Elective carotid stenting fulfills quality standards defined in guidelines

Neurologically controlled data compared to emergency interventions for acute stroke

Elektives Carotis-Stenting erfüllt die in Leitlinien festgelegten Qualitätsstandards

Neurologisch kontrollierte Daten im Vergleich zu Notfalleingriffen beim akuten Schlaganfall

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ABSTRACT

Purpose According to evidence from randomized trials and current guidelines, elective carotid artery stenting (CAS) is still considered second-line therapy compared with carotid endarterectomy (CEA). However, the publication of randomized comparative trials for patients with symptomatic stenoses occurred well over 10 years ago. In view of problems regarding German quality assurance when differentiating elective from emergency interventions and low case numbers for CAS indications, it seemed reasonable to present neurologically controlled CAS results and to investigate whether elective CAS consistently fulfills the strict quality criteria and what differences exist with respect to emergency CAS interventions in acute ischemic stroke.

Materials and Methods Between 01/2012 and 07/2022, 141 elective CAS procedures were performed to treat patients with symptomatic (n = 123) and asymptomatic (n = 18) stenoses. Protection by a filter system was achieved in 134 of these elective procedures (95 %). During the same period, 158 patients underwent carotid stenting for acute stroke. Complication rates were determined using neurologically controlled data. CAS-related complications (stent thrombosis, stent-associated vascular damage, thromboembolism, and symptomatic hemorrhage) were extracted from emergency interventions, and clinical outcome (NIHSS progression) was determined during the inpatient stay.

Results The rate of stroke and death determined during the inpatient stay for elective symptomatic patients was 0.8 %. Early treatment within the first 7 days after the index event, age > 70 years, and operator experience were not significant risk factors for the occurrence of complications. No complications were observed after CAS of asymptomatic stenoses. The procedure-related complication rate for emergency procedures was 7.8 %, which was significantly higher than after elective CAS, as expected (p < 0.006).

Conclusion Even with limited indications and limited case numbers, compliance with the strict quality criteria of the current S3 Guideline 2022 for elective CAS interventions is possible for both symptomatic and asymptomatic stenoses in an experienced center. Emergency CAS interventions have significantly higher complication rates under other conditions and must be considered separately with regard to quality assurance.

Key Points:
- Elective carotid stenting fulfills the strict quality criteria of the current S3 guideline 2022.
- Emergency carotid stenting has significantly higher complication rates than elective procedures.
- Elective and emergency carotid stenting cannot be meaningfully compared.

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ZUSAMMENFASSUNG

Einleitung Nach der Evidenz aus randomisierten Studien und aktuellen Leitlinien wird das elektive Carotis-Stenting (CAS) gegenüber der Carotisendarteriektomie (CEA) immer noch als Zweitlinientherapie angesehen. Die Publikation der randomisierten Vergleichsstudien für Patienten mit symptomatischen Stenosen erfolgte allerdings vor deutlich mehr als 10 Jahren. Angesichts von Problemen der deutschen Qualitätssicherung bei der sauberen Trennung zwischen elektiven und Notfalleingriffen und geringen Fallzahlen für die CAS-Nischenindikationen erschien es sinnvoll, neurologisch kontrollierte CAS-Ergebnisse darzustellen, und zu untersuchen, ob elektives CAS die strengen Qualitätskriterien durchgängig erfüllt und welche Unterschiede zu notfälligen CAS-Eingriffen beim akuten ischämischen Schlaganfall bestehen.

Material und Methoden Zwischen 01/2012 und 07/2022 wurden 141 elektive CAS-Eingriffe zur Behandlung von Patienten mit symptomatischen (n = 123) und asymptomatisch (n = 18) Stenosen durchgeführt. Bei 134 dieser elektiven Eingriffe (95 %) konnte eine Protektion durch ein Filtersystem erfolgen. Im gleichen Zeitraum wurden 158 Patienten im Rahmen eines akuten Schlaganfalles mittels Carotis-Stent behandelt. Die Komplikationsrate wurde anhand neurologisch kontrollierter Daten ermittelt. Bei den Notfall-Eingriffen wurden CAS-bezogene Komplikationen (Stent-Thrombosen, Stent-assoziierte Gefäßschäden, Thrombembolien und symptomatische Blutungen) extrahiert und das klinische Outcome (NIHSS-Verlauf) während des stationären Aufenthalts ermittelt.

Ergebnisse Die während des stationären Aufenthalts für elektive symptomatische Patienten ermittelte Rate an Schlaganfällen und Todesfällen lag bei 0,8 %. Eine frühe Behandlung innerhalb der ersten 7 Tage nach dem Indexereignis, Alter > 70 Jahre und Erfahrung des Operateurs waren keine signifikanten Risikofaktoren für das Auftreten von Komplikationen. Nach CAS-asymptomatischer Stenosen wurden keine Komplikationen beobachtet. Die prozedurbezogene Komplikationsrate bei Notfalleingriffen lag bei 7,8 % und war damit erwartungsgemäß signifikant höher als nach elektivem CAS (p < 0,006).

