Original Article

Vascular

Vascular
2023, Vol. 0(0) 1–10

DOI: 10.1177/17085381231160957
journals.sagepub.com/home/vas
SAGE

Carotid stenting: Does stent design matter?

Mohamed Shahat[1], Enrico Cieri[2], Joao Rocha-Neves[3] and Khairy SA[1]

Abstract

Background: Carotid artery stenting (CAS) is considered an important tool in carotid revascularization. Carotid artery stenting is usually performed by using self-expandable stent with different designs. The stent design influences many physical characteristics. Also, it may affect the complication rate with special relevance to perioperative stroke, hemodynamic instability, and late restenosis.

Methods: This study comprised all consecutive patients who underwent carotid artery stenting for atherosclerotic carotid stenosis from March 2014 to May 2021. Both symptomatic patient and asymptomatic patients were included. Patients with a symptomatic carotid stenosis of ≥50% or asymptomatic carotid stenosis of ≥60% were selected for carotid artery stenting . Patients with fibromuscular dysplasia and acute or unstable plaque were not included. Variables of clinical relevance were tested in multivariable analysis using binary logistic regression model.

Results: A total of 728 patients were enrolled. The majority of this cohort was asymptomatic (578/728, 79.4%), while 150/728 (20.6%) were symptomatic. The mean degree of carotid stenosis was 77.82 ± 4.73%, with a mean plaque length of 1.76 ± 0.55 cm. A total of 277 (38%) patients were treated with Xact® Carotid Stent System. Successful carotid artery stenting was achieved in 698 (96%) of patients. Of these patients, stroke rate in symptomatic patients was nine (5.8%), while in asymptomatic patients was 20 (3.4%). In a multivariable analysis, the open-cell carotid stent was not associated with a differential risk for combined acute and sub-acute neurologic complications as compared with closed-cell stents. Patients treated with open cell stents had a significantly lower rate of procedural hypotension (*P* 0.0188) at bivariate analysis.

Conclusion: Carotid artery stenting is considered a safe alternative to CEA that can be used in selected average surgical risk patient. Different stent designs can affect the rate of major adverse events in carotid artery stenting patients, but further studies are necessary with avoiding different bias to study the effect of different stent designs.

Introduction

Ischemic stroke is identified as a major cause of preventable disability, and it has a massive economic, medical, and social impact.[1] Although carotid endarterectomy (CEA) is still considered the gold standard for the treatment of carotid stenosis, it also carries significant drawbacks. The incidence of perioperative stroke of carotid endarterectomy varies from 1.5% to 3%, depending on the published series.[2,3] Carotid artery stenting (CAS) is considered complementary to CEA especially in centers with mature experience with this delicate procedure as the learning curve positively influences the complications rate. The less invasive nature and simplicity of CAS as compared to CEA make CAS a popular alternative to CEA.[4–6] CAS is an emerging procedure with an efficacy compared to CEA especially in high-risk surgical patient, and it represents the treatment of choice for surgically hostile lesions; moreover, the usage of embolic protection device surely reduces the risk of stroke and death.[7]

Different stents, with various designs and shapes, are available for stenting of the carotid artery. In general, closed-cell stents have a smaller cell size and less plaque protrusion through the stent struts than open-cell stents.[8] On the other hand, open-cell stents have better wall apposition and less thrombus formation outside the placed stent.[9] Multiple studies have demonstrated a predisposition of open-cell carotid stent configuration to strokes, in contrary closed-cell design has been associated with a higher risk of periprocedural hemodynamic instability (HI).[10,11]

[1]Department of Vascular and Endovascular Surgery, Assiut University Hospital, Assiut University, Assiut, Egypt
[2]Vascular and endovascular surgery unit university of Perugia, ospedale S.Maria della Misericordia, Perugia, Italy
[3]Department of Biomedicine – Unit of Anatomy, Faculdade de Medicina da Universidade do Porto, Portugal

Corresponding author:
Dr Mohamed Shahat, Assiut University Hospital, Department of Vascular and Endovascular Surgery, Faculty of Medicine, Assiut University, Assiut, Egypt.
Email: dms_here@yahoo.com

Hemodynamic instability (HI) is a precisely defined periprocedural complication following carotid angioplasty.[12] Some authors found a correlation between HI and cardiac or neurologic complication but, it is still a matter of debate.[13] The effect of stent design on the incidence of procedural HI is not well studied until now.[14]

Thereafter, closed-cell and open-cell devices have variable physical characteristics which control the risk of in-stent restenosis (ISR) and influence the primary patency of carotid stent.[15] Most studies found low ISR rates <20%, with only few predictors of ISR.[16]

The main aim of this study is to evaluate the role of stent design on the result of CAS.

Methods

-Population

This is a retrospective study of prospectively collected data comprising all consecutive patients who underwent CAS for atherosclerotic carotid artery stenosis from March 2014 to May 2018 in the Division of Vascular and Endovascular Surgery, University of Perugia, Perugia, Italy; and Department of Vascular and Endovascular Surgery, Assiut University Hospital, Assiut, Egypt. Both asymptomatic and symptomatic patients with carotid artery stenosis were included. Indications for CAS in our study were symptomatic carotid stenosis of ≥50% or asymptomatic carotid stenosis of ≥60%.[17,18] Patients with isolated common carotid artery (CCA) lesions, previous ipsilateral CEA, carotid stenosis due to fibromuscular dysplasia, and those with acute or unstable symptoms were excluded. Patients were extracted from the prospectively collected departmental database. The Institutional Review Board of the University of Perugia, Assiut University Hospital waived the need for ethics approval or informed consent for the use of anonymized and retrospectively analyzed data. This study was reported according to STrengthening the Reporting of OBservational studies in Epidemiology (STROBE) guidelines.[19] The study protocol is in congruence with the Helsinki Declaration.

