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CAS-OPCABG vs OPCABG-alone in patients with asymptomatic carotid Stenosis: Multi-center experience

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ABSTRACT

Objective: The objective was to evaluate the relationship between carotid stenting and off-pump coronary artery grafting (CAS-OPCABG) and OPCABG only in patients with asymptomatic severe carotid stenosis.

Methods: This study retrospectively included 669 patients with asymptomatic severe carotid artery stenosis who underwent OPCABG at multiple centers. After propensity score matching for baseline characteristics, the study compared two groups of patients with clinical data, early and midterm death, stroke, and myocardial infarction (MI).

Results: After matching, there was no significant difference between two groups at baseline. The rates of early stroke, midterm stroke, and intensive care unit (ICU) stay were significantly lower in the CAS OPCABG group, yet the use of the internal mammary artery (IMA) was comparatively lower. Kaplan–Meier analysis revealed that there was no significant difference in midterm mortality between two groups. In the bilateral asymptomatic carotid stenosis subgroup, the early stroke rate was significantly lower after CAS-OPCABG, but there was no significant difference in the unilateral carotid stenosis subgroup. Multivariate logistic regression analysis identified previous atrial fibrillation, previous stroke, aortic atherosclerosis, bilateral carotid stenosis and the use of an intra-aortic balloon pump (IABP) as significant risk factors for early postoperative stroke, CAS emerged as a protective factor. Use of IMA was found to be a protective factor against postoperative mortality.

Conclusions: CAS-OPCABG is an efficacious and safe approach for the treatment of asymptomatic severe carotid artery stenosis, effectively decreasing the incidence of postoperative stroke.

1. Introduction

Stroke is a common complication after coronary artery bypass graft (CABG), which seriously affects the patient's prognosis. Once stroke occurs after CABG, the mortality rate increases to 32 %[1]. Several studies have demonstrated that severe carotid stenosis is an independent risk factor for stroke after CABG [2,3]. Carotid artery stenting (CAS) is an important treatment for carotid stenosis that is becoming an alternative procedure for patients with carotid stenosis combined with CABG because of its minimal invasiveness, local anesthesia, and low hemodynamic impact; moreover, CAS is effective in reducing the rate of postoperative stroke after CABG [4–6]. However, no study has confirmed whether prophylactic CAS should be performed preoperatively to reduce the incidence of stroke.

The choice of surgical approach between on-pump CABG (ONCABG) and off-pump CABG (OPCABG) is not clearly established. The advantage of OPCABG is less aortic manipulation, avoiding blood pressure fluctuations and the risk of bleeding due to cardiopulmonary bypass. OPCABG is effective in reducing the perioperative stroke rate of CABG compared with ONCABG [7,8]. OPCABG should be strongly considered in high-risk patients. Therefore, this study compared the clinical outcomes of CAS-OPCABG and OPCABG alone for the treatment of asymptomatic carotid artery stenosis and investigated whether CAS is necessary for stroke prevention before OPCABG in patients with asymptomatic carotid artery stenosis.

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2. Methods

2.1. Participants and definitions

Patients with asymptomatic severe carotid stenosis who underwent OPCABG from January 2018 to December 2022 at Beijing Anzhen Hospital, Beijing Chaoyang Hospital, and Beijing Tiantan Hospital were included. Patients were divided into CAS-OPCABG group and OPCABG alone group according to whether they had CAS before OPCABG, of which 114 patients were in CAS-OPCABG group and 555 patients were in OPCABG alone group.The CAS-OPCABG group was divided into concomitant CAS-OPCABG group and staged CAS-OPCABG group according to whether the interval between CAS and OPCABG was more than 24 h. The interval between OPCABG and CAS in the staged group was 12.59 (2–21) days.