Schlussfolgerung Auch bei begrenzter Indikationsstellung und eingeschränkter Fallzahl ist die Einhaltung der strengen Qualitätskriterien der aktuellen S3-Leitlienie 2022 für elektive CAS-Eingriffe sowohl bei symptomatischen als auch bei asymptomatischen Stenosen in einem erfahrenen Zentrum möglich. Notfall-CAS-Eingriffe haben bei anderen Voraussetzungen signifikant höhere Komplikationsraten und müssen bezüglich der Qualitätssicherung separat betrachtet werden.

Introduction

According to current guidelines and system. Reviews portray carotid angioplasty (CAS) with stenting compared to carotid endarterectomy (CEA) as the recommended standard as a second-line therapy for patients who are not suitable for open surgery [1–3]. The main reason for this is that the complication rates are higher for CAS in randomized controlled trials (RCTs) [4–7]. Although the differences between endovascular and surgical therapy even out in the long term [8–10], these results led to a decreasing number of CAS cases. Therefore, according to Statutory Quality Assurance Data, approx. 4000 CAS interventions are performed each year compared to more than 24 000 CEA procedures [11]. Many German CAS centers have low case numbers with a maximum of 10 interventions per year [12]. When evaluating current evidence, it must be taken into consideration that the publication of RCTs for patients with symptomatic stenoses is more than 10 years old. Current data from RCTs is only available for patients with asymptomatic stenoses. The ACST-2 study was not able to show any significant differences between CAS and CEA regarding the acute complication rate and in the long term [9]. After the failure of two European RCTs regarding CAS vs. CEA vs. best medical treatment (BMT) due to a lack of participation [13, 14], no new RCTs are planned for the near future. In the United States, only CREST-2 is still recruiting patients with asymptomatic stenoses for comparison of BMT vs. CEA vs. CAS [15].

Given the lack of current RCT data for symptomatic patients, mandatory quality assurance registries can help to document CAS complication rates [11]. However, in Germany, elective and emergency CAS interventions are recorded together without a clear differentiation.

In light of this, it seemed useful to examine neurological data in order to determine whether endovascular treatment fulfilled the strict quality criteria for elective carotid revascularization and which differences there are in comparison to emergency interventions in interventional stroke treatments.

Materials and Methods

A monocentric retrospective analysis of all carotid stent patients treated between 1/2012 and 7/2022 at a neurovascular center was performed. Both patients with high-grade symptomatic and asymptomatic carotid stenosis who were treated electively and patients with acute stroke due to a carotid stenosis treated with CAS on an emergency basis were included in the analysis. Patients

with intradural carotid stenoses and proximal ACC stenoses and cases with covered stents for treating aneurysms or bleeding from ENT tumors were excluded.

All CAS patients underwent a neurological examination both preintervention and postintervention and were treated on an inpatient basis in the neurology department.

The indication for **elective CAS procedures** was determined in an interdisciplinary conference including neurologists, neurosurgeons, vascular surgeons, and neuroradiologists under consideration of guideline recommendations and patient preference. In addition, the degree on stenosis determined by Doppler ultrasound, a CTA or MRA examination of the cervical vessels and cerebral imaging were available. All elective patients were informed of the treatment alternatives CAS, CEA, or BMT and provided their written consent for the procedure. The study protocol was approved by the local ethics committee.

- **Elective CAS procedures** were conducted under local anesthesia with an anesthesiologist on standby. 75 mg clopidogrel and 100 mg ASA 5 days before the intervention (alternatively 600 mg clopidogrel and 100 mg ASA the day before the intervention) were administered for preinterventional platelet aggregation inhibition. During the intervention, 5000 IU heparin were administered intravenously as a bolus and diluted Nimotop was administered via the irrigation solution. After 3 months dual platelet aggregation inhibition was replaced by monotherapy with 100 mg ASA.

The CAS procedure was performed in a standardized manner with minimal materials as follows:

After transfemoral insertion of a 6F sheath into the common carotid artery to be treated, the stenosis was probed with an embolic protection system (Filter-Wire, Boston or Spider, Medtronic) after angiographic imaging. The filter was released in a straight section of the vessel above the stenosis. Predilation with a 3-mm PTA balloon was performed, when necessary, via the wire of the filter system. A self-expanding carotid stent (Wallstent, Boston Scientific; Precise, Cordis; C-Guard, Balt; Casper, Microvention) was released above the stenosis and was then dilated to 5 mm. After removal of the filter, the treated carotid artery and the dependent intracranial arteries were checked with DSA series, the access system was withdrawn, and the puncture site in the groin was sealed (Angio-Seal, Terumo).

All patients underwent neurological monitoring postintervention at the stroke unit. The patency of the stents was checked sonographically. Cerebral imaging was only performed in the case of new neurological deficits. After discharge, follow-up was performed during the hospital's consultation hours for vascular neurological diseases.

- The indication for **emergency CAS interventions** was determined in consensus between neurologists and neuroradiologists based on cerebral imaging with native CT and CTA or MRI and MRA in severely affected patients (NIHSS > 5).

All emergency interventions were performed under endotracheal anesthesia. As soon as the need for stent implantation was determined, medication-based platelet aggregation inhibition with intravenous administration of 250 mg of ASA and a loading dose of 600 mg clopidogrel or 180 mg ticagrelor administered via stomach tube was initiated. This was performed independent of preinterventional intravenous lysis treatment.

