Original Article

Comparing carotid endarterectomy and carotid artery stenting: retrospective single-center analysis

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Background: Extracranial cerebrovascular diseases represent approximately 20% of ischemic stroke cases. Carotid endarterectomy (CEA) was the gold standard procedure for carotid artery stenosis treatment until the introduction of carotid artery stenting (CAS) in the 1980s. While there have been several multicenter randomized trials comparing CEA and CAS, a more efficacious procedure has not been conclusively distinguished. This study reports the results of CAS versus CEA in patients with symptomatic or asymptomatic carotid stenosis and compares them with those from other studies.

Methods: This study is a single-center retrospective study and included patients who underwent CAS and CEA as elective surgery between January 2012 and December 2020. The final analysis included patient baseline characteristics, postoperative complications, and patient outcomes.

Results: The 235 patients included were assigned to the CAS (n=128) and CEA (n=107) groups. Within 30 days postoperatively, no significant differences were noted in myocardial infarction [n=1, 0.8% (CAS); n=1, 0.9% (CEA); P=0.899], cerebral infarction [n=4, 3.1% (CAS); n=1, 0.9% (CEA); P=0.247], and patient mortality [n=1, 0.8% (CAS); n=0, 0% (CEA); P=0.247].

Conclusions: In elective surgery, CAS and CEA had the same effect of preventing cerebral infarction with no difference in postoperative complications.

Keywords: Carotid endarterectomy (CEA); carotid artery stenting (CAS); retrospective single-center analysis

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Introduction

Stroke is the leading cause of disability in the elderly and the third most common cause of death in developed countries (1). About 75–80% of all strokes are of ischemic etiology, and 20% of ischemic strokes are extracranial cerebrovascular diseases (2).

Carotid artery stenosis refers to narrowing or blockage of the lumen of an artery due to the formation of plaque in the blood vessels. It is caused by atherosclerosis in >90% of patients. Carotid endarterectomy (CEA) was the standard-of-care for carotid artery stenosis until the introduction of carotid artery stenting (CAS) in the 1980s. Despite numerous multicenter randomized clinical trials, a distinctly superior method has not been determined. This study reports the results of CAS versus CEA in patients with symptomatic or asymptomatic carotid stenosis and compares them with those from other studies. We present the following article in accordance with the STROBE reporting checklist (available at https://apm.amegroups.com/article/view/10.21037/apm-22-797/rc).

Methods

Study design

This single-center retrospective cross-sectional study analyzed patients who underwent CEA and CAS as elective surgeries between January 2012 and December 2020. Symptomatic criteria included patients with a history of stroke, transient ischemic attack, or amaurosis fugax within the last 6 months. CEA or CAS was performed if 50–99% of carotid artery stenosis was present. Moreover, they were conducted in asymptomatic patients with 70–99% of carotid artery stenosis. All patients were diagnosed with carotid stenosis by duplex ultrasound. The degree of stenosis was evaluated based on the North American Symptomatic Carotid Endarterectomy Trial using transfemoral carotid artery angiography. Computed tomography (CT), carotid angiography, and CT perfusion were used to evaluate the carotid artery before surgery. Considering the patient's condition and of the risks associated with surgery, a neurologist, neurointerventionist, and cardiovascular surgeon consulted each other to determine the best treatment method. CAS was considered first for patients with severe comorbidities or challenging technical and/or anatomic factors. Severe comorbidities included class III/IV congestive heart failure or angina, left main coronary artery occlusive disease, coronary artery occlusive disease involving more than two vessels, ≥30% left ventricle ejection fraction, recent myocardial infarction, and severe lung or renal disease.

Challenging technical or anatomic factors included prior neck operation or neck irradiation, post-endarterectomy restenosis, and an extremely high lesion location (above the 2nd cervical vertebra). Both CEA and CAS were performed while on antiplatelets.

Therapeutic protocol and surgical technique

CEA was preferentially implemented under regional anesthesia (RA) with the awake test. However, if the patient was uncooperative or anxious, and if their carotid artery level was at the 2nd cervical vertebra; the procedure was performed under general anesthesia (GA) with a routine shunting if the patient refused RA.