We used duplex ultrasound to diagnose carotid stenosis according to guideline recommendations, with severe stenosis of the carotid artery (≥70 % stenosis) defined as a combination of peak systolic velocity of 230 cm/s and an end-diastolic velocity of ≥ 100 cm/s or a peak systolic velocity ratio between the internal and common carotid artery of ≥ 4[9]. Asymptomatic was defined as patients with no significant neurologic symptoms or no history of transient ischemic attack, stroke, or black blindness within 6 months.

We used coronary angiography to determine the extent of coronary artery stenosis and selected appropriate patients for coronary bypass surgery based on guideline recommendations [10]. Inclusion criteria included patients with stable angina, unstable angina, and myocardial infarction. Exclusion criteria included age less than 18 years or more than 80 years, coagulation disorders, history of stroke within 6 months, history of other cardiac surgeries or coronary artery bypass grafting combined with other cardiac surgeries, and patients who failed to undergo carotid artery ultrasound for emergent coronary artery bypass grafting.

2.2. Carotid stenting technique

All patients had a carotid artery diameter reduction of greater than 70 %.Patients were examined by a neurologist, and the decision to perform carotid stenting was based on a multidisciplinary consultation opinion as well as the patient's wishes. Embolic protection devices were used in CAS in all patients.

2.3. Periprocedural anticoagulation protocol

All patients undergoing OPCABG alone received mono-antiplatelet therapy with aspirin (100 mg, QD) before admission and bridging anticoagulation with low molecular heparin therapy (0.6 mg,Q12h) after admission, which was discontinued 24 h before surgery. The anticoagulation regimen for concomitant CAS-OPCABG was the same as for the OPCABG alone. Staged CAS-OPCABG patients were treated with antiplatelet therapy with aspirin and clopidogrel after CAS until clopidogrel was discontinued 5 days before OPCABG. If the interval between CAS and OPCABG was < 5 days, bridging anticoagulation with low molecular heparin was applied. All patients resumed aspirin + clopidogrel early in the postoperative period, depending on drainage and bleeding risk. All received dual antiplatelet therapy for 1 year, after which clopidogrel was discontinued and aspirin was taken for life.

2.4. End points

The primary endpoints of the study were myocardial infarction, stroke, and death after cardiac surgery. All study follow-ups were from post-discharge telephone follow-up. Stroke was defined as localized cerebral dysfunction lasting more than 24 h and confirmed by imaging findings. Myocardial infarction was defined as serum creatine kinase-cardiac strip or troponin T levels more than twice the upper limit of normal, new pathological Q waves, a history of chest discomfort for at least 30 min, or new left bundle branch conduction block.

2.5. Statistical analyses

To reduce the effect of possible selective bias, patients in the CAS-OPCABG and OPCABG groups were matched 1:1 for PSM with a caliper value of 0.02, respectively. Matching factors included age, hypertension and previous PCI.

SPSS 26.0 statistical software was applied for PSM and analysis. Measurement data were expressed as mean ± standard deviation (SD), and *t*-test was used for comparison between groups. Count data were expressed as percentages (%), and the X^2 test or Fisher exact test was used for comparisonbetween groups. The Kaplan-Meier method was used to calculate survival rates and plot survivalcurves, and the Log-rank test was used for survival analysis. We used logistic regression for univariate analysis and variables with P-value < 0.10 in univariate analysis were entered into multivariate regression analysis. P-value < 0.05 was considered statistically significant.

3. Results

The mean age of the patients was 65.4 ± 7.5 years, with 64.6 ± 7.5 years in the CAS-OPCABG group and 65.6 ± 7.6 years in the OPCABG-alone group. The baseline data of the patients in both groups are shown in Table 1. PSM was performed for age, hypertension and previous PCI in both groups, and there was no significant difference in the baseline levels between the two groups after matching.