After transfemoral introduction of a long 6F sheath and angiographic vascular imaging, plaque was aspirated in the case of an occluded internal carotid artery. The extracranial stenosis was then passed via a wire with an aspiration catheter (Sofia, Microvention) and, when possible, with the sheath. High-grade stenoses were predilated for this purpose. As a rule, intracranial thrombectomy was first performed. Primary stent implantation was needed to pass the stenosis only in individual cases. Intracranial thrombi were removed with aspiration and a stent retriever with the goal of recanalizing the intracranial vessels as completely as possible.

After thrombectomy, the access system was retracted under aspiration into the common carotid artery below the stenosis and a self-expanding carotid stent was released. In the case of mural thrombi, double-layer stents were preferably used. A protection system was not typically used.

After a final check of the extracranial internal carotid artery and the downstream intracranial arteries, the access system was removed and the puncture site in the groin was closed.

After the intervention, the patient was monitored for at least 24 hours at the neurological intensive care unit with the target systolic blood pressure values being between 120 mmHg and 140 mmHg. The patient was extubated as quickly as possible. Subsequent treatment included dual platelet aggregation inhibition with 75 mg clopidogrel and 100 mg ASA or 2x 90 mg ticagrelor and 100 mg ASA for 3 months, followed by continuous monotherapy with 100 mg ASA. On the following day, all patients underwent cerebral imaging, preferably CT, to determine the extent of infarction and to rule out bleeding. After the end of intensive treatment, further treatment was performed in the stroke unit until discharge or transfer to a rehab facility.

The two patient groups were evaluated separately:

- For **elective patients**, the CAS indications and technical success rates were described. Postinterventional strokes, deaths, and vascular complications like dissection, thromboembolic events, or stent thromboses were determined during the inpatient stay. In the case of new neurological deficits, a differentiation was made between ischemic stroke, symptomatic bleeding, and reperfusion edema, and the probable cause was determined. The severity of neurological limitations was determined on the basis of the National Institute of Health Stroke Scale (NIHSS) [16]. Non-neurological complications like groin hematoma, femoral artery occlusion, and heart attack were also documented.
- To determine the complication rate of **emergency interventions**, we tried to differentiate CAS-related events from thrombectomy or stroke-associated complications. Stent thromboses, stent-associated intracranial embolisms, and CAS-associated vascular damage were defined as CAS-related. Since symptomatic intracranial bleeding could be caused by aggressive platelet aggregation inhibition, this was also considered a CAS complication [17, 18].

The degree of intracranial recanalization was evaluated using the mTICI scale [19]. An mTICI score ≥ 2b was defined as successful recanalization.

The neurological treatment result was evaluated based on the NIHSS at discharge.

Statistical evaluation was performed using SPSS Statistics 27 (IBM) with the Pearson's chi-square test, Fischer's exact test, and logistical multivariate regression analysis.

Results

Of the 299 included patients, 141 were **elective cases** (▶ **Table 1**) with symptomatic (n = 123) and asymptomatic (n = 18) stenoses and 158 were **emergency patients**.

97 patients with *elective CAS* were male. The average age was 67.8 years (± 9.1). The average degree of stenosis was 83,8 % (± 10.7 SD). Preinterventionally, 17 (13.8 %) of the symptomatic patients had a TIA and 101 (82.1 %) had a stroke. The degree of severity of neurological impairment prior to the intervention was 2.3 NIHSS points on average. 22 patients (15.6 %) had a severe stroke ≥ 16 points.

The CAS indications for symptomatic and asymptomatic cases established on an interdisciplinary basis are provided in ▶ **Table 2**. The main indications for CAS were occlusion or high-grade stenosis of the contralateral internal carotid artery or other multi-vessel stenoses (n = 35), high cervical position of the stenosis (n = 5), restenosis after CEA (n = 10), and patient request (n = 88). Symptomatic patients received early treatment within the first 7 days after the index event in 73 of 123 cases (59.3 %). 39 % of all elective CAS patients were older than 70 years at the time of intervention.

74 of 158 *emergency patients* (▶ **Table 3**) were male and the average age was 67.9 years (± 12.1). Primarily patients with tandem lesions were treated (84.2 %). More rarely hemodynamic ischemia without intracranial vascular occlusion was seen. The average NIHSS at the time of admission was 12.5 points (± 6,1). 94 patients had an extracranial occlusion of the internal carotid artery and 74 had a high-grade stenosis of the internal carotid artery. In the case of tandem lesions, M1 occlusions were most common (n = 76; 57.1 %). The distal internal carotid artery (n = 13), carotid-T (n = 19), and M2 (n = 22) were more rarely occluded.

Except for in one case, all **elective procedures** were technically successful (n = 140/141). In one patient with pronounced calcified stenosis, residual constriction > 30 % was seen postinterventionally. There was one death due to myocardial infarction around the time of inpatient admission. There were no cases of stroke postintervention. One patient had reversible vision impairment due to retinal microembolisms. Two patients experienced temporary worsening of preexisting neurological deficits without detection of a new infarction on MRI. In both cases, reperfusion edema after recanalization of a high-grade carotid stenosis with significant hemodynamic impairment was the most probable cause. Symptomatic bleeding or stent thromboses were not seen in the elective patients. Two groin hematomas and one femoral artery occlusion were observed as further non-neurological complications. Two patients developed pneumonia.