An anesthesiologist introduced the RA using an ultrasound-guided deep cervical block injection into the C3–C5 vertebral transverse processes. Thereafter, the patient was lightly sedated while continuously being infused with dexmedetomidine targeted on the level-2 sedation status of the Richmond Agitation-Sedation Scale. Five minutes prior to CEA clamping, we performed the awake test: speech, grasping a rubber ball, and toe flexion and extension. After CEA clamping, we performed the awake test immediately and thereafter every 5 minutes. A carotid artery shunt (Pruitt-Inahara carotid shunt with T-port; Le maître Vascular Inc., Burlington, MA, USA) was inserted, in cases of abnormal awake test findings during the operation, to allow patients to recover from the cerebral ischemic state. In the RA group, arteriotomy was directly closed except in the patients with a shunt. In the GA with routine shunt group, arteriotomy was closed using path angioplasty of the bovine pericardium (Vascu-Guard; Biovascular, St. Paul, MN, USA). All patients then immediately underwent postoperative computed tomographic angiography of the brain to evaluate the following complications: anastomotic site stenosis, acute thrombosis, vascular spasm, embolism, cerebral edema, and hemorrhage.

Neurointerventionists performed CAS through the common femoral artery under local anesthesia. The Mo.Ma™ Ultra Proximal Cerebral Protection Device (Medtronic, Minneapolis, MN, USA) or SpiderFX Embolic Protection Device (Medtronic) was used in all cases to prevent procedure-related embolic cerebral infarction. As for the carotid stent, WALLSTENT (Boston Scientific, Natick, MA, USA) or Protégé™ RX GPS™ (Medtronic)

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was used at the discretion of the operator.

After the intervention, the patients were transferred to the neurologic ICU for at least a day to strictly monitor their blood pressure (systolic blood pressure <140 mmHg), neurologic deficits, and operative wound complications.

For asymptomatic patients, clopidogrel single antiplatelet therapy (SAPT) was mainly used, and clopidogrel was maintained for both CAS and CEA before intervention. In symptomatic patients, dual antiplatelet therapy (DAPT) was performed, and in CEA, the operation was performed with clopidogrel SAPT from 5 days before the operation, and it was maintained after the operation. In CAS, the procedure was performed using DAPT, and clopidogrel alone was used at discharge. Furthermore, antihypertensive and lipid-lowering therapy were continuously maintained.

Statistical analyses

The statistical analysis was carried out using the IBM SPSS Statistics for Windows version 21.0. (IBM Corp, Armonk, NY, USA). Statistical significance was defined as P<0.05. The characteristics of the study population are presented as proportions for categorical variables and as mean ± standard deviation for continuous variables. Pearson's chi-square test was used to test the association between CAS and CEA, and mean differences between the two groups were analyzed by a *t*-test. Spearman's correlation coefficient was used to assess the correlation between baseline characteristics, operation characteristics, and risk factors for postoperative complications for CAS.

Ethical statement

The study was conducted in accordance with the Declaration of Helsinki (as revised in 2013). The study was approved by the institutional review board of Pusan National University Hospital (No. 2111-030-109), and individual consent for this retrospective analysis was waived based on the retrospective observational nature of the study.

Results

Of the 235 patients who underwent elective surgery for carotid stenosis, 107 and 128 underwent CEA and CAS, respectively. The patient's baseline characteristics are described in *Table 1*. Current smokers were statistically significantly more in number in the CEA group (27.1% in CEA *vs.* 16.4% in CAS; P=0.046).