In terms of the OPCABG surgical operation, the IMA (internal mammary artery, IMA) utilization rate in the CAS-OPCABG group was lower than that in the OPCABG-alone group, and the remaining data showed no significant difference. Within 30 days after the operation, there were 3 cases of postoperative stroke in the CAS-OPCABG group, all of which were ischemic strokes and among which 2 patients had carotid stent-contralateral strokes and 1 patient had bilateral strokes; 46 patients in the OPCABG-only group had strokes, and all of them were ischemic strokes except for 1 case, and the difference between the two groups was statistically significant (P<0.05). Death, myocardial infarction, and complications within 30 days after surgery in both groups are summarized in Table 2. Logistic analysis and forest plotting of the risk factors for early postoperative mortality revealed that male sex, previous stroke, previous infarction, and early postoperative stroke were independent risk factors for early postoperative mortality. The use of IMA was an independent protective factor for early postoperative death (Fig. 1).

During a median follow-up period of 24 months, 6 patients died in the matched CAS-OPCABG group, and 34 patients died in the OPCABG-only group. Of these, 33.3 % (2/6) died from major adverse arrhythmic cardiac events (MACCEs) in the CAS-OPCABG group, and 47.5 % died from MACCEs in the OPCABG-only group. There were 6 S patients in the CAS-OPCABG group, all of whom had ischemic strokes and all of whom had CAS-contralateral strokes. The OPCABG-only group had 15 ischemic strokes, and the incidence of midterm stroke was lower in the CAS-OPCABG group than in the OPCABG-only group (*P*=0.04). There was no statistically significant difference in mortality (P=0.78), myocardial infarction (*P*=0.68), or revascularization (*P*=0.38) during follow-up. The follow-up results are shown in Table 2. Kaplan–Meier survival analysis showed no significant difference in follow-up mortality between the two combined surgical groups (log-rank, P=0.42; Fig. 2).

In patients with combined asymptomatic unilateral carotid stenosis, there were no significant differences between the CAS-OPCABG and OPCABG-only groups in terms of death, stroke, and infarction. In patients with bilateral stenosis, the early postoperative stroke rate was significantly lower in the CAS-OPCABG group than in the OPCABG-alone group (p = 0.03), and the differences in the remaining outcomes

Table 1
Baseline statistics and propensity score matching assessment for clinical characteristics of off-pump coronary artery bypass grafting (OPCABG) patients.