In the case of a low event rate, no statistically significant predictors of periinterventional complications could be determined. In particular, neither early treatment of symptomatic patients nor an age of more than 70 years was associated with a poor outcome. In a team of 6 interventionalists with varying levels of experience, we were not able to determine a dependence of the complication rate on the person performing the intervention.

In the **emergency interventions**, CAS was technically successful in 155 of 158 cases (98.1 %). In patients with tandem lesions, successful recanalization ≥ mTICI 2b was able to be achieved in 124 of 133 cases (93.2 %). 16 stent thromboses (10.1 %) occurred after stent implantation. Four dissections occurred including one fatal aortic dissection in the case of an aortic aneurysm.

Symptomatic bleeding was observed in 12 cases (7.6 %). New ischemic deficits in connection with stent implantation were seen in three cases (1.9 %). ▶ **Table 4** shows the complication rates for elective and emergency interventions.

In the case of different initial values, the complication rates and clinical outcome of emergency patients were significantly worse than in elective interventions. The rate of good clinical outcomes (NIHSS 0–4) was 90.8 % for elective CAS and 40 % for emergency CAS (p < 0.001) around the time of inpatient admission. Under consideration of clinical improvements (≥ 2 NIHSS points), a good clinical result of 95.7 % vs. 67.1 % was achieved (p < 0.001).

Discussion

Analysis of our data shows that **elective CAS interventions** are possible with very low complication rates even in the case of moderate case numbers using strict indication criteria. Our numbers are lower than the upper limit of periinterventional strokes and deaths during the inpatient stay (4 % in symptomatic and 2 % in asymptomatic patients) [1, 2]. This refutes the generalization that CAS interventions are fundamentally associated with increased risks compared to CEA. However, we are aware that this small single-center case series is based on the results in an experienced CAS center and cannot serve as the foundation for general recommendations for CAS.

The fact that 39 % of our patients were > 70 years and the majority (59.3 %) of symptomatic cases were treated early within 1 to 7 days after the index event shows that not only patients with a low intervention risk were treated [20, 21]. 19.5 % of the included patients already had cerebral infarction with significant neurological deficits preintervention (NIHSS ≥ 5). The mean degree of stenosis was 83.8 %. The percentage of high-grade stenoses (70–99 %) was 92.9 % higher than in the large RCTs [20] regarding symptomatic carotid stenosis (82.5 %) and in the German QA Registry [11] (91.6 %). Elective patients unsuitable for endovascular treatment due to extreme vessel elongation or circumferential plaque calcification underwent vascular surgery.

The decision criteria that were used for elective CAS intervention in the interdisciplinary conference require discussion. Except for several exceptions (restenosis after CEA, high cervical stenosis, tandem stenosis, radiogenic stenosis), there is no clear definition of the patient groups in which elevated CEA risks are to be expected [1, 2]. However, current systematic reviews confirm our as-

▶ **Table 1** Patient characteristics in elective CAS.