Table 2 highlights the outcomes of CEA and CAS. The operative times (128.69±30.66 min in CEA *vs.* 75.79±26.03 min in CAS; P=0.000) and length of hospital stay (14.79±44.35 days in CEA *vs.* 5.77±4.89 days in CAS; P=0.023) were statistically significantly longer in the CEA group than in the CAS group. Cerebral infarction within 30 days after surgery was more commonly observed in the CAS group, but not significantly different from CEA (3.1% and 0.9%, respectively; P=0.247). The stroke that occurred within 30 days after CAS in all four patients were procedure-related multiple embolic infarctions and intracranial hemorrhage. Three of the four patients were symptomatic. One of the four patients who underwent CAS and developed 30-day postoperative stroke developed ipsilateral procedure-induced stroke. In two patients, bilateral hemorrhagic transformation with procedure-induced stroke was observed on magnetic resonance imaging, but no surgical treatment was required. The other patient underwent craniectomy owing to bilateral intraventricular hemorrhage and surrounding intracerebral hemorrhage but died on the 28th postoperative day owing to infection and multiorgan failure. Cerebral infarction (CI) occurred within 30 days of CEA in a symptomatic patient. The patient suffered from brain edema with multifocal acute infarction. However, no additional neurologic symptoms other than mild drowsy mentality progressed upon discharge. There were no patients with hyperperfusion syndrome in either group.

In the CAS group, contrast-induced nephrotoxicity occurred in a patient with atrial fibrillation; stage 4 chronic kidney disease after CAS occurred in another case, in which hemodialysis was performed. There were five cases of hematoma at the puncture site, but no special treatment was required. In the CEA group, one patient with asthma had an asthma attack in the intensive care unit after surgery and underwent reintubation. After steroid intake, the patient improved and was discharged without any special problems. Three patients developed a postoperative hematoma, two patients were discharged without special treatment, and one patient used compression and hemostatic agents. However, there were no cases where reoperation was required owing to bleeding. After surgery, there was one case of vagus nerve injury and four cases of hypoglossal nerve injury. All five patients had improved symptoms before discharge and did not develop any disability.

There were more cases of reoperation due to restenosis after surgery in the CAS group, but there was no statistically significant difference (0.0% in CEA *vs.* 1.6% in CAS;

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Table 1 Patient baseline characteristics in carotid artery stenting and carotid endarterectomy

Variables	Total [235]	CAS [128]	CEA [107]	P
Age (years), mean ± SD	74±8	74±7	74±9	0.950
Sex, female (%)	19 (8.1)	10 (7.8)	9 (8.4)	0.867
Hypertension (%)	173 (93.6)	86 (67.2)	87 (81.3)	0.014
Diabetes mellitus (%)	104 (44.3)	57 (44.5)	47 (43.9)	0.926
Myocardial infarction (%)	25 (10.6)	12 (9.4)	13 (12.1)	0.492
Atrial fibrillation (%)	31 (5.5)	4 (3.1)	9 (8.4)	0.078
PAOD (%)	5 (2.1)	3 (2.3)	2 (1.9)	0.802
COPD (%)	7 (3.0)	4 (3.1)	3 (2.8)	0.885
Liver disease (%)	4 (1.7)	3 (2.3)	1 (0.9)	0.406
ESRD (%)	6 (2.6)	4 (3.1)	2 (1.9)	0.543
Cancer (%)	43 (18.3)	28 (21.9)	15 (14.0)	0.121
Current smoker (%)	50 (21.3)	21 (16.4)	29 (27.1)	0.046
Symptomatic (%)	164 (69.8)	84 (65.6)	80 (74.8)	0.129
Left surgery area (%)	113 (48.1)	63 (49.2)	50 (46.7)	0.704
Stenosis ≥70% (%)	187 (80.3)	104 (80.1)	83 (79.0)	0.674
Charlson comorbidity index, mean ± SD	5.58±2.30	5.82±2.36	5.29±2.21	0.079

SD, standard deviation; CAS, carotid artery stenting; CEA, carotid endarterectomy; PAOD, peripheral arteriosclerotic occlusive disease; COPD, chronic obstructive pulmonary disease; ESRD, end-stage renal disease.

Table 2 Outcomes of carotid artery stenting and carotid endarterectomy

Variables	Total [235]	CAS [128]	CEA [107]	P
Operation time (minutes)	100±37	76±26	129±31	<0.001
Length of hospital stay (days)	10±30	6±5	15±44	0.023
Follow-up duration (months)	34±29	33±28	36±29	0.389
ICU stay (days)	2±3	2±3	2±2	0.307
30-day postoperative MI (%)	2 (0.9)	1 (0.8)	1 (0.9)	0.899
30-day postoperative CI (%)	5 (2.1)	4 (3.1)	1 (0.9)	0.247
In-hospital postoperative death (%)	1 (0.4)	1 (0.8)	0 (0.0)	0.360
Reoperation owing to restenosis (%)	2 (0.9)	2 (1.6)	0 (0.0)	0.194

Data are presented as mean ± SD or n (%). CAS, carotid artery stenting; CEA, carotid endarterectomy; ICU, intensive care unit; MI, myocardial infarction; CI, cerebral infarction; SD, standard deviation.