Clinical variables	Unmatched			Matched		
	CAS-OPCABG (N=114)	OPCABG only (N=555)	*P*	CAS-OPCABG (N=114)	OPCABG only (N=114)	*P*
Male sex(%)	102(89.5)	481(86.7)	0.42	102(89.5)	102(89.5)	>0.99
Age,years	64.6 ± 7.5	65.6 ± 7.6	0.18	64.6 ± 7.5	65.9 ± 6.7	0.16
Smoking(%)	66(42.2)	283(48.8)	0.18	66(57.9)	60(52.6)	0.42
Drinking(%)	39(34.2)	159(28.6)	0.24	39(34.2)	37(34.5)	0.78
Hypertension(%)	88(77.6)	381(68.7)	0.07	88(77.2)	92(80.7)	0.52
Diabetes(%)	52(46.6)	226(40.4)	0.33	52(45.6)	48(42.1)	0.59
Dyslipidemia(%)	49(42.2)	266(47.9)	0.34	49(43.0)	50(43.9)	0.89
COPD(%)	2(1.8)	3(0.5)	0.20	2(1.8)	1(0.9)	>0.99
Renal failure(%)	1(0.9)	6(1.1)	>0.99	1(0.9)	0(0)	–
Atrial fibrillation(%)	1(0.9)	17(3.1)	0.34	1(0.9)	5(4.4)	0.21
Previous stroke(%)	26(12.9)	114(20.2)	0.59	26(11.4)	31(18.4)	0.44
Previous MI(%)	24(21.6)	86(15.9)	0.15	24(21.1)	22(19.3)	0.74
Previous PCI(%)	18(16.4)	139 (24.5)	0.03	18(15.8)	20(17.5)	0.72
LVEF,%	59.8 ± 8.1	60.2 ± 8.1	0.56	59.8 ± 8.1	61.1 ± 9.5	0.22
Aortic atherosclerosis(%)	5(4.4)	25(4.5)	0.96	5(4.4)	10(8.8)	0.18
SBP(mmHg)	143.7 ± 14.8	143.7 ± 17.2	0.99	143.7 ± 14.8	145.0 ± 20.2	0.59
DBP(mmHg)	85.8 ± 6.9	84.6 ± 8.5	0.19	85.8 ± 6.9	87.5 ± 9.5	0.12
Laboratory parameters						
LDL-C(mmol/L)	3.79 ± 1.2	3.79 ± 1.6	>0.99	3.79 ± 1.2	3.55 ± 1.2	0.12
HLD-C(mmol/L)	0.98 ± 0.3	0.98 ± 0.3	0.98	0.98 ± 0.3	0.95 ± 0.3	0.39
Blood glucose(mmol/L)	6.4 ± 1.7	6.1 ± 1.8	0.14	6.4 ± 1.7	6.3 ± 1.9	0.50
Medication use						
CCB(%)	82(71.9)	368(66.3)	0.24	82(71.9)	89(78.1)	0.28
ACEI/ARB(%)	10(8.8)	36(6.5)	0.38	10(8.8)	8(7.0)	0.62
Acarbose(%)	19(16.7)	108(19.5)	0.49	19(16.7)	18(15.8)	0.86
Metformin(%)	42(36.8)	197(35.5)	0.79	42(36.8)	40(35.1)	0.78
Insulin(%)	9(7.9)	39(7.0)	0.74	9(7.9)	9(7.9)	>0.99
Statins(%)	110(96.5)	521(93.9)	0.27	110(96.5)	108(94.7)	0.52
Beta-blockers(%)	93(81.5)	425(76.6)	0.25	93(81.5)	96(84.2)	0.60
Aspirin(%)	110(96.5)	519(93.5)	0.22	110(96.5)	106(93.0)	0.24
P2Y12i(%)	90(78.9)	405(73.0)	0.19	90(78.9)	90(78.9)	>0.99
DOACs(%)	0(0)	12(2.2)	–	0(0)	4(3.5)	–
VKA(%)	1(0.9)	5(0.9)	>0.99	1(0.9)	1(0.9)	>0.99
Carotid Stenosis						
Bilateral(%)	77(67.5)	364(65.6)	0.69	77(67.5)	74(64.9)	0.67
Occlusion(%)	8(6.9)	64(11.1)	0.16	8(7.0)	13(11.4)	0.25
Coronary artery disease						
Left main disease(%)	6 (5.3)	32 (5.8)	0.83	6(5.3)	10(8.8)	0.30
LAD stenosis degree(%)	89.8 ± 5.3	90.0 ± 5.3	0.70	89.8 ± 5.3	89.8 ± 5.6	0.95
LCX stenosis degree(%)	85.3 ± 10.3	84.5 ± 11.7	0.53	85.3 ± 10.3	83.2 ± 11.1	0.15
RCA stenosis degree(%)	87.3 ± 15.2	87.5 ± 16.2	0.89	87.3 ± 15.2	84.9 ± 16.0	0.25
SYNTAX score	32.0 ± 4.2	32.1 ± 4.4	0.72	32.0 ± 4.2	31.8 ± 4.0	0.77

COPD,chronic obstructive pulmonary disease;MI, myocardial infarction;PCI, percutaneous coronary intervention; LVEF, left ventricular ejection fraction;SBP, systolic blood pressure;DBP, diastolic blood pressure; LDL-C, low density lipoprotein;HDL-C, high density lipoprotein; CCB, Calcium Channel Blockers;ACEI,Angiotensin-convertingenzymeinhibitors;ARB,Angiotensin Receptor Blockers; P2Y12i, P2Y12 inhibitor; DOACs,direct oral anticoagulants; VKA, Vitamin K antagonist;LAD, left anterior descending branch;LCX, left circumflex;RCA, Right Corona.
Values are presented as mean ± standard deviation or number (%) unless indicated otherwise.

were not statistically significant (Table 3).

