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ORIGINAL ARTICLE

Aortic arch types and postoperative outcomes after carotid artery stenting in asymptomatic and symptomatic patients

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ABSTRACT

Background: The aim of this study was to investigate the influence of the aortic arch type on technical and clinical success of carotid artery stenting (CAS) procedure.

Methods: Clinical and anatomical data of consecutive patients who underwent CAS from 2010 to 2018 were prospectively collected and retrospectively analyzed. Primary outcome was technical success, define as successful stent delivery and deployment and <30% residual carotid stenosis. Secondary outcomes were death, stroke, myocardial infarction (MI) and transient ischemic attack (TIA) rates at 30 days after CAS. Subgroups analysis with asymptomatic and symptomatic patients were also performed.

Results: During the study period, 523 patients were enrolled and analyzed. Among these, 176 (33.6%) had Type I, 227 (43.4%) had Type II and 120 (23.0%) had Type III or bovine aortic arch (BAA) type. Technical success rate was achieved in 96.0% of cases. At 30 days, if compared with Type I or II, patient with Type III or BAA experienced a higher death rate (0 *vs.* 0 *vs.* 1.8%, respectively; P=0.056) and combined postoperative stroke/TIA rate (3% *vs.* 2.8% *vs.* 9.9%, respectively; P=0.012). No differences for same outcomes between asymptomatic and symptomatic patients were described, although the latter group experienced more postoperative MI. A multivariate analysis revealed Type III or BAA as an independent risk factor for postoperative stroke/TIA (HR 3.23, IC95% 1.40-7.45; P=0.006).

Conclusions: In this cohort of patients, death and postoperative neurological complications rates were associated with Type III or BAA, irrespective of symptomatic patients' status. Extremely attention is required during perioperative period in patients who were candidate to CAS and with challenging aortic arch anatomy.

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Key words: Carotid artery diseases; Carotid arteries; Stents; Stroke; Aorta, thoracic.

The role of carotid artery stenting (CAS) in preventing ischemic stroke is showing increasingly convincing perioperative and long-term results,[1] with a lower incidence of cranial nerve palsy and myocardial infarction (MI), thanks to the improvement in endovascular techniques and the increase in operator experience.[2, 3]

Evidence suggests that systemic factors and medical comorbidities[4-6] may have a prognostic impact on the adverse event rate for carotid endarterectomy whereas local anatomic and lesions factors increase the technical difficulties[7] and risk of neurologic complications[8] associated with CAS.

There is growing evidence that the ability of the operator impacts on the effectiveness of carotid stenting in achieving minimal complications and preventing stroke.[9]

The severity of carotid stenosis, the degree of tortuosity,[10] and the aortic arch type[8, 11, 12] have been identified as possible causes of technical failure.

In fact, aortic arch type plays an important role in determining the technical success rate and perioperative risk of complications. Difficult aortic arch may require repeated aggressive manipulation, which may generate emboli. Moreover, unfavorable arch anatomy increases the difficulty in guiding catheter or long sheath insertion.

Complex aortic arch anatomy is recurrent in the population. It has been estimated that up to 10% of the population presented with bovine aortic arch, in which the left common carotid artery originates from the brachiocephalic trunk, rather than arising directly from the aortic arch as a separate branch as occurs in the most common aortic arch branching patterns.[13]

However, data on the impact of aortic arch anatomy on technical success and clinical outcome are sparse and patient selection and exclusion criteria differed among the studies.

The purpose of this study was to investigate the influence of the aortic arch anatomy on the technical and clinical success of carotid artery stent implantation.

Materials and methods

Patient population

The clinical data of all consecutive patients who underwent CAS for carotid revascularization from 2010 to 2018 were analyzed retrospectively. Data were recorded prospectively. Indications for CAS were a carotid artery diameter reduction of at least 50%, in case of symptomatic patients, or ≥80%, in case of asymptomatic ones, diagnosed by head and neck computer tomography angiography (CTA) or magnetic resonance angiography (MRA) using the North American Symptomatic Carotid Endarterectomy Trial (NASCET) criteria.[14] To describe aortic arch type, maximum intensity projection (MIP) and multiplanar reconstruction (MPR) technique were used. To characterize aortic arch type, for each patient the diameter of the left common carotid artery (LCCA) and the arch height were measured, according to current literature recommendations.[15, 16] An arch height <1 time the LCCA diameter indicates a Type I arch, 1-2 times a Type II and >2 times a Type III arch. Bovine aortic arch (BAA) was defined as a common origin for the innominate and left common carotid arteries or other variants.[17]

All patients provided written informed consent. The study was approved by the local Ethics committee.