P=0.194). The 2 (1.6%) patients who developed restenosis after the first CAS had a reoccurrence at 13 and 51 months, respectively. One patient underwent further CAS owing to severe in-stent restenosis. Another patient had moderate to severe in-stent restenosis. However, he refused additional treatment because his life expectancy was not long owing to the terminal stage of small cell lung cancer. There was one case of death within 30 days after CAS. CAS was performed due to cerebral infarction that occurred during treatment due to anastomosis leakage and infection after surgery for esophageal cancer. The patient died 4 days after CAS from septic shock.

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Table 3 Outcomes of carotid artery stenting and carotid endarterectomy in all symptomatic patients and patients over 70 years of age

Variables	Total	CAS	CEA	P
All symptomatic patients	164	84	80	
30-day postoperative MI (%)	2 (1.2)	1 (1.2)	1 (1.2)	0.972
30-day postoperative CI (%)	4 (2.4)	3 (3.6)	1 (1.3)	0.335
In-hospital postoperative death (%)	1 (0.6)	1 (1.2)	0 (0.0)	0.274
>70 years old	124	65	59	
30-day postoperative MI (%)	2 (1.6)	1 (1.5)	1 (1.7)	0.945
30-day postoperative CI (%)	3 (2.4)	2 (3.1)	1 (1.7)	0.617
In-hospital postoperative death (%)	–	–	–	–

CAS, carotid artery stenosis; CEA, carotid endarterectomy; MI, myocardial infarction; CI, cerebral infarction.

Table 4 Outcomes of carotid artery stenting and carotid endarterectomy in asymptomatic patients

Variables	Total	CAS	CEA	P
All symptomatic patients	71	44	27	
30-day postoperative MI (%)	–	–	–	–
30-day postoperative CI (%)	1 (1.4)	1 (2.3)	0 (0.0)	0.430
In-hospital postoperative death (%)	–	–	–	–
>70 years old	48	29	19	
30-day postoperative MI (%)	–	–	–	–
30-day postoperative CI (%)	–	–	–	–
In-hospital postoperative death (%)	–	–	–	–

CAS, carotid artery stenosis; CEA, carotid endarterectomy; MI, myocardial infarction; CI, cerebral infarction.

There were 164 symptomatic patients, 80 in the CEA and 84 in the CAS group. No significant difference was observed in outcomes between the two groups in symptomatic patients. Moreover, no significant difference was found in outcomes of symptomatic patients >70 years old (*Table 3*). There were 71 asymptomatic patients, 27 in the CEA and 44 in the CAS group. In asymptomatic patients, there was only one case of 30-day postoperative CI in the CAS group, and no other major complications occurred. There were no 30-day postoperative MI, 30-day postoperative CI, and in-hospital postoperative death in the asymptomatic patient group over 70 years of age (*Table 4*).

During the follow-up period (34±29 months), CI occurred in three patients (1.3%) of 235 patients after postoperative day 30. There was one case (0.8%) in the CAS group and two cases (1.9%) in the CEA group, with no significant difference (P=0.53). Information on three patients is presented in *Table 5*.

Discussion

The goal of treatment for carotid artery stenosis is to prevent stroke. If the carotid atherosclerotic plaque promotes stenosis of more than 50% of the carotid artery lumen, hemodynamically significant carotid stenosis is induced, and CEA or CAS is considered (3). According to the recently updated summary of evidence from the Society for Vascular Surgery, CEA is superior to medical therapy in the long-term prevention of stroke/death, and it is superior to CAS in minimizing long-term stroke/death in symptomatic low-risk surgical patients (4).