Perioperative stroke influencing factors in patients with combined asymptomatic carotid stenosis combined with coronary artery bypass grafting were analyzed using logistic regression modeling. After univariate analysis, age, previous atrial fibrillation, previous stroke, aortic atherosclerosis, bilateral carotid stenosis, intra-aortic balloon pump (IABP) use and CAS were entered into a multifactorial analysis. The multifactorial analysis identified previous atrial fibrillation, previous stroke, aortic atherosclerosis, bilateral carotid stenosis and IABP use as independent risk factors for stroke in patients, and CAS was an independent protective factor (Table 4).

4. Discussion

To our knowledge, this study is the first to compare CAS-OPCABG and OPCABG alone in patients with asymptomatic severe carotid stenosis combined with coronary artery disease. The following findings were obtained from our study: (1) CAS was effective in reducing the incidence of stroke in OPCABG patients with asymptomatic severe carotid stenosis without increasing the risk of postoperative death. (2) Previous atrial fibrillation, previous stroke, aortic atherosclerosis, bilateral carotid stenosis and IABP use are risk factors for early postoperative stroke. (3) IMA does not increase the rate of stroke in OPCABG performed for asymptomatic severe carotid stenosis and reduces early postoperative mortality.

Perioperative stroke in CABG remains a serious complication affecting the prognosis of patients, and when it occurs, it can have a serious impact on the prognosis. Carotid stenosis is an important risk factor for perioperative stroke in CABG patients. For CABG patients with comorbid asymptomatic carotid stenosis, the 2018 ESC/EACTS Guidelines [10] on myocardial revascularization and 2023 ESVS guidelines [11] on the management of atherosclerotic carotid and vertebral artery disease recommend carotid revascularization in the presence of severe bilateral carotid artery stenosis/occlusion; carotid intervention is not recommended in patients with asymptomatic unilateral 70–99 % carotid stenosis. Klarin et al.[12] found that concomitant carotid endarterectomy and CABG (CEA-CABG) did not significantly reduce the 30-day postoperative stroke rate but increased the risk of death in patients with combined carotid stenosis compared with CABG alone. Concurrent CEA-CABG procedures were longer and more invasive; staged CEA-

Table 2
Propensity score matching assessment for operative characteristics、early outcomes and midterm outcomes of off-pump coronary artery bypass grafting (OPCABG) patients.

Clinical variables	Unmatched			Matched		
	CAS-OPCABG (N=114)	OPCABG only (N=555)	*P*	CAS-OPCABG (N=114)	OPCABG only (N=114)	*P*
CABG						
No.of grafts(%)	3.2 ± 0.7	3.1 ± 0.6	0.15	3.2 ± 0.7	3.2 ± 0.7	0.78
Complete revasclarization(%)	102(89.5)	513(92.4)	0.29	102(89.5)	101(88.6)	0.83
IMA(%)	58(50.9)	383(69.0)	<0.01	58(50.9)	83(72.8)	<0.01
Blood loss(ml)	755.3 ± 233.9	724.1 ± 219.5	0.17	755.3 ± 233.9	725.4 ± 217.3	0.32
Operative time(hours)	4.3 ± 0.8	4.5 ± 1.0	0.16	4.3 ± 0.8	4.2 ± 0.8	0.10
IABP(%)	3(2.6)	7(1.3 %)	0.39	3(2.6)	3(2.6)	>0.99
Early outcomes						
Death(%)	1 (0.9)	16 (2.9)	0.33	1 (0.9)	4(3.5)	0.37
Stoke(%)	3 (2.6)	46 (9.1)	0.03	3(2.6)	14(12.3)	0.01
MI(%)	1 (0.9)	5 (0.9)	>0.99	1 (0.9)	0(0)	–
Infection(%)	1 (1.8)	8(1.4)	>0.99	1 (0.9)	3(2.6)	0.62
Renal injury(%)	0(0)	4(0.9)	–	0(0)	3(2.6)	–
Atrial fibrillation(%)	27(23.7)	153(27.6)	0.39	27(23.7)	36(31.6)	0.18
Hypoxemia (%)	10(8.8)	34(6.1)	0.30	10(8.8)	6(6.0)	0.30
Re-operation(%)	1(0.9)	5(1.2)	>0.99	1 (0.9)	1(0.0)	>0.99
ICU stay(days)	1.6 ± 1.5	1.8 ± 2.5	0.50	1.6 ± 1.5	2.5 ± 3.9	0.03
Follow up						
Death(%)	6 (6.0)	34 (6.3)	0.72	6 (6.0)	7(6.1)	0.78
Stoke(%)	6 (5.2)	31 (5.6)	0.89	6 (5.2)	15(13.2)	0.04
MI(%)	4 (3.5)	17 (3.1)	0.78	4 (3.5)	2(1.8)	0.68
Revascularization(%)	4 (3.5)	9 (1.6)	0.25	4 (3.5)	8(7.0)	0.38