All patients underwent duplex ultrasound (DUS) examination by a validated operator for detection of the degree of stenosis, diameters of both CCA and internal carotid artery (ICA), and specifying the plaque morphology according to Gray-Weale scale. All data were confirmed by computed tomography angiography (CTA). The degree of carotid stenosis was determined according to North American Symptomatic Carotid Endarterectomy Trial (NASCET). The Gray Weale scale was used to stratify carotid stenosis based on the internal carotid artery's peak systolic velocity (PSV) (ICA). The carotid stenosis was stratified into classes total occlusion, near occlusion, ≥70% stenosis to near occlusion, stenosis, 50–69% stenosis, <50%, and normal (no stenosis).[20] In addition, patients with isolated common carotid artery (CCA) lesions and >80 years were included, as well as those with bilateral carotid stenosis; however, they were treated by staged procedures with at least on month interval. CT brain was selectively performed to symptomatic patients.[3] Patients with carotid stenosis were considered too vulnerable group for cardiovascular events, so all patients underwent noninvasive testing for coronary artery disease (CAD). All patients underwent cardiac consultation and electrocardiogram even if they didn't have any CAD symptoms. Also, full neurological examination was carried out, and symptomatic patients were categorized according to the NIH Stroke Scale/Score (NIHSS).

Procedure

All patients scheduled for CAS received dual antiplatelet therapy consisting of aspirin (75 mg/day) and clopidogrel (300 mg) as a loading dose 12 h before the procedure. Antihypertensive drugs were continued except beta blocker withheld at the day of surgery since the prior use of beta blockers was associated with an increased adjusted risk for hypotension or bradycardia.[21]

All procedures were performed by experienced vascular surgeons, under local anesthesia and conscious sedation, in a hybrid operating room equipped with either a fixed digital angiographic system (Perugia) (Axiom Artis FA, Siemens Healthineers, Erlangen, Germany) or mobile C-arm (Assiut) (BV Pulsera, Philips Medical Systems, Eindhoven, the Netherlands).

Percutaneous transfemoral access was the standard utilized access in most of our patients left femoral and sometimes trans-radial access was used especially in aortoiliac occlusion bovine arch, and hostile arch patients. After sheath insertion, 100 IU/kg IV bolus of heparin was administered, and activated clotting time (ACT) was measured during the procedure, with a target range of 250–300 s. Afterward, angiography was performed in two different projections to confirm the diagnosis, measure the vessel diameter, and assess the intracerebral circulation to be used as a reference image in case of intra-operative complications.

Standard navigation guide wire was used to cannulate the aortic arch. Left anterior oblique (LAO) angle was used to open the aortic arch. Sim catheter was used to cannulate the left ICA, headhunter catheter was used to cannulate the right ICA, and then a standard guide wire was parked in middle CCA to avoid crossing the target lesion while the neuroprotection device was not employed. We usually inserted the long sheath inside the short one, as the short sheath was used for the measurement of pressure, and heparin infusion. We used Cordis VISTA BRITE TIP® IG, and once the sheath was stabilized in mid-CCA, heparin infusion

switched to the long sheath to provide continuous washing and prevent air embolism.

We deployed embolic protection device (EPD) routinely in our patients. We used distal filter type, and its wire was used as a working wire to accomplish the procedure only through it. The filter was deployed in the petrous part of ICA at least 3 cm away from the targeted lesion to allow sufficient space for manipulation and stent implantation. Distal filters (FilterWire EZ™, Boston Scientific, Marlborough, MA, USA) were used especially with concomitant contralateral occlusion or external carotid artery ECA occlusion. However, proximal occlusion balloon (Mo.Ma; Medtronic Inc., Santa Rosa, CA, USA) was sometimes used especially with vessel tortuosity (>120°); highly vulnerable plaque with large thrombotic burden was taken as a risk factor for the procedure.

Pre-stent balloon angioplasty, using 3–4 mm balloon, was performed selectively in cases of tight lesions. Stent diameter and length were selected according to artery diameter and lesion length from the diagnostic angiography. The type of stent was chosen according to the symptomatic state of the patient and plaque morphology. Our policy was to use closed-cell stent except in the case of vessel tortuosity and proximal CCA lesion. Xact™Rapid Exchange Carotid Stent (Abbot Vascular, Santa Clara, CA, USA) was the preferred stent in our cohort. Post-stent balloon dilatation, using 5–6 mm balloon at a pressure of 8–10 atm for 5 s, was performed routinely in all patients. Finally, completion angiography was performed in different views to assess both local and central results and detect possible complications

Following CAS procedures, vital signs and neurologic state were continuously monitored for a minimum of 24 h. Patients were usually discharged on the first postoperative day if no complications were encountered. Postoperatively, a regimen of aspirin (75 mg/day) and clopidogrel (75 mg/day) was maintained for a minimum of 1 month, after which aspirin was continued. Afterward, they were scheduled for routine follow-up visits comprising both physical and duplex ultrasound examination at our outpatient clinic after 1 month and then every 6 months thereafter. In patients with abnormal DUS (direct sign: >300 cm/s peak systolic velocity within or at the ends of the CCA stent), significant (>70%) ISR was suspected. Stent occlusion was diagnosed by no color or Doppler signal detection within the stent and confirmed by either CTA or DSA.