CAS procedure

As preoperative evaluations, physical examination baseline assessment, carotid duplex ultrasound scan (DUS) of the supra-aortic vessels and a neurological assessment measured using the National Institutes of Health Stroke Scale (NIHSS) were performed. Dual antiplatelet therapy was administered within 24 hours before the procedure. All patients received a loading dose of clopidogrel (300 mg) one hour before the procedure. CAS treatments were performed following an established internal protocol which has been previously described.[18] All procedures were done in the operating room, equipped with a portable imaging fluoroscopic C-arm (OEC 9900 elite; GE Medical Siemens, Wisconsin), by two skilled operators with a high

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volume experience (>50 CEA/CAS procedures per year as first operator). Iodinated or gadolinium contrast was used in patients with normal creatinine level or creatinine >1.5 mg/dL (132 mmol/L), respectively. Intraoperative anticoagulation was achieved using an intravenous unfractionated heparin bolus (100-units/kg heparin) in order to ensure an activated clotting time (ACT) >250 s throughout the procedure. All patients were treated with percutaneous transfemoral approach, under DUS control. The right common femoral artery was preferred, although femoral calcifications may change this preference.

Open-cell, closed-cell, hybrid and micromesh carotid stents were employed, as a function of lesion characteristics and vessel anatomy. Temporary distal or proximal cerebral protection was performed in all patients during the procedure using a Emboshield NAV6 system (Abbott Vascular, Green Oaks, IL, USA) or a Mo.Ma system (Medtronic, Minneapolis, MN, USA), respectively. The lesion was post dilated using a 4.5- or 5.5-mm diameter Rx Viatrak 14 Plus balloon (Abbott Vascular, Green Oaks, IL, USA).

Medical therapy continued with 100 mg of aspirin once daily for a lifelong period and 75 mg clopidogrel once daily for 1 month after CAS procedure.

Definitions and endpoints

Primary endpoint was intraoperative CAS success rate, in terms of technical achievement. Technical success was defined as efficacious delivery and deployment of the carotid stent at the carotid target lesion site, with <30% residual stenosis. Secondary endpoints were death, stroke, TIA and MI rate within 30 days after intervention, in the entire population, and depending on arch type. Subgroups analysis were also performed to test differences in asymptomatic and symptomatic patients.

Minor strokes were defined as neurological deficits (NIHSS≤4), which resolved completely within 30 days or those which did not cause chronic functional impairment in daily activities, as assessed by the neurologist. Otherwise, stroke was defined as major neurological damage (NIHSS>4). All patients affected by postoperative neurological complications was submitted to postoperative brain computed tomography and neurological evaluation to better assess injury entity and gravity.

Statistical analysis

Categorical variables were presented as number and percentages and were compared using the Fisher exact test. Continuous variables were presented as mean±standard deviations (SD) and were compared using the Student's *t* test. Multivariate analysis was carried out to examine the independent associations among procedural outcomes and patients baseline characteristics. All probability values were two-sided and a value of P≤0.05 was considered statistically significant. All analyses were performed using STATA™ (STATA Corp., version 14.0, College Station, TX, USA).

Results

In total, 523 patients were included in the analysis, 329 (62.9%) asymptomatic and 194 (37.1%) symptomatic. Baseline characteristics of the study participants are summarized in Table I, II, divided according to arch type and symptomatic status, respectively. A majority of the patients presented with Type II aortic arch (N.=227, 43.4%). Type I and Type III or BAA aortic arch were present in 33.7% (N.=176) and 16.4% (N.=86) of the patients, respectively. Finally, BAA was present in 6.5% (N.=34) of the patients. Patients with Type III or BAA were most likely to be smokers (43.3% *vs.* 31.3% and 29.0% in Type II and I, respectively; P=0.03), and to have chronic obstructive pulmonary disease (COPD, 35.0% *vs.* 10.6% *vs.* 14.8%; P<0.01). On the contrary, patients with Type I arch were most likely to be symptomatic (55.1% *vs.* 24.2% and 35.0% in Type II and III+BBA, respectively; P<0.01), and to have had a congestive heart failure (CHF, 17.0% *vs.* 7.5% and 15.8% in Type II and III or BAA, respectively; P<0.01). Patients with Type II arch were most likely to