No.of grafts,number of grafts; IMA, internal mammary artery;IABP, intra-aortic balloon pump;ICU, intensive care unit;MI, myocardial infarction.
Values are presented as mean ± standard deviation or number (%) unless indicated otherwise.

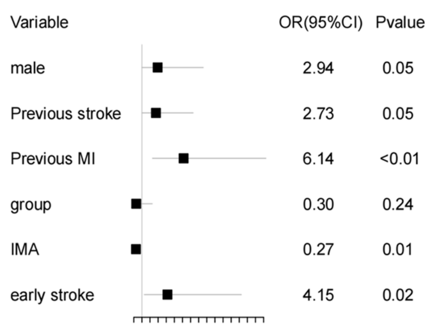

Fig. 1. Adjusted multivariable Logistic regression analysis for risk factors of early mortality; MI,myocardial infarction; group means CAS–OPCABG; IMA, internal mammary arteryMI, myocardial infarction;group,CAS-OPCABG;IMA, internal mammary artery.

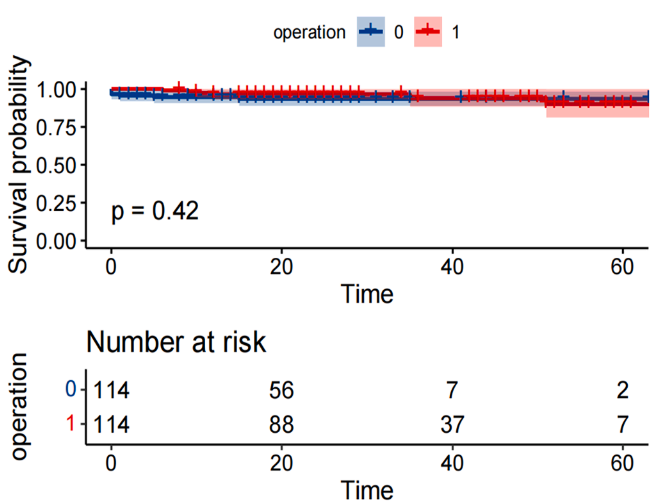

Fig. 2. Kaplan-Meier curve: X line: follow-up time since OPCABG (months). Y line: rate of freedom from composite events. 0:OPCABG alone 1:CAS-OPCABG.

Table 3
Early outcomes and midterm outcomes of CAS-OPCABG versus OPCABG only in unilateral carotid stenosis and bilateral carotid stenosis subgroups.