Hemodynamic protocol

According to the hemodynamic protocol, routine prophylactic atropine at a standardized dose of 0.4 mg was given intravenously to all the patients before stent deployment. If bradycardia is not improved, additional intravenous atropine (0.5–1 mg) was given. Hypotension was managed by intravenous fluids (250–500 mL of 0.9% hydrochloride). The fluid rate was adjusted according to the blood pressure and cardiac state of the patient. Vasopressors were given to patients in case of persistent hypotension after failed response to fluid infusion. Norepinephrine was administered at a rate of 2–6 mcg/kg boluses, and dopamine sometimes was needed. Patients with persistent HI were evaluated by an experienced cardiologist in-hospital.

Continuous monitoring of the heart rate (HR), blood pressure (BP), oxygen saturation, and neurological state was carried out throughout the procedure every 5 min by assessing conscious level response to verbal command and contralateral muscle power assessment by a toy. Following the procedure, patients were transferred to the intensive care unit (ICU), where monitoring was continued every 15 min for the first 2 h. Afterward, the follow-up was done every hour for 24 h. The presence and duration of any periprocedural HI were recorded. Cardiac morbidity, based on cardiac enzymes and ECG changes or clinical evidence of congestive heart failure (CHF), was recorded. Patient preparation, procedure technique, hemodynamic protocol, and monitoring were the same in the two centers.

Definitions

Outcome assessment: technical success

- ✓ Technical success: Successful selective completion carotid (extracranial and intracranial) angiograms were performed, and a residual stenosis less than 30% and no 30 days postoperative stroke.
- ✓ Technical failure: more than 30% residual stenosis, failure to cross the lesion.
- o Primary patency: it is defined as carotid stent freedom from significant ISR or any intervention performed to maintain patency. Open stents after re-intervention were defined as secondary patency.
- o Major adverse cardiac or cerebrovascular event (MACCE) is composite of death, stroke, or myocardial infarction.
- o Stroke was defined as *de novo* or worsened focal neurological symptoms lasting >24 h. The stroke was considered major when lasting at least 30 days and if a National Institutes of Health Stroke Scale of ≥4 points and a modified Rankin Scale score of ≥3 were present.[22]
- o Myocardial infarction was defined as elevation of cardiac enzymes (creatine kinase/CK isoenzymes M and B) to more than twice the upper limit of the normal laboratory value or a significant rise of troponin I in addition to pathological ECG changes or typical chest pain lasting longer than 30 min.[23]
- o Hemodynamic instability (HI)[14]: We have defined the hypotension by a symptomatic or asymptomatic decrease in the systolic blood pressure lower than 90

mmhg, and bradycardia is defined by heart rate lower than 60 beats per minute regardless of using atropine fluid vasopressor.

- ISR: patients with abnormal DUS (direct sign: >300 cm/s peak systolic velocity within or at the ends of the CCA stent), significant (>70%) ISR was suspected.[24] Stent occlusion was confirmed by no color or Doppler signal detection within the stent.

Statistical analysis

Statistical analysis was performed using SPSS 25.0 (SPSS Inc, Chicago, IL, USA) and MedCalc 16.8 (MedCalc Software, Ostend, Belgium). Continuous variables were expressed as mean ± standard deviation (SD) and/or median and interquartile range (IQR) and categorical variables as frequency and percentage. Baseline characteristics were compared between the two cohorts using the Student t-test for continuous variables and chi-square test for categorical variables. Multivariate analysis using binary logistic regression model with stepwise approach was generated to assess the influence of various demographic and lesion characteristics on hemodynamic instability, with results presented as odds ratio (OR) and 95% confidence interval (CI). Variables with clinical relevance included in the multivariable analysis were associated with the group in the univariate analysis with statistical significance. *P*-value <0.05 was considered statistically significant.

Results

This study represented seven hundred and twenty eight consecutive patients with various degrees of carotid stenosis that underwent CAS in two centers from March 2014 to May 2021. Forty of them had bilateral CAS in a staged fashion at least 1 month apart. The demographic characteristics are summarized in Table 1.

The majority of the cohort presented asymptomatic carotid stenosis (578/728, 79.4%). Symptomatic carotid stenosis was either TIA in 124/728 (17%) or stroke in 26/728 (3.6%) of patients, more or less equally divided between right and left sides in the last 6 months. The mean degree of carotid stenosis was 77.82 ± 4.73%, with a mean plaque length of 1.76 ± 0.55 cm. Other lesion characteristics are illustrated in Table 2. A total of 375 (51.5%) asymptomatic patients were defined by the anesthesiologists as having a high surgical risk, and 115 (15.8%) patients had hostile neck or restenosis, while 88 (12%) patients had average surgical risk. Clinical presentation of patients in our study is shown in Table 2.

Contralateral carotid status was classified as patent (<50% stenosis), stenotic (>50% stenosis), or occluded. Tortuosity was determined according to the operative dictation of the attending surgeon. In our study, only 10% has concomitant contralateral occlusion of ICA, where 46% has more than 50% stenosis.

All patients underwent CAS under cover of EPD (100%). The most used device was FilterWire EZ system, Boston Scientific, Natick, MA, USA (n = 672, 96%); Emboshield Filter, Abbott Laboratories, Abbott Park, Illinois, USA, (n = 19, 2.7%); SpideRX Filter, EV3, Plymouth, MN, USA (n = 7, 1%); Angioguard RX Filter, Johnson and Johnson-Cordis, Warren, NJ, USA (n = 2, 0.3%).

The types of stents used were as follow: 277 (38%) of our patients were treated with Xact® Carotid Stent System (Abbot vascular technology), carotid WALLSTENTS (Boston Scientific Corp., Natick, MA, USA) were used in 30%, Precise stents (Johnson and Johnson-Cordis, Warren, NJ, USA) were used in 15%, and Protégé™ RX self-expanding carotid stent system (Medtronic) was used in 15%.