		Elective (n = 141)	Symptomatic CS (n = 123)	Asymptomatic CS (n = 18)	p-value
Age (years)	Mean (±SD)	67.8 (± 9.1)	68 (± 2.6)	66.7 (± 7)	
▪ **>70 years**	n (%)	55 (39 %)	50 (40.7 %)	5 (27.8 %)	0.296a
▪ **>80 years**	n (%)	13 (9.2 %)	13 (10.6 %)	0 (0 %)	0.374b
Sex (male)	n (%)	97 (68.8 %)	82 (66.7 %)	15 (83.3 %)	0.154a
NIHSS-pre (points)	Mean (±SD)	2.3 (± 3.7)	2.6 (± 3.8)	0 (± 0)	
▪ **NIHSS 0**	n (%)	68 (48.2 %)	50 (40.7 %)	18 (100 %)	**<0.001a**
▪ **NIHSS 1–4**	n (%)	51 (36.2 %)	51 (41.5 %)	0 (0 %)	**<0.001a**
▪ **NIHSS 5–15**	n (%)	20 (14.2 %)	20 (16.3 %)	0 (0 %)	0.076b
▪ **NIHSS 16–20**	n (%)	1 (0.7 %)	1 (0.8 %)	0 (0 %)	1b
▪ **NIHSS 21–42**	n (%)	1 (0.7 %)	1 (0.8 %)	0 (0 %)	1b
▪ **NIHSS ≥16**	n (%)	2 (1.4 %)	2 (1.6 %)	0 (0 %)	
New infarction (on imaging)	n (%)	100 (70.9 %)	99 (80.5 %)	1 (5.6 %)	**<0.001a**
▪ **Ipsilateral or bilateral**	n (%)	99 (70.2 %)	98 (79.7 %)	1 (5.6 %)	**<0.001a**
Old infarction (on imaging)	n (%)	36 (25.5 %)	32 (26 %)	4 (22.2 %)	1b
Preexisting conditions and risk factors	n (%)				
▪ **Cerebrovascular diseases**	n (%)	41 (29.1 %)	33 (26.8 %)	8 (44.4 %)	0.164b
▪ **Coronary heart disease**	n (%)	29 (20.6 %)	23 (18.7 %)	6 (33.3 %)	0.208b
▪ **Peripheral artery disease**	n (%)	13 (9.2 %)	12 (9.8 %)	1 (5.6 %)	1b
▪ **Vasc. diseases (cerebrovascular disease, coronary heart disease, peripheral artery disease)**	n (%)	60 (42.6 %)	48 (39 %)	12 (66.7 %)	0.027b
▪ **Hypertension**	n (%)	80 (56.7 %)	73 (59.3 %)	7 (38.9 %)	0.102a
▪ **Diabetes**	n (%)	34 (24.1 %)	31 (25.2 %)	3 (16.7 %)	0.562b
▪ **Hypercholesteremia/hyperlipidemia**	n (%)	22 (15.6 %)	20 (16.3 %)	2 (11.1 %)	0.739b
▪ **Nicotine abuse**	n (%)	48 (34 %)	42 (34.1 %)	6 (33.3 %)	0.946a
▪ **Atrial fibrillation**	n (%)	8 (5.7 %)	6 (4.9 %)	2 (11.1 %)	0.271b
▪ **Cardiac insufficiency**	n (%)	2 (1.4 %)	2 (1.6 %)	0 (0 %)	1b
▪ **Malignant primary disease**	n (%)	14 (9.9 %)	14 (11.4 %)	0 (0 %)	0.216b
Degree of stenosis in the ipsilateral internal carotid artery (%)	Mean (±SD)	83.8 (± 10.7)	83.5 (± 11.1)	86.1 (± 8)	
▪ **Moderate (50–69 %)**	n (%)	8 (5.7 %)	8 (6.5 %)	0 (0 %)	0.596b
▪ **Severe (70–99 %)**	n (%)	131 (92.9 %)	113 (91.9 %)	18 (100 %)	0.361b
▪ **Occlusion**	n (%)	2 (1.4 %)	2 (1.6 %)	0 (0 %)	1b
Side (rights)	n (%)	78 (55.3 %)	67 (54.5 %)	11 (61.1 %)	0.597a
Stenosis features	n (%)	18 (12.8 %)	17 (13.8 %)	1 (5.6 %)	0.469b
▪ **Dissection**	n (%)	1 (0.7 %)	1 (0.8 %)	0 (0 %)	1b
▪ **With thrombi**	n (%)	3 (2.1 %)	3 (2.4 %)	0 (0 %)	1b
▪ **Radiogenic stenosis**	n (%)	4 (2.8 %)	4 (3.3 %)	0 (0 %)	1b
▪ **Restenosis after CEA**	n (%)	10 (7.1 %)	9 (7.3 %)	1 (5.6 %)	1b
Contralateral internal carotid artery stenosis/occlusion	n (%)	58 (41.1 %)	48 (39 %)	10 (55.6 %)	0.183a
▪ **Occlusion**	n (%)	12 (8.5 %)	10 (8.1 %)	2 (11.1 %)	0.652b
Vertebral artery stenosis	n (%)	29 (20.6 %)	27 (22 %)	2 (11.1 %)	0.366a
Multi-vessel obstruction	n (%)	59 (41.8 %)	50 (40.7 %)	9 (50 %)	0.453a

p-values in bold were statistically significant. NIHSS: National Institutes of Health Stroke Scale; SD: standard deviation. a: Chi-square test; b: Fisher's exact test

▶ **Table 2** Elective CAS indications.

		Elective (n = 141)	Symptomatic CS (n = 123)	Asymptomatic CS (n = 18)
Differential indication (CAS instead of CEA)				
▪ **High surgical risk**	n (%)	32 (22.7 %)	27 (22 %)	5 (27.8 %)
Contralateral internal carotid artery occlusion	n (%)	12 (8.5 %)	10 (8.1 %)	2 (11.1 %)
Radiogenic stenosis	n (%)	4 (2.8 %)	4 (3.3 %)	0 (0 %)
Restenosis after CEA	n (%)	10 (7.1 %)	9 (7.3 %)	1 (5.6 %)
Contralateral recurrent laryngeal nerve paralysis	n (%)	0 (0 %)	0 (0 %)	0 (0 %)
Cardiac risk factors[a]	n (%)	8 (5.7 %)	6 (4.9 %)	2 (11.1 %)
▪ **Caused by stenosis**	n (%)	27 (19.1 %)	23 (18.7 %)	4 (22.2 %)
High cervical internal carotid artery stenosis	n (%)	5 (3.5 %)	3 (2.4 %)	2 (11.1 %)
Thoracic tandem stenosis	n (%)	4 (2.8 %)	4 (3.3 %)	0 (0 %)
Intracranial tandem stenosis	n (%)	19 (13.5 %)	17 (13.8 %)	2 (11.1 %)
▪ **Patient request**	n (%)	88 (62.4 %)	77 (62.6 %)	11 (61.1 %)
Stroke risk factor in asymptomatic CS				
▪ **Stenosis progression**	n (%)			13 (72.2 %)
▪ **Multivessel obstruction with limited collateralization**	n (%)			11 (61.1 %)
▪ **Contralateral TIA or stroke**	n (%)			4 (22.2 %)