	CAS-OPCABG	OPCABG only	*P*
Unilateral carotid Stenosis			
N	37	191	–
Early outcomes			
Death(%)	0 (0)	3 (1.5)	–
Stroke(%)	1 (2.7)	8 (4.2)	>0.99
MI(%)	1 (0)	3 (1.2)	0.51
Follow up			
Death(%)	3(8.1)	10(5.2)	0.45
Stroke(%)	1(2.7)	6(3.1)	>0.99
MI(%)	2(5.4)	4(2.1)	0.25
Bilateral carotid Stenosis			
N	77	364	
Early outcomes			
Death(%)	1 (1.2)	13 (3.6)	0.48
Stroke(%)	2 (2.6)	38 (10.4)	0.03
MI(%)	0 (0)	2 (0.5)	–
Follow up			
Death(%)	3(3.9)	24(6.6)	0.60
Stroke(%)	5(6.5)	25(6.9)	0.91
MI(%)	2(2.6)	13(3.6)	>0.99

MI, myocardial infarction

CABG procedures received two general anesthetic strikes, significantly increasing the risk of perioperative infarction. In contrast, CAS-CABG is less invasive, avoids complex manipulation of the neck, and significantly increases the safety of the procedure, making CAS-CABG an effective alternative for treating CABG patients with combined asymptomatic severe carotid stenosis. However, the guidelines did not include studies comparing CAS-CABG with CABG alone, especially CAS-OPCABG, which is effectively addressed in this article.

This study retrospectively included patients who underwent OPCABG in the presence of asymptomatic severe carotid stenosis at three centers from 2018 to 2022, of whom 17.0 % underwent combined CAS-OPCABG, and the 30-day mortality and in-hospital stroke incidence rates for the CAS-OPCABG procedure were 0.9 % and 2.6 %, respectively, as previously observed in multiple studies after CAS-CABG early

Table 4
Analysis of perioperative stroke risk factors.

	Univariable		Multivariable	
	OR (95 %CI)	*P*	OR (95 %CI)	*P*
Male	1.14 (0.50,2.63)	0.76	–	–
Age	1.05 (1.00,1.09)	0.04	1.03(0.98,1.08)	0.23
Smoking	0.73(0.41,1.31)	0.29	–	–
Drinking	0.67(0.34,1.34)	0.26	–	–
Hypertension	0.79(0.43,1.46)	0.45	–	–
Diabetes	1.51(0.84,2.70)	0.17	–	–
Atrial fbrillation	9.22 (3.40,25.02)	<0.01	12.62 (3.82,41.77)	<0.01
LVEF	0.98 (0.94,1.00)	0.15	–	–
Previous MI	0.99(0.45,2.18)	0.98	–	–
Previous stroke	6.05 (3.31,11.04)	<0.01	7.83 (3.86,15.89)	<0.01
Previous PCI	0.94(0.47,1.89)	0.86	–	–
Bilateral carotid stenosis	2.37(1.32,4.28)	<0.01	2.82(1.42,5.62)	<0.01
Carotid stenosis occlusion	1.70(0.76,3.77)	0.20	–	–
IMA	0.67(0.37,1.21)	0.18	–	–
Blood loss(ml)	1.00(1.00,1.00)	0.24	–	–
IABP	9.10 (2.48,33.41)	<0.01	17.51 (3.89,78.81)	<0.01
Aortic atherosclerosis	10.8 (4.86,24.20)	<0.01	15.35 (5.91,39.88)	<0.01
Operative time	0.93(0.69,1.26)	0.64	–	–
Hipoksaemia	0.92(0.28,3.09)	0.89	–	–
CAS	0.30 (0.09,0.979)	0.05	0.11(0.02,0.50)	<0.01

LVEF,left ventricular ejection fraction;MI,myocardial infarction;PCI, percutaneous coronary intervention; IMA, internal mammary artery; IABP, intra-aortic balloon pump;CAS,carotid artery stenting.

mortality rates ranged from 2 % to 9 %, and stroke rates ranged from 3 % to 6 %[4,13–15]. The surgical results in this study were consistent with, and even better than, those previously published in the literature, and such results may be related to appropriate preoperative patient screening and the use of intraoperative brain protection devices for CAS. In this study, we found that CAS-OPCABG led to a statistically significant reduction in early and mid-term postoperative stroke compared with that in the OPCABG-only group. Of note, there were no fatal strokes in the CAS-OPCABG group but 4 fatal strokes in the OPCABG-only group. During follow-up, all strokes in the CAS-OPCABG group occurred on the side contralateral to the stent, whereas 77 % (24/31) of the patients in the OPCABG-only group experienced strokes on the side of the carotid stenosis or on the side of the stenosis that was more severe. Thus, CAS was effective in reducing the incidence of stroke after OPCABG.

