was only significant for patients experiencing postoperative hypertension, but not postoperative hypotension. Lastly, information regarding carotid artery plaque morphology was not delineated in this study. It has been demonstrated that certain plaque characteristics like ulceration, intraplaque hemorrhage, thrombus, fibrous cap rupture, echolucency, or plaque thickness ≥3 mm confer a higher risk of complications to the patient; however, this was not controlled for during the analysis.[30]

CONCLUSIONS

Postoperative hemodynamic instability manifested by hypertension or hypotension requiring IVBPmed after CAS is associated with an increased risk of in-hospital stroke, death, MI, and bleeding. Postoperative hypotension and hypertension are associated with worse survival at 1 year following CAS. This analysis confirms prior studies' findings on avoiding post-stent ballooning. Close follow-up and aggressive medical management are needed to maximize these patients' survival.

AUTHOR CONTRIBUTIONS

Conception and design: NE, CC, MR, OA, RM, MM
Analysis and interpretation: NE, MM
Data collection: Not applicable
Writing the article: NE, CC, MR
Critical revision of the article: NE, OA, RM, MM
Final approval of the article: NE, CC, MR, OA, RM, MM
Statistical analysis: NE
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Overall responsibility: MM

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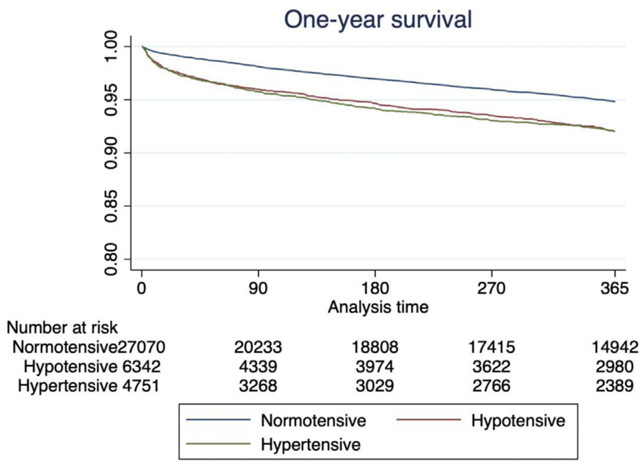

Supplementary Fig (online only). One-year survival.