Technical success was achieved in 698 (96%) of patients. Of these patients, stroke rate in symptomatic patients was nine (5.8%) while stroke rate detected in asymptomatic patients was twenty (3.4%). However, failed CAS was evident in 30 (4%) of patients; 20 patients due to difficulty to cross the lesion. Patients were converted immediately to open surgery with no perioperative complication. In seven patients, there was a residual 30% ISR after procedure. In three patients, complete occlusion of the stent has occurred and immediately converted to urgent CEA with stent removal. Complications were classified into four types: access site–related in 57/728 (7.8%), neurologic in 51/728 (7%), cardiovascular in 376/728 (52%) mainly HI, and other complications.

Neurologic events (51/728, 7%) were reported in the first 30 days after CAS; including twenty nine (4%) transient ischemic events, fourteen minor strokes, seven major strokes, and one fatal stroke. Most events (37/728, 5%) occurred during or within 6 h after the procedure. Increased age revealed nonsignificant increase in the risk of procedural strokes. Patients younger than 70 years had a 3.6% stroke incidence; while patients aged 70–79 years had a 4.6% incidence (p = 0.0695). Sex, presence or absence of neurological symptoms, presence of coronary artery disease, diabetes mellitus, hypercholesterolemia, or smoking did not show a significant association with procedural neurological events. Presence of bilateral carotid lesions or contralateral carotid occlusion also did not significantly influence the incidence of neurological complications.

By multivariable analysis, the open-cell carotid stent design was not associated with a differential risk for combined acute and sub-acute neurologic complications as compared with closed-cell stents (Table 3). Procedural HI was encountered in 207 (28.5%) due to hypotension in 68 patients (9.4%), bradycardia in 34 (4.7%), and both hypotension and bradycardia in 105 (14.5%) (Table 4).

Table 1. Demographics of the study cohort.

	Overall (*n* = 728) (%)	Open cell (*n* = 227) (%)	Closed cell (*n* = 501) (%)	*p*-Value
Age, years				0.695
Mean±SD	71.00±7.40	70.84±7.56	71.07±7.33	
Range	51–87	51–85	53–87	
Median (IQR)	72 (12)	72 (12)	72 (12)	
Gender (male)	479 (65.8)	150 (66.1)	329 (65.7)	0.981
Diabetes	216 (29.7)	78 (34.4)	138 (27.5)	0.076
Hypertension	581 (79.8)	190 (83.7)	391 (78.0)	0.097
CAD	191 (26.2)	65 (28.6)	126 (25.1)	0.369
Previous MI	124 (17.0)	39 (17.2)	85 (17.0)	0.972
COPD	135 (18.5)	38 (16.7)	97 (19.4)	0.459
Current smoking	385 (52.9)	110 (48.5)	275 (54.9)	0.126
Dyslipidemia	263 (36.1)	88 (38.8)	175 (34.9)	0.360
CKD	56 (7.7)	17 (7.5)	39 (7.8)	0.991

CAD: coronary artery disease, COPD: chronic obstructive lung disease, CKD: chronic kidney disease.

Table 2. Lesion characteristics.

	Overall (*n* = 728) (%)	Open cell (*n* = 227) (%)	Closed cell (*n* = 501) (%)	*p*-Value
Side				0.091
Right	359 (49.3)	123 (54.2)	236 (47.1)	
Left	369 (50.7)	104 (45.8)	265 (52.9)	
Symptomatic				0.461
TIA	124 (17.0)	46 (20.3)	78 (15.6)	
Stroke	26 (3.6)	5 (2.2)	21 (4.2)	
Asymptomatic	578 (79.4)	176 (77.5)	402 (80.2)	0.461
High surgical risk	375 (51.5)			
Hostile neck or stenosis	115 (15.8)			
Average surgical risk	88 (12)			
Degree of stenosis, %				0.065
Mean±SD	77.82±4.73	78.30±6.43	77.60±3.70	
Range	60–90	60–90	65–85	
Median (IQR)	80 (5)	80 (5)	80 (5)	
Plaque length, cm				0.059
Mean±SD	1.76±0.55	1.82±0.38	1.74±0.61	
Range	0.7–2.5	1.0–2.5	0.7–2.5	
Median (IQR)	1.9 (0.8)	1.9 (0.5)	1.9 (1.0)	
Plaque echogenicity				0.058
Type I/II	289 (39.7)	78 (34.4)	211 (42.1)	
Type III/IV	439 (60.3)	149 (65.6)	290 (57.9)	
Contralateral occlusion	73 (10.0)	23 (10.1)	50 (10.0)	0.944
Hostile neck	25 (3.4)	11 (4.8)	14 (2.8)	0.235

TIA: transient ischemic attack; plaque echogenicity according to the Gray-Weale Classification.

Patients treated with open-cell design stents had a significant lower rate of procedural hypotension (P 0.0188) at bivariate analysis. Postoperative HI at 24 h occurred in 258/728 (35.5%) patients and was due to hypotension in 113 patients (15.6%), bradycardia in 65 (9.0%), and both hypotension and bradycardia in 79 (10.9%) (Table 4). Despite the HD occurrence, no preprocedural increase in cerebrovascular event was associated. Our study showed no difference in the occurrence of 30 day MACCE or death in this subgroup (Table 5).

For long-term analysis, at least one-year follow-up was completed for all patients, and the immediate postprocedure survival rate in our study was (99%, 742/750). A total of 30 patients (4%, 30/750) were lost to follow-up at different times

Table 3. Outcomes of the study population by stent cell design in our study.