In our study, we found that previous atrial fibrillation, previous stroke, aortic atherosclerosis, bilateral carotid stenosis, and IABP use all increased the risk of early postoperative stroke, while CAS was a protective factor against stroke. The results of several studies suggest that carotid revascularization should be performed before CABG in patients with carotid stenosis who have had a previous stroke [16–18]. In patients with combined bilateral asymptomatic carotid stenosis, the stroke rate after OPCABG was elevated 2.8-fold. At the same time, in the bilateral asymptomatic carotid stenosis subgroup, CAS-OPCABG significantly reduced stroke. In contrast, in the unilateral carotid stenosis subgroup, CAS did not significantly reduce the incidence of stroke, and the stroke rate was not significantly higher in patients with unilateral asymptomatic carotid stenosis who underwent OPCABG alone. Naylor [19] found postoperative stroke rates of 2 %-5.7 % in cardiac patients with asymptomatic unilateral carotid stenosis, and there is no compelling evidence supporting a role for prophylactic carotid artery revascularization in cardiac surgery patients with unilateral asymptomatic carotid disease. Therefore, the surgical indications for carotid artery surgery should be optimized in patients with asymptomatic carotid stenosis who are undergoing OPCABG, and patients with bilateral carotid artery stenosis should be aggressively managed with CAS for the prevention of carotid artery stenosis.

In this study, we found that use of the IMA did not increase the incidence of postoperative stroke after OPCABG or reduce the perioperative mortality in patients. Our analysis suggests that this survival and stroke benefit may be related to the fact that the IMA reduces the number of aortic perforations and thus reduces aortic manipulation. In addition, the IMA graft patency was higher, and the incidence of myocardial infarction was lower. Thus, the data from this study suggest that the IMA can be safely used in patients with CAS-OPCABG and may improve surgical outcomes and reduce early postoperative mortality in patients and that use of the IMA should be maximized in patients with OPCABG combined with asymptomatic carotid stenosis.

The limitations of this study are as follows. (1) Lesions of intracranial vessels are also important risk factors for stroke after CABG. An intracranial vascular examination was not performed in all patients preoperatively, and an improved cerebrovascular analysis is needed to clarify the effect of carotid artery stenosis on CABG stroke. (2) Asymptomatic carotid artery stenosis was defined based on a combination of medical history and preoperative head CT, but not all patients underwent a postoperative review of head CT, and some occult strokes were not detected. (3) The staging CAS-OPCABG interval in this study resulted in missing data, as some patients died while waiting for cardiac surgery. Future high-quality clinical studies with larger sample sizes are needed to further confirm the effectiveness of CAS for stroke prevention in patients with asymptomatic severe carotid stenosis who are undergoing CABG to determine the optimal regimen for their treatment.

5. Conclusion

CAS-OPCABG is a safe and effective treatment for patients presenting coronary artery disease combined with asymptomatic severe carotid artery stenosis. This procedure can effectively reduce the incidence of postoperative stroke in such patients without increasing the risk of death. Moreover, there is no significant difference in outcome between synchronous and staged surgery.

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Mingxiu Wen: Writing – review & editing, Writing – original draft, Project administration, Methodology, Formal analysis, Data curation, Conceptualization. **Jinzhang Li:** Writing – original draft, Methodology, Data curation. **Songhao Jia:** Investigation, Data curation. **Shipan Wang:** Investigation, Data curation. **Shuanglei Zhao:** Methodology, Data curation. **Pixiong Su:** Data curation. **Dong Xu:** Data curation. **Ming Gong:** Writing – review & editing, Writing – original draft, Supervision, Methodology, Investigation, Funding acquisition, Data curation.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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