CAS: carotid artery stenting; CEA: carotid endarterectomy; CS: carotid stenosis; NYHA: New York Heart Association; RF: risk factors. a: cardiac insufficiency NYHA 3/4, unstable angina pectoris, recent myocardial infarction

sumption that the CEA risks are higher in patients with high-grade obstruction of the contralateral internal carotid artery and CAS is thus reasonable [2, 3]. If the quality criteria are met, there is no reason to reject CAS procedures if requested by the patient after an interdisciplinary discussion. We attempted to meet the indication criteria in accordance with the guidelines. The relatively low number of cases (approx. 15 elective CAS cases per year) speaks against excessive use and expansion of the indication to include endovascular treatment.

Consequently, CAS centers are faced with the dilemma that CAS is rarely performed due to the niche indications but high case numbers and a high level of experience on the part of interventionalists are considered important prerequisites for a low complication rate [3, 22, 23]. Our case series shows that high quality standards can be met even with a limited number of cases by interventionalists with varying levels of experience. The referral of interventions based on level of experience, the standardization of procedures and materials with a limit to 2 filter types and 4 carotid stents, and awareness of the risks when manipulating atherosclerotic vessels are the most likely reasons for this [1].

Our consistent use of filter protection systems is not supported by dedicated RCTs or subgroup analyses. However, in our opinion, such systems help to prevent macroembolisms [24, 25]. Such events or severe filter complications were not observed in our series.

The consistent use of filter systems in American CAS studies (CREST, ACT-1), years of good experiences, and standardized ap-

plication with corresponding interventionalist training support use of such systems. Balloon catheters for temporary closure of the external and internal carotid arteries or flow reversal catheters with additional connection to the femoral vein can ensure protection against embolic complications similar to filter systems [26]. Due to the limited availability and limitations regarding the inner lumen, they were not used in our study. The additional introduction of balloon occlusion systems was also not conducive to the goal of technique standardization.

The consistent implementation of antithrombotic therapy and the peri- and post-interventional monitoring under consideration of upper blood pressure limits probably also contributed to the low complication rate.

In addition to acetylsalicylic acid (ASA), we primarily used clopidogrel for elective interventions. Ticagrelor has the advantage of a faster onset of action of only 2 hours after administration of a loading dose of 180 mg. Therefore, it was preferred for emergency interventions. Moreover, ticagrelor resistance is rarer than clopidogrel resistance. We did not perform any systematic testing regarding clopidogrel or ASA resistance in this study. According to our results, stent thromboses are barely a factor in elective stenting so that there is no need for testing in our opinion. For emergency interventions, use of a GP IIb/IIIa inhibitor like tirofiban IV with its advantage of an immediate onset of action instead of our preferred intravenous administration of ASA + ticagrelor via stomach tube should be discussed. However, it is unclear whether this increases the risk of bleeding complications. According to recent

▶ **Table 3** Patient characteristics in emergency CAS.