	Total	Symptomatic	Stroke	Asymptomatic	Stroke	*p*-Value
Open cell	227	45	6 (12.12)	197	2 (6.67%)	0.51
Closed cell	501	480	41 (8.54)	21	2 (9.52%)	0.53

Stroke: refers to 30-day postoperative stroke.

Table 4. Clinical outcomes of patients who underwent carotid artery stent placement with self-expanding stents in our study.

Parameter	All patients (*n* = 728)	Open cell (*n* = 227)	Closed cell (*n* = 501)	*p*-Value*
Procedural hypotension	68(9.4)	12(5.2)	56(11.3)	0.0188
Procedural bradycardia	34(4.7)	20 (9.1)	14(2.7)	0.1315
Procedural hypotension and procedural bradycardia	105(14.5)	37(16.5)	68(13.5)	0.2560
24 h hypotension	113(15.6)	10(9.1)	103(20.5)	0.2550
24 h bradycardia	65(9)	6(9.1)	59(25.9)	0.5629
24 h hypotension and procedural bradycardia	79(10.9)	11.4(9)	70(13.9)	0.4337
Stroke	29(3.9)	2(6.8)	20(3.9)	0.999
Transient ischemic attack	29(3.9)	8(2.3)	19(3.7)	0.6075
Myocardial infarction	8 (1.1)	0	8(1.5)	NA
Death	3 (0.4)	0	3(0.5)	0.999

Note: Data are given as numbers of patients. Numbers in parentheses are percentages. NA: not applicable.

Table 5. Periprocedural outcomes in patients with and without HI following CAS.

	Overall (*n* = 728)	HI (*n* = 227)	Non-HI (*n* = 501)	*p*-Value
TIAs	9 (1.2)	4 (1.8)	5 (1.0)	0.616
Stroke	10 (1.4)	6 (2.6)	4 (0.8)	0.102
MI	8 (1.1)	3 (1.3)	5 (1.0)	0.997
Death	3 (0.4)	2 (0.9)	1 (0.2)	0.481

HI: hemodynamic instability, TIAs: transient ischemic attacks, MI: myocardial infarction.
MACEs: major adverse cardiovascular events.

during the study period. Survival rates of patients who had CAS at 1 month, 6 months, 12 months, and 24 months was 96.3%, 95%, 93%, and 90%, respectively (standard error <10%).

After the first month of postoperative period, the incidence of stroke rate was 3.2%. In our cohort study, 22 patients (3%) required repeated angioplasty. Two patients (0.3%) required CEA after a failed angioplasty. The two-year follow-up stroke-free patient percentage was 88+/−2%. Re-intervention plain balloon angioplasty has been used in sixteen patients, and stent implantation was conducted in four patients with nonocclusive ISR; two patients had ipsilateral TIA, and the other two patients had ISR progression on medical treatment. The remaining patients with nonocclusive ISR or entire CCA occlusion were asymptomatic and received best medical treatment (BMT). Recurrent ISR was noted in two cases: one was treated with a drug-coated balloon (DCB), while the other continued on BMT.

Univariate and multivariate analyses of different clinical and risk factors in relation with the technical success and primary patency revealed no significant relationship except for hyperlipidemia (p= <0.001). Additionally, vessel-related parameter like elongation of the CCA is defined as an S- or C-shaped tortuosity or lesion-related parameters: degree, length of the stenosis, presence and grade of calcification, and location of the lesion have no significant statistical difference (Table 6).

Discussion

Extracranial carotid artery atherosclerosis is considered a major cause of preventable strokes; it accounts for 20–30% of all ischemic strokes.[25] The treatment of carotid artery stenosis relays mainly on preventable treatment for many decades. The only available option was CEA, but recently CAS has been identified as a complementary tool

Table 6. Effect of risk factors and clinical characteristics on technical success and primary patency in our study.

	Technical success		Patients under primary patency 1 year	
Risk factors and clinical characteristics	No.	*p*-Value	No.	*p*-Value
Patient-related parameters				
Age (year), median (IQR)	63.5(55.2–68.3)	0.531	62.7 (55.2–68.7)	0.908
Female sex	95(692)	0.274	256 (35.1)	0.206
Smoking (current or former)	96(699)	0.300	669 (91.9)	0.606
Hypertension	98(713)	0.661	708 (97.3)	>0.999
Hyperlipidemia	65(473)	908	374 (51.4)	<0.001
Diabetes mellitus	33(240)	0.206	216 (29.7)	0.507
Obesity (BMI >30 kg/m2)	21(153)	0.606	194 (21.6)	>0.999
Lesion-related parameters				
Stenosis grade (%)median (IQR)	80 (75–90)	0.388	80 (75–90)	0.319
Length (mm), median (IQR))	13 (10–20)	0.655	12 (9–20)	0.668
Stent-related parameters				
Diameter (mm), median (IQR)	8 (7–9)	0.8	8 (7–9)	0.227
Length (mm), median (IQR)	30 (30–40)	0.7	40 (30–40)	0.280

IQR: interquartile range.

in the treatment of extracranial carotid artery stenosis with minimally invasive, safe, and effective advantages in special category of patient. Many RCTs have proved the concept of noninferiority of CAS in comparison to CEA regarding periprocedural major adverse events, especially stroke rate.[7,26,27] The long-term efficacy of CAS in stroke prevention is still debatable and needs more RCTs to be proved.