TABLE I.—*Baseline characteristics according to arch type.*

Characteristic	Aortic arch type			
	Type I	Type II	Type III+BAA	P
Age≥80	93 (52.5)	111 (48.9)	66 (55.0)	0.520
Gender (M)	100 (56.8)	140 (61.7)	74 (61.7)	0.570
Smokers	51 (29.0)	71 (31.3)	52 (43.3)	0.030
Symptomatic	97 (55.1)	55 (24.2)	42 (35.0)	<0.001
Diabetes	64 (36.4)	74 (32.6)	51 (42.5)	0.190
Hyperlipidemia	138 (78.4)	167 (73.6)	94 (78.5)	0.460
Coronary artery disease	53 (30.1)	62 (27.3)	31 (25.8)	0.710
Hypertension	136 (77.3)	192 (84.6)	83 (69.2)	<0.001
Chronic obstructive pulmonary disease	26 (14.8)	24 (10.6)	42 (35.0)	<0.001
History of stroke	23 (13.1)	70 (30.8)	37 (30.8)	<0.001
Chronic heart failure	30 (17.0)	17 (7.5)	19 (15.8)	<0.001
History of myocardial infarction	36 (20.5)	34 (15.0)	30 (25.0)	0.072
Total	176 (33.6)	227 (43.4)	120 (23.0)	

Values are expressed as N. (%).
BAA: bovine aortic arch.

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TABLE II.—*Baseline characteristics according to symptomatic status.*

Characteristic	Asymptomatic	Symptomatic	P
Gender (M)	204 (62.0)	110 (56.7)	0.270
Smokers	91 (27.7)	83 (42.8)	<0.001
Aortic arch type			
Type I	79 (24.0)	97 (50.0)	<0.001
Type II	171 (52.0)	55 (28.4)	<0.001
Type III+BAA	79 (24.0)	42 (21.6)	0.590
Age≥80	164 (49.8)	106 (54.6)	0.170
Diabetes	102 (31.0)	87 (44.8)	0.002
Hyperlipidemia	266 (80.9)	133 (68.6)	0.001
Coronary artery disease	75 (22.8)	71 (36.6)	0.001
Hypertension	245 (74.5)	166 (85.6)	0.003
Chronic obstructive pulmonary disease	47 (14.3)	45 (23.2)	0.012
History of stroke	79 (24.0)	51 (26.3)	0.600
Chronic heart failure	43 (13.1)	23 (11.9)	0.780
History of myocardial infarction	75 (22.8)	25 (12.9)	0.006
Total	329 (62.9)	194 (37.1)	

Values are expressed as N. (%).
BAA: bovine aortic arch.

TABLE III.—*Intraoperative characteristics according to arch type.*

Characteristic	Aortic arch type			
	Type I	Type II	Type III+BAA	P
Target vessel (right)	92 (52.3)	133 (58.6)	104 (86.7)	<0.001
Stent type				
Open cell stent	59 (33.5)	103 (45.4)	92 (76.7)	<0.001
Closed cell stent	99 (56.3)	42 (18.5)	0 (0.0)	<0.001
Hybrid stent	17 (9.7)	52 (22.9)	1 (0.8)	<0.001
Micromesh stent	1 (0.6)	30 (13.2)	27 (22.5)	<0.001
X-ray time (s, mean±SD)	737.5±345.7	763.5±491.4	814.1±365.8	0.641
X-ray dose (mGy, mean±SD)	93.7±71.8	75.4±40.5	80.1±57.0	0.329
Technical failure	5 (2.8%)	6 (2.6%)	10 (8.3%)	0.042
Total	176 (33.6)	227 (43.4)	120 (23.0)	

Values are expressed as N. (%).
BAA: bovine aortic arch.

have hypertension if compared with Type I and III or BAA (84.6% *vs.* 77.3% and 69.2%, respectively; P<0.01). No statistically significant differences were found in the other demographic and clinical characteristics among the aortic arch types. Regarding differences between asymptomatic and symptomatic group, the latter had more Type I and less Type II arch. Furthermore, symptomatic patients experienced more comorbidities.