		Emergency (n = 158)	Tandem (n = 133)	Hemodynamic (n = 25)	p-value
Age (years)	Mean (±SD)	67.9 (± 12.1)	67.1 (± 11.8)	72.3 (± 8.2)	
▪ **>70 years**	n (%)	72 (45.6%)	59 (44.4%)	13 (52%)	0.482a
▪ **>80 years**	n (%)	29 (18.4%)	20 (15%)	9 (36%)	**0.022b**
Sex (male)	n (%)	74 (46.8%)	57 (42.9%)	17 (68%)	**0.021a**
NIHSS-pre (points)	Mean (±SD)	12.5 (± 6.1)	13.3 (± 5.6)	8.2 (± 6.6)	
▪ **NIHSS 0**	(%)	2 (1.3%)	1 (0.8%)	1 (4%)	0.292b
▪ **NIHSS 1–4**	(%)	17 (10.8%)	10 (7.5%)	7 (28%)	**0.007b**
▪ **NIHSS 5–15**	(%)	83 (52.5%)	70 (52.6%)	13 (52%)	0.954a
▪ **NIHSS 16–20**	(%)	47 (29.7%)	45 (33.8%)	2 (8%)	**0.01b**
▪ **NIHSS 21–42**	(%)	9 (5.7%)	7 (5.3%)	2 (8%)	0.635b
▪ **NIHSS ≥16**	(%)	56 (35.4%)	52 (39.1%)	4 (16%)	
New infarction (on imaging)	(%)	140 (88.6%)	121 (91%)	19 (76%)	**0.042b**
▪ **Ipsilateral or bilateral**	(%)	139 (88%)	120 (90.2%)	19 (76%)	0.085b
Old infarction (on imaging)	(%)	28 (17.7%)	20 (15%)	8 (32%)	0.05b
Preexisting conditions and risk factors	(%)				
▪ **Cerebrovascular diseases**	(%)	18 (11.4%)	11 (8.3%)	7 (28%)	**0.01b**
▪ **Coronary heart disease**	(%)	22 (13.9%)	19 (14.3%)	3 (12%)	1b
▪ **Peripheral artery disease**	(%)	9 (5.7%)	8 (6%)	1 (4%)	1b
▪ **Vasc. diseases (cerebrovascular disease, coronary heart disease, peripheral artery disease)**	(%)	38 (24.1%)	30 (22.6%)	8 (32%)	0.311a
▪ **Hypertension**	(%)	86 (54.4%)	71 (53.4%)	15 (60%)	0.542a
▪ **Diabetes**	(%)	25 (15.8%)	21 (15.8%)	4 (16%)	1b
▪ **Hypercholesteremia/hyperlipidemia**	(%)	20 (12.7%)	14 (10.5%)	6 (24%)	0.094b
▪ **Nicotine abuse**	(%)	44 (27.8%)	39 (29.3%)	5 (20%)	0.34a
▪ **Atrial fibrillation**	(%)	16 (10.1%)	12 (9%)	4 (16%)	0.286b
▪ **Cardiac insufficiency**	(%)	5 (3.2%)	5 (3.8%)	0 (0%)	1b
▪ **Malignant primary disease**	(%)	10 (6.3%)	10 (7.5%)	0 (0%)	0.365b
Degree of stenosis in the ipsilateral internal carotid artery (%)	Mean (±SD)	96.5 (± 6.7)	97.3 (± 5.8)	92.2 (± 9)	
▪ **Moderate (50–69%)**	(%)	1 (0.6%)	1 (0.8%)	0 (0%)	1b
▪ **Severe (70–99%)**	(%)	74 (46.8%)	55 (41.4%)	19 (76%)	**<0.001a**
▪ **Occlusion**	(%)	94 (59.5%)	88 (66.2%)	6 (24%)	**<0.001a**
Side (rights)	(%)	68 (43%)	62 (46.6%)	6 (24%)	**0.036a**
Stenosis features	(%)	20 (12.7%)	17 (12.8%)	3 (12%)	1b
▪ **Dissection**	(%)	10 (6.3%)	8 (6%)	2 (8%)	0.659b
▪ **With thrombi**	(%)	7 (4.4%)	6 (4.5%)	1 (4%)	1b
▪ **Radiogenic stenosis**	(%)	1 (0.6%)	1 (0.8%)	0 (0%)	1b
▪ **Restenosis after CEA**	(%)	11 (7%)	2 (1.5%)	9 (36%)	1b
Contralateral internal carotid artery stenosis/occlusion	(%)	31 (19.6%)	21 (15.8%)	10 (40%)	**0.011b**
▪ **Occlusion**	(%)	11 (7%)	5 (3.8%)	6 (24%)	**0.002b**
Vertebral artery stenosis	(%)	18 (11.4%)	11 (8.3%)	7 (28%)	**0.01b**
Multi-vessel obstruction	(%)	32 (20.3%)	24 (18%)	8 (32%)	0.111a

p-values in bold were statistically significant. NIHSS: National Institutes of Health Stroke Scale; SD: standard deviation. a: Chi-square test; b: Fisher's exact test

▶ **Table 4** Comparison of complications in elective and emergency interventions.

		Elective (n = 141)	Emergency (n = 158)	p-value
Stroke or death	n (%)	1 (0.7 %)	32 (20.3 %)	**< 0.001a**
▪ Procedure-related	n (%)	0 (0 %)	11 (7 %)	**< 0.001a**
▪ Stroke-related	n (%)	1 (0.7 %)	11 (7 %)	**0.006a**
▪ Unclear etiology	n (%)	0 (0 %)	10 (6.3 %)	**0.002b**
Death	n (%)	1 (0.7 %)	25 (15.8 %)	**< 0.001a**
▪ Caused by infarction	n (%)	0 (0 %)	17 (10.8 %)	**< 0.001a**
▪ Cardiac	n (%)	1 (0.7 %)	3 (1.9 %)	0.625b
▪ Other cause	n (%)	0 (0 %)	5 (3.2 %)	0.062b
New or progressive stroke	n (%)	0 (0 %)	20 (12.7 %)	**< 0.001a**
Reperfusion edema	n (%)	2 (1.4 %)		
Neurological worsening	n (%)	1 (0.7 %)	12 (10.5 %)	**< 0.001a**
▪ Moderate (2–3 NIHSS points)	n (%)	1 (0.7 %)	6 (5.3 %)	**0.048b**
▪ Relevant (≥ 4 NIHSS points)	n (%)	0 (0 %)	6 (5.3 %)	**0.008b**
Cerebral hemorrhage	n (%)	0 (0 %)	36 (22.8 %)	**< 0.001a**
▪ Minor	n (%)	0 (0 %)	19 (12 %)	**< 0.001a**
▪ Major (PH2)	n (%)	0 (0 %)	17 (10.8 %)	**< 0.001a**
▪ Symptomatic (sICH)	n (%)	0 (0 %)	12 (7.6 %)	**< 0.001a**
▪ Fatal	n (%)	0 (0 %)	8 (5.1 %)	**0.008b**
Vascular complications	n (%)	1 (0.7 %)	31 (19.6 %)	**< 0.001a**
▪ Symptomatic	n (%)	0 (0 %)	7 (4.4 %)	**0.016b**
▪ Stent thrombosis	n (%)	1 (0.7 %)	16 (10.1 %)	**< 0.001a**
Complete	n (%)	0 (0 %)	9 (5.7 %)	**0.004b**
Symptomatic	n (%)	0 (0 %)	3 (1.9 %)	0.25b
▪ Embolization	n (%)	0 (0 %)	14 (8.9 %)	**< 0.001a**
Symptomatic	n (%)	0 (0 %)	3 (1.9 %)	0.25b
▪ Dissection	n (%)	0 (0 %)	4 (2.5 %)	0.125b
Symptomatic	n (%)	0 (0 %)	1 (0.6 %)	1b
▪ Carotid cavernous fistula	n (%)	0 (0 %)	2 (1.3 %)	0.5b
Neurological complications	n (%)	3 (2.1 %)	67 (42.4 %)	**< 0.001a**
▪ Symptomatic	n (%)	0 (0 %)	27 (17.1 %)	**< 0.001a**
Non-neurological complications	n (%)	7 (5 %)	50 (31.6 %)	**< 0.001a**
▪ Fatal	n (%)	1 (0.7 %)	25 (15.8 %)	**< 0.001a**
▪ Acute myocardial infarction	n (%)	1 (0.7 %)	4 (2.5 %)	0.375b
Fatal	n (%)	1 (0.7 %)	2 (1.3 %)	1b
▪ Pneumonia	n (%)	2 (1.4 %)	40 (25.3 %)	**< 0.001a**
Fatal	n (%)	0 (0 %)	3 (1.9 %)	0.25b
▪ Groin hematoma	n (%)	2 (1.4 %)	8 (5.1 %)	0.109b
▪ Femoral artery occlusion	n (%)	1 (0.7 %)	1 (0.6 %)	1b