The authors suggest that CAS might be the best choice for carotid revascularization in the following situations: internal carotid artery lesion superior to level of the mandible angle, requiring complex surgical maneuvers and difficult to access by surgery, like in irradiated neck or following neck previous dissection; recurrent stenosis following CEA. CAS is not the usual standard treatment for asymptomatic carotid stenosis, and adaptation of CAS for asymptomatic carotid stenosis in average surgical risk patient is not in line with guidelines.[28] Despite, this issue is still a matter of debate, patients with complete carotid occlusion and an incomplete Circle of Willis may have less stroke rate with CAS than with traditional CEA.[29]

The combined minor and major stroke and procedure-related death rates of our study were 5.8% in the symptomatic patient group and 3.4% in the asymptomatic patient group. Our results corroborate the findings of previous studies that reported 5.76% in the symptomatic patient group and 3.38% among the asymptomatic subset (25). Only six deaths were delineated into the two subsets. Hence, it appears that the complication rate for carotid stent placement is acceptable for symptomatic patients and asymptomatic patients. Accordingly, the risks of carotid stent placement are comparable to the American Heart Associations (AHA) guidelines for carotid endarterectomy: less than 6% for symptomatic patients.[25,26]

In this study, there was no significant difference between the group of patients with symptomatic and asymptomatic carotid artery stenosis; (90.3% vs. 96.5%) with a *p*-value of 0.998), which is in agreement with the results of the SAPPHIRE trial.[26] We included both symptomatic carotid stenosis (150, 20.6%) and asymptomatic patients (578, 79.4%). Contrary to the results of the SAPPHIRE trial that involved too few patients with the asymptomatic disease to permit any conclusions regarding the relative benefit of the intervention in this subgroup. Although a benefit of either invasive strategy over current medical therapy may be uncertain for these high-risk, asymp-tomatic patients to permit any conclusions regarding the relative benefit of intervention in this subgroup. After that, the benefit of invasive strategy over current medical therapy may be uncertain for these high-risk, asymp-tomatic patients.[7]

Patients older than 80 years were not excluded, with promising results. CAS in octogenarians is still a matter of debate and may give worse results as occurred in multicenter randomized controlled trials (RCTs) (e.g., EVA 3S, SPACE, and ICSS).[27,30] Our study showed no significant difference in the stroke rate or at all complication between patient below 79 years old or more than 80 years. This is mostly attributable to the improvement in the procedural equipment, techniques, and appropriate case selection. As a result, CAS can be performed with lower periprocedural adverse events.

All of our cases were performed under the protection of EPD which is now considered standard of care.[24] We used distal filter protection in 96% of our patients, while in four

lesions (0.5%), it was impossible to cross the lesion by the filter wire. In addition, we preferred the filter type protection in the case of contralateral occlusion or severe stenosis of ECA. The endoluminal clamping systems were used preferentially in case of vessel tortuosity, and predilation was used selectively. No differences were found in the result between proximal and distal protection types, but some studies showed that proximal occlusion seemed to have a lower risk of distal debris embolization to the anterior cerebral territory.[31] Filters, as a type of CPD, have many advantages such as allowing varying degrees of procedural cerebral perfusion, maintaining antegrade flow, providing an access to angiography and visualization with more precise stent placemen, and tolerating well by all patients with no signs of ischemia during procedures.[32]

Most of our cases were performed with Xact® Carotid Stent System (Abbot vascular technology), a closed stent type. Closed-cell stents have a smaller free-cell area between the stent lattices, as a consequence are more rigid. The theoretical advantage of this stent is the ability to better scaffold labile carotid plaques and minimize their increased risk of distal embolization. Gurbel et al. confirmed our result and observed that closed-cell stents may result in less platelet aggregation.[33,34]

Open-cell stents can easily navigate through tortuous vessels and allow easy deployment in unfavorable anatomy. The malleable nature of open-cell stents can prevent kinking due to unnecessary vessel straightening. Arterial kinking may increase the risk of cerebrovascular insufficiency and sustained hypertension, so we admit the use of open-cell stent in asymptomatic patient in tortuous anatomy of ICA. Our result was confirmed by another study that documented a substantial evidence of nonsignificant differences in neurological adverse event rates according to the stent used. In particular, the postprocedural complication rates in the symptomatic population were highest for the open-cell types and increased with a larger free-cell area, while this difference could be lower in the asymptomatic population.[10]

The study by Bosiers et al.[34] has discussed the superior ability of the closed-cell design. No doubt, the theory of greater wall scaffolding by a closed-cell carotid stent can stabilize the atheroma and interestingly more safety might be produced. Unfortunately, this theory cannot be proven scientifically on a large-scale RCT, as bias can disturb the result, especially the selection bias. Most importantly, the proportion of symptomatic patients was lower in favor of open-cell carotid stents. However, we did conclude a clear advantage of closed-cell stents over open-cell stents.

Carotid angioplasty with hemodynamic instability (HI) has occurred in up to two-thirds of our cohort. Our result proved that HI occurred in a frequent manner in patients undergoing CAS, and it puts hallmark on major discrepancies between two different sets of self-expanding carotid stents. The etiology of HI after CAS has been explained by the manipulation of the carotid sinus, which results in irritation of the baroreceptor and leads to reflex inhibition of adrenergic signals to the peripheral vascular bed and increased parasympathetic output to the heart and consequently lead to decrease the rate of heart beats and blood pressure decrease.[32]

Various angiographic and demographic characteristics have been controlling the occurrence of HI. For example, the use of balloon-expandable stents with higher radial forces on the vessel wall and carotid sinus as compared to the force of self-expanding stents, and this has a positive correlation with higher rates of HI.[15] Persistent postprocedural hypotension occurred more commonly in patients with carotid stenosis treated with closed-cell stents and nitinol stents alike. In the light of the fact, the carotid sinus plays a corner stone role in short-term blood pressure control; this result might be explained by continuing postdeployment expansion of self-expanding stents. The frequency of major complication in our study was not influenced by HI after carotid stent deployment. Moreover, we found no correlation between the frequency of complication and different stent types from one side and the occurrence of HI from the other side.