Angiographic and procedural characteristics are summarized in Table III. The mean fluoroscopy time did not differ among the three groups, ranging from a mean value of 737.5±345.7 s in Type I aortic arch to a mean value of 814.1±365.8 s in Type III or BAA. No significant differences were found in the x-ray dose according to the aortic arch type. The greatest dose was used in Type I aortic arches (93.7±71.8 mGy), and the lowest dose was used in Type II aortic arches (75.4±40.5 mGy).

Technical success rate could be achieved in 96.0% of cases (502 patients). The procedures were suspended and/or converted to open surgery mostly due to the difficult anatomy of the aortic arch configuration, which made it impossible the deployment of the stent. Technical failures due to arch tortuosity was higher in Type III or BAA, compared with Type I and II (8.3% *vs.* 2.6% *vs.* 2.8%, respectively; P=0.042).

The all 30-day adverse events are shown in Table IV. Sixteen adverse events occurred in patients with Type III or BAA arch, including two deaths (1.8%), seven strokes (6.3%), three MIs (2.7%), and four TIAs (3.6%). The incidence of postoperative neurological accidents was higher in patients with Type III or bovine arches with respect to those with Type I or II arches (10.0% *vs.* 2.9% *vs.* 2.7%, respectively; P=0.012).

Dividing patients in asymptomatic and symptomatic status, the group with preoperative neurological symptoms experienced more postoperative MI but no postoperative neurological complications, if compared with asymptomatic ones (Table V, VI).

Multivariate analysis revealed Type III or BAA as an independent risk factor for postoperative stroke/TIA (Hazard Ratio, HR 3.23, 95% Confidence Interval, IC95% 1.40-

TABLE IV.—*Thirty-day outcomes according to arch type.*

Outcome	Aortic arch type			
	Type I	Type II	Type III+BAA	P
Death	0 (0.0)	0 (0.0)	2 (1.8)	0.056
Myocardial infarction	4 (2.3)	4 (1.8)	3 (2.7)	0.795
Postoperative neurological complications	5 (3.0)	6 (2.8)	11 (9.9)	0.012
Total	176 (33.6)	227 (43.4)	120 (23.0)	

Values are expressed as N. (%).
BAA: bovine aortic arch.

TABLE V.—*Thirty-day outcomes according to symptomatic status.*

Outcome	Asymptomatic	Symptomatic	P
Death	0 (0.0)	2 (1.1)	0.149
Myocardial infarction	2 (0.6)	9 (4.8)	0.003
Postoperative neurological complications	10 (3.2)	12 (6.5)	0.113
Total	329 (62.9)	194 (37.1)	

Values are expressed as N. (%).

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TABLE VI.—*Independent risk factors for stroke/transient ischemic attack.*

	Adjusted HR	95% CI	P
Type I aortic arch	0.37	0.12-1.14	0.084
Type II aortic arch	0.34	0.12-0.98	0.046
Type III+BAA	3.23	1.40-7.45	0.006
Symptomatic	1.73	0.70-4.27	0.232
Hypertension	1.19	0.39-3.62	0.758
COPD	1.83	0.72-4.68	0.203
History of stroke	2.65	1.05-6.71	0.039
Target vessel, right	2.14	0.78-5.88	0.14
Stent type	1.11	0.75-1.66	0.59

7.45; P=0.006). Furthermore, also a history of stroke was independently associated with postoperative neurological complications (HR 2.65, IC95% 1.05-6.71; P=0.039).

Discussion

Aortic arch type remains a well-known preoperative characteristic that may predict postoperative outcomes after CAS. This report was design to evaluate if difficult arch anatomy (Type III or BAA) remains and independent predictor of postoperative neurological complications, death and MI, irrespective of symptomatic or asymptomatic patients' preoperative status.