Although CAS has been suggested as a valuable alternative to CEA, uncertainty about the relative benefits of CAS over CEA in patients with carotid artery stenosis

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Table 5 Patients with cerebral infarction 30 days after surgery (carotid artery stenting and carotid endarterectomy)

No.	Procedure	Age (years)/sex	Symptom	Contralateral stenosis	Infarction site at recurrence	Restenosis	Duration (months)
1	Left CAS	78/F	Symptomatic (TIA)	Yes	Acute infarction at the left posterior temporal lobe	No	42
2	Right CEA	74/F	Symptomatic (TIA)	Yes	Multifocal acute to subacute infarction at the Rt hippocampus, Rt frontal lobe, and Lt parietal lobe	No	31
3	Left CEA	62/M	Symptomatic (TIA)	Yes	Acute infarction at the left medulla	No	10

CAS, carotid artery stenosis; CEA, carotid endarterectomy; F, female; M, male; TIA, transient ischemic attack.

persists remains (5). Additionally, results of the International Carotid Stenting Study (ICSS) randomized trial did not distinguish a more efficacious procedure (6). According to the ICSS, stenting is as effective as endarterectomy in preventing fatal or disabling stroke (6.4% versus 6.5%, respectively). In the ICSS, carotid stenting was associated with a higher procedure-related and long-term risk of non-disabled stroke; however, there was no difference in the neurological outcome. Similarly, there were no significant differences regarding myocardial infarction, cerebral infarction, in-hospital mortality, or follow-up procedures due to re-stenosis within 30 days, postoperatively. Our findings cannot conclusively distinguish the more efficacious procedure.

The Carotid Revascularization Endarterectomy *vs.* The Stenting Trial (CREST) reported greater CEA efficacy in people >70 years of age (7). The Carotid Stenting Trialists' Collaboration analyzed outcomes in 4,754 patients from 4 clinical trials. CEA was superior to CAS in these randomized controlled trial in patients aged ≥70–74 years (8). Based on this, CEA is recommended for symptomatic patients aged >70 years, according to the 2021 American Heart Association (AHA)/American Stroke Association Guideline for the Prevention of Stroke in Patients With Stroke and Transient Ischemic Attack (9). This is caused by increased torsion of blood vessels and calcification of atherosclerotic plaques in elderly patients (10,11). In a study that included all randomized clinical trials comparing CAS and CEA for the treatment of carotid artery stenosis (12), in the symptomatic patient group, CAS had a higher risk of death or stroke within 30 days of treatment [periprocedural period; OR, 1.70 (95% CI, 1.31–2.19); P<0.0001, I^2=5%; 10 trials, 5,396 participants] than CEA. In particular, the rate of periprocedural death or stroke was significantly higher with CAS than with CEA in those over 70 years of age [OR, 2.23 (95% CI, 1.61–3.08), interaction P=0.007]. We found no significant difference between CEA and CAS in symptomatic patients aged >70 years (*Table 3*). Our study did not show any correlation between a patient's age and the risk of post-procedural neurological complications. However, in a study analyzing CAS and CEA in a group of patients after CREST (2010 to 2015), when the characteristics of the patients and the severity of the disease were matched, CEA patients had a higher rate of periprocedural stroke than CAS patients, driven by increased stroke risk in symptomatic CEA patients [8.1% versus 5.6%; odds ratio, 1.47 (CI, 1.29–1.68); P<0.001] but a lower rate of overall inpatient mortality [0.8% versus 1.4%; odds ratio, 0.57 (CI, 0.48–0.68); P<0.001] (13).

According to the second Asymptomatic Carotid Surgery Trial (ACST-2) (14), overall, 1% of patients had disabling stroke or death procedurally (15 allocated to CAS and 18 to CEA) and 2% had non-disabling procedural stroke (48 allocated to CAS and 29 to CEA). In this study, there was one case (1.4%) of 30-day postoperative CI among asymptomatic patients, and it occurred among the patients who underwent CAS. There was no in-hospital postoperative death (*Table 4*). Also, there was no 30-day postoperative MI, CI, and in-hospital postoperative death following either CAS or CEA in the asymptomatic patient group over 70 years of age.