Till now there are no recommendations to select specific stent in specific lesion; although, precise stents are preferred in lengthy plaques, and in heavily calcified, the Xact stents are commonly used. Wallstents are routinely preferred in noncalcified shorter plaque. However, our series proves the result of previous studies that nitinol stents are positively correlated with the occurrence of HI.[35]

There was a difference between the two subsets of carotid stents, and the most two commonly implanted nitinol stents were Precise and Xact stents. HI was more commonly encountered in patients treated with the Xact device. The etiology of this finding can be attributed to the different physical proprieties of the device, like the difference in radial forces of the stent. The structure of the device also plays a role; nitinol (Precise and Xact) stents have a ring-shaped framework, while Wallstents have a braided skeleton made of a cobalt/chromium/nickel–based alloy.[8] Result of pervious trial searching in the physical properties of different devices showed that radial force exerted by single stent is different with different lesions, length, and stress hysteresis, what is a special feature of the nitinol alloy, makes it even harder to understand the physics of the stents.[36]

Limitations of this study include its retrospective nature and potential for patient selection and treatment bias. Patient proposal for surgery could represent a selection bias since subjective frail patients are more likely to be selected for noninvasive procedures. This study was performed in two large academic teaching institutions, which might affect the external validity of the results to community hospitals that perform a large proportion of CEA. Even though the data

collection was prospective, it has some limitations since it is a post hoc analysis of the data. Strength of the present study is presenting one of real-word biggest cohorts of carotid stenting reporting the values and risk factors for hemodynamic instability.

Conclusion

"Selecting the appropriate stent for the CAS procedure is a crucial issue affecting procedural outcomes. When choosing a stent, the embolic potential of the plaque and carotid tortuosity should be considered. However, it cannot be concluded from this study that different stent designs affect major adverse events in CAS patients. However, the possibility of stent design affecting procedural outcomes cannot be excluded based on the findings of this study. Further studies are necessary to prove or exclude this point." Different subsets of carotid stents are associated with the incidence of HI. Nevertheless, HI was not associated with any increase in the major adverse event in this study.

Declaration of conflicting interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Funding

The author(s) received no financial support for the research, authorship, and/or publication of this article.

ORCID iDs

Mohamed Shahat https://orcid.org/0000-0002-7087-8674
Joao Rocha-Neves https://orcid.org/0000-0002-2656-8935

References

1. Gupta N, Mocumbi A, Arwal SH, et al. Prioritizing health-sector interventions for noncommunicable diseases and injuries in low- and lower-middle income countries: National NCDI poverty commissions. *Glob Health Sci Pract*. 2021; 9(3):626–639.
2. Ederle J, Bonati LH, Dobson J, et al. Endovascular treatment with angioplasty or stenting versus endarterectomy in patients with carotid artery stenosis in the Carotid and Vertebral Artery Transluminal Angioplasty Study (CAVATAS): long-term follow-up of a randomised trial. *Lancet Neurol*. 2009; 8(10): 898–907.
3. Mayberg MR and Winn HR. Endarterectomy for asymptomatic carotid artery stenosis: resolving the controversy. *JAMA*. 1995; 273(18): 1459–1461.
4. Ederle J, Dobson J, Featherstone RL, et al. Carotid artery stenting compared with endarterectomy in patients with symptomatic carotid stenosis (International Carotid Stenting Study): an interim analysis of a randomised controlled trial. *Lancet (London, England)* 2010 Mar; 375(9719): 985–997.
5. Brott TG, Hobson RW, Howard G, et al. Stenting versus endarterectomy for treatment of carotid-artery stenosis. *N Engl J Med* 2010 May 28; 363(1): 11–23. Available at: DOI: 10.1056/NEJMoa0912321.
6. Murad MH, Flynn DN, Elamin MB, et al. Endarterectomy vs stenting for carotid artery stenosis: a systematic review and meta-analysis. *J Vasc Surg* 2008 Aug; 48(2): 487–493.
7. Gurm HS, Yadav JS, Fayad P, et al. Long-term results of carotid stenting versus endarterectomy in high-risk patients. *N Engl J Med* 2008 Apr; 358(15): 1572–1579.
8. Muller-Hulsbeck S, Schafer PJ, Charalambous N, et al. Comparison of carotid stents: an in-vitro experiment focusing on stent design. *J Endovasc Ther* 2009; 16(2): 168–177.
9. Wissgott C, Schmidt W, Behrens P, et al. Experimental investigation of modern and established carotid stents. *Rofo* 2014; 186(2): 157–165.
10. Bosiers M, de Donato G, Deloose K, et al. Does free cell area influence the outcome in carotid artery stenting? *Eur J Vasc Endovasc Surg* 2007 Feb; 33(2): 135–141; discussion 142-143.
11. Rhim JK, Jeon JP, Park JJ, et al. Prediction of prolonged hemodynamic instability during carotid angioplasty and stenting. *Neurointervention*, [Internet]. 2016/09/03. 2016 Sep;11(2):120–126. Available at: https://pubmed.ncbi.nlm.nih.gov/27621949
12. Saleh M., Ali H, Atalla K, et al. Predictors of carotid artery stenting-induced hemodynamic instability. *Vasc Endovascular Surg* 2021; 55(5): 475–481.
13. Wu TY., Ham SW and Katz SG (2015). Predictors and consequences of hemodynamic instability after carotid artery stenting. *Ann Vasc Surg* 29(6): 1281–1285.
14. Gupta R, Abou-Chebl A, Bajzer CT, et al. Rate, predictors, and consequences of hemodynamic depression after carotid artery stenting. *J Am Coll Cardiol* 2006 Apr; 47(8): 1538–1543.
15. Duda SH, Wiskirchen J, Tepe G, et al. Physical properties of endovascular stents: an experimental comparison. *J Vasc Interv Radiol* 2000 May; 11(5): 645–654.
16. Paukovits TM, Haász J, Molnár A, et al. Transfemoral endovascular treatment of proximal common carotid artery lesions: a single-center experience on 153 lesions. *J Vasc Surg* 2008 Jul; 48(1): 80–87.
17. Nicolaides AN., Kakkos SK, Kyriacou E, et al. (2010). Asymptomatic internal carotid artery stenosis and cerebrovascular risk stratification. *J Vasc Surg* 52(6): 1486–1496. e1-5. e1481-1485.
18. Naylor R., Rantner B, Ancetti S, et al. (2023) Editor's choice - European society for vascular surgery (ESVS) 2023 clinical practice guidelines on the management of atherosclerotic carotid and vertebral artery disease. *Eur J Vasc Endovasc Surg* 65(1): 7–111.
19. von Elm E., Altman DG, Egger M, et al. The strengthening the reporting of observational studies in epidemiology