As first important findings, although Type III or BAA type was found as an independent risk factor for poor postoperative outcomes, no differences were evaluated in term of X-ray time and dose during CAS. Indirectly, although it was not analyzed, operation time may be supposed similar among arch type groups. This data differs from previously published data. Shen *et al*.[15] found that Type III aortic arches were associated with a longer fluoroscopy time and higher contrast agent dose, in a group of 224 patients presenting with Type I, II and III aortic arch types. Such results were confirmed by other findings suggesting that angiographic characteristics and the tortuosity of the target vessel were associated with increased fluoroscopic time, which reflects a technically challenging procedure.[19, 20] Discrepancy between this and others comparative studies may be explained by the great variability in X-ray dose and time within each group (standard deviations in the majority of case exceeded the half of average value) and surgeon experience which minimized radiation exposure also in case of challenging cases.[21] On the other hand, although not statistically significant difference is visible and probably is not consistent due to the relative low sample size of groups.

Despite these, technical failure remains much more present in case of arch Type III or BAA.

Macdonald and coworkers developed a scoring system to identify expected difficulties during CAS procedure, based on a consensus among several specialists, such as interventional radiologists, neuroradiologists, interventional cardiologists and vascular surgeons.[22] A different study proposed a standardized method for quantifying tortuosity in carotid arteries, by adopting angulation measurements used in other anatomic areas.[10] In this study, only proximal tortuosity was found to be significantly associated with successful deployment of stent in the target lesion and risk of neurologic intraoperative and postoperative complications.

Although it did not increase intraoperative time, challenging anatomy and technical difficulty remain related with poor postoperative outcomes, not only in terms of neurological complications, but also for death. In literature, a significant relationship has been found between the incidence of stroke and the catheterization difficulties, especially when less experienced operators performed the procedures.[23] It is known that CAS is a technically demanding procedure, with a steep "learning curve"[24-27]. It has been previously reported suboptimal CAS results caused by low operator experience. It is worth noting that all the procedures of the present study were conducted by the same surgeon team with a high CAS volume and extensive experience.

During CAS, the aortic arch and the common carotid artery must be manipulated and traversed to reach the diseased carotid artery. Thus, the increased incidence of perioperative complications during CAS in Type III or BAA group may be related to the unfavorable vascular anatomy.[11, 15, 16] Furthermore, despite a higher percentage of right treated carotid artery was described in Type III or BAA patients (suggesting a "longer way" to target carotid artery as a risk factor), no significant correlation with postoperative outcomes was finally obtained after multivariate analysis.

This personal retrospective analysis on the relationship between aortic arch type and perioperative complications have change drastically our approach in patients with unfavorable anatomy. At this time, all patients with Type III or BAA are treated with transcervical approach. Four patients (3 male and 1 female, all asymptomatic) were treated with this approach, with no perioperative complications (unpublished data).

Transcervical approach, with or without flow reversal, has been established as a safe and valid method in patients with unfavorable anatomy, to avoid aortic arch and the risk of increase embolization rate.[28, 29] Furthermore, a recent in-

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vestigation from the Society for Vascular Surgery Vascular Quality Initiative (SVS-VQI) demonstrated the superiority of transcervical compared with transfemoral CAS.[30] Due to non-univocal and robust results, in our daily practice, a transcervical approach remains reserved only in patients with relative or absolute contraindication to transfemoral access. This also because a low perioperative complication rate, a validated operative protocol and CAS operators skilled experience with transfemoral approach have been obtained among years.

Several potential limitations concerning our study findings need to be addressed. First, it is a retrospective study and the potential patient selection and treatment bias may not be excluded. Second, diffusion weighted magnetic resonance imaging (DW-MRI) and transcranial doppler were not performed in this cohort, so the incidence of new ischemic brain lesions from the target lesion or embolic signal in the basal arteries of the brain were not evaluated. Third, only short-term (30 days) adverse events were collected, although the prognostic effects of intraprocedural technique may be associated also with mid-term or long-term complications.

Conclusions

In this cohort of unselected consecutive patients, although there were no preoperative and intraprocedural differences between patients with arch Type I, II and III or BAA, the latter group experienced more postoperative cerebrovascular events. A careful patient selection, based on arch anatomy and history of cerebrovascular accidents, and well-experienced operators are pivotal to reduce postoperative complications rate during CAS procedures.

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