Short-Term Results of Carotid Endarterectomy and Stenting After the Introduction of Carotid Magnetic Resonance Imaging: A Single