(STROBE) statement: guidelines for reporting observational studies. *Int J Surg* 2014; 12(12): 1495–1499.
20. Gornik HL., Rundek T, Gardener H, et al. Optimization of duplex velocity criteria for diagnosis of internal carotid artery (ICA) stenosis: a report of the intersocietal accreditation commission (IAC) vascular testing division carotid diagnostic criteria committee. *Vasc Med* 2021; 26(5): 515–525.
21. Popescu D., Mergeani A, Bajenaru OA, et al. Hemodynamic instability after elective carotid stenting: frequency and risk factors. *Maedica (Bucur)* 2011; 6(4): 258–261.
22. Kleindorfer DO., Towfighi A, Chaturvedi S, et al. 2021 Guideline for the prevention of stroke in patients with stroke and transient ischemic attack: a guideline from the American Heart Association/American stroke association. *Stroke* 2021; 52(7): e364–e467.
23. Hartikainen TS., Sorensen NA, Haller PM, et al. Clinical application of the 4th Universal definition of myocardial infarction. *Eur Heart J* 2020; 41(23): 2209–2216.
24. Zeebregts CJ. and Paraskevas KI. The new 2023 European society for vascular surgery (ESVS) carotid guidelines - the European perspective. *Eur J Vasc Endovasc Surg*, 2022; 65(1): 3–4.
25. Wholey MH, Wholey M, Mathias K, et al. Global experience in cervical carotid artery stent placement. *Catheter Cardiovasc Interv.* 2000 Jun;50(2):160–167.
26. Moore WS, Barnett HJ, Beebe HG, et al. Guidelines for carotid endarterectomy. a multidisciplinary consensus statement from the ad hoc committee, American Heart Association. *Stroke* 1995 Jan; 26(1): 188–201.
27. Stanziale SF, Marone LK, Boules TN, et al. Carotid artery stenting in octogenarians is associated with increased adverse outcomes. *J Vasc Surg* 2006 Feb; 43(2): 297–304.
28. Ricotta JJ, Aburahma A, Ascher E, et al. Updated society for vascular surgery guidelines for management of extracranial carotid disease. *J Vasc Surg* 2011; 54(3): e1–e31. Available at: DOI: 10.1016/j.jvs.2011.07.031
29. Yadav JS, Roubin GS, King P, et al. Angioplasty and stenting for restenosis after carotid endarterectomy. Initial experience. *Stroke* 1996 Nov; 27(11): 2075–2079.
30. Hobson RW 2nd, Howard VJ, Roubin GS, et al. Carotid artery stenting is associated with increased complications in octogenarians: 30-day stroke and death rates in the CREST lead-in phase. *J Vasc Surg* 2004 Dec; 40(6): 1106–1111.
31. Grunwald IQ, Reith W, Kühn AL, et al. Proximal protection with the Gore PAES can reduce DWI lesion size in high-grade stenosis during carotid stenting. *EuroIntervention*, [Internet]. 2014 Jun;10(2):271. 276, Available at: DOI: 10.4244/EIJV10I2A45
32. Timmers HJLM, Wieling W, Karemaker JM, et al. Denervation of carotid baro- and chemoreceptors in humans. *J Physiol* 2003; 553(Pt 1): 3–11.
33. Gurbel P. A., Callahan KP, Malinin AI, et al. Could stent design affect platelet activation? results of the platelet activation in STenting (PAST) study. *J Invasive Cardiol* 2002; 14(10): 584–589.
34. Bosiers M, Deloose K, Verbist J, et al. Carotid artery stenting: which stent for which lesion? vascular. *Vascular* 2005; 13(4): 205–210.
35. Nii K, Tsutsumi M, Aikawa H, et al. Incidence of hemodynamic depression after carotid artery stenting using different self-expandable stent types. *Neurol Med Chir (Tokyo)* 2011; 51(8): 556–560.
36. Hirdes MMC, Vleggaar FP, de Beule M, et al. In vitro evaluation of the radial and axial force of self-expanding esophageal stents. *Endoscopy* 2013 Dec; 45(12): 997–1005.