p-values in bold were statistically significant. NIHSS: National Institutes of Health Stroke Scale; PH2: parenchymal hemorrhage type 2 (bleeding in > 30 % of the infarction region with relevant space-occupying effect); sICH: symptomatic cerebral hemorrhage. a Chi-square test; b: Fisher's exact test

registry data, aggressive platelet function inhibition is superior to ASA administration alone even in emergency CAS and results in a better clinical outcome due to the prevention of stent thromboses. A statistically significant relationship between the type of aggressive treatment regime and the rate of associated bleeding complications has not yet been able to be proven given the small case numbers in the corresponding subgroups.[27, 28].

We are aware that the topic of antithrombotic therapy is controversial particularly with respect to emergency interventions. A detailed presentation would exceed the scope of this study and would presumably require further prospective multicenter studies.

Our own good results are confirmed by the CAS data from the mandatory German quality assurance, and they make in-hospital stroke and death rates of up to 4 % in symptomatic stenoses and up to 2 % in asymptomatic stenoses seem realistic even on a multicenter basis [12, 29]. In patients with asymptomatic stenoses, good CAS results are also confirmed by the ACST-2 study, which was not able to show any significant differences with respect to CEA [9].

The comparison of elective results to **emergency CAS interventions** in acute stroke shows significantly higher complication rates and worse clinical treatment results. With a stent thrombosis rate of 10.1 % and symptomatic bleeding in 7.6 % of cases, our results regarding the most important CAS-associated complications are in the range of published data from other studies [30–37]. Thus, relatively aggressive and systematic platelet aggregation inhibition did not result in a clear increase in bleeding rate. The lower rate of stent occlusion (5.7 %) compared to the literature [38–41] (10–22 %) may have been due to the very early initiation of dual platelet aggregation inhibition. However, further studies with a greater number of cases are needed to clarify the risks associated with stent implantation [42]. Our technical success rates for reperfusion (93.3 % mTICI ≥ 2b) were above the published results of the German Stroke Registry and the older Titan Registry [36, 37].

The usual 3 months of data for stroke studies for evaluating the clinical treatment result were not available for this case series. The treatment result during inpatient treatment with a mortality rate of 15.6 % and a good outcome (NIHSS 0–4) of 40 % is largely comparable with other CAS studies on tandem lesions [36, 37, 43].

Limitations of our study are primarily due to the retrospective monocentric study design with a limited number of cases. A comparison with CEA and BMT groups is lacking. However, the monocentric design has the advantage that the interventions were conducted using a defined standard and thus the CAS results should not be affected by the use of different intervention regimes and materials. For patients with symptomatic stenoses, new randomized studies would be needed but it is not currently realistic to implement them. Mandatory quality assurance registries allow complete recording of all procedures with evaluation of quality in the case of examinations performed by an independent neurologist.

Conclusion

In spite of limited indications and case numbers, it is possible to meet the quality criteria for elective CAS interventions in patients with symptomatic and asymptomatic stenoses in accordance with the guidelines. Adjustment of the indication to the level of experience of the interventionalist and standardization of techniques and materials are important requirements here.

Emergency CAS interventions cannot be compared with elective cases in terms of QA. Separate documentation with definition of procedure-related complications and the clinical outcome is needed for this purpose.

Conflict of Interest

The authors declare that they have no conflict of interest.

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