In this study, ipsilateral CI (excluding the perioperative period) after postoperative day 30 occurred in all symptomatic patients, one case (0.8%) in the CAS and two cases (1.9%) in the CEA group. According to the Asymptomatic Carotid Trial (ACT I), the 5-year incidence of ipsilateral stroke was 2.2% in CAS and 2.7% in CEA (15). In CREST, symptomatic and asymptomatic patients were cohort mixed, and the rate of 10-year ipsilateral stroke (excluding the perioperative period) was 6.9% in CAS and 5.6% in CEA (7). Since the follow-up duration of our study was on average 34±29 months, which was shorter than that of both the above mentioned studies and not all individuals were followed up for a long period of time, our results

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cannot be compared with those of ACT I and CREST. However, ipsilateral CI did not occur during the follow-up period (excluding the perioperative period) in asymptomatic patients, and longer-term results are necessary to confirm this finding.

The operative times (128.69±30.66 min in CEA versus 75.79±26.03 min in CAS; P=0.000) and length of hospital stay (14.79±44.35 days in CEA versus 5.77±4.89 days in CAS; P=0.023) were significantly longer in the CEA group than in the CAS group. The cause of the difference in length of hospital stay is that CAS is performed immediately after transfemoral carotid angiography. However, in the case of CEA, since dual antiplatelet treatment is used in almost all patients before surgery, the procedure is performed 5–7 days after stopping one antiplatelet treatment. This period included, it seems that there was a significant difference in the length of hospitalization between the two groups. Another reason is that, according to Korea's medical insurance system, even if the length of hospital stay is long, it does not represent a substantial additional economic burden when compared with the costs of the surgical procedures. In addition, patients frequently refuse to be discharged from the hospital because very few out-of-hospital facilities can offer rehabilitation after surgery. There is no way to force a patient to be discharged even after treatment has been delivered, so the hospitalization period is inevitably longer than that in other countries. Moreover, according to the Korean medical system, patients are not discharged to go to a rehabilitation hospital following surgery: they are discharged at the end of the rehabilitation treatment. For this reason, the length of hospital stay for symptomatic patients includes rehabilitation.

This study had some notable limitations. The accuracy of the results could have been affected by continual technological advances that occurred over the time frame for retrospective inclusion of cases. The availability of new and improved proximal and distal neuroprotective devices and new mesh-covered stents may reduce the number of disabling strokes (16). Furthermore, this study only included cases from a single institution with a small number of patients. Therefore, the lack of randomization may have introduced a selection bias and the operator preferences may have influenced the results. Nevertheless, the minimum sample size was satisfied. This study's sample size was calculated for a large effect size and for alpha =0.05 and beta =0.80, using the G-Power 3.1.9.7. As a result, at least 132 patients were calculated (two groups of 66, respectively). Moreover, we would like to draw attention to a published study with a similar research design and comparable numbers of participants reported by Pasqui *et al.* (17). That study's total sample size was 234 (98 CEA and 136 CAS), and the data were retrospectively analyzed from a prospectively compiled single-center database.

Conclusions

In elective surgery, CAS and CEA had a similar effect on preventing cerebral infarction, and there were no differences in postoperative complications. The publication of the results of CREST-2 and other multicenter randomized trials is highly awaited to provide clearer treatment criteria when selecting CEA and CAS.

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Footnote

Reporting Checklist: The authors have completed the STROBE reporting checklist. Available at https://apm.amegroups.com/article/view/10.21037/apm-22-797/rc

Data Sharing Statement: Available at https://apm.amegroups.com/article/view/10.21037/apm-22-797/dss

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Conflicts of Interest: All authors have completed the ICMJE uniform disclosure form (available at https://apm.amegroups.com/article/view/10.21037/apm-22-797/coif). The authors have no conflicts of interest to declare.

Ethical Statement: The authors are accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved. The study was conducted in accordance with the Declaration of Helsinki (as revised in 2013), and ethical approval was obtained from the institutional review board of Pusan National University Hospital (No. 2111-030-109). The Ethics Committee waived the requirement for written informed consent based on the retrospective observational nature of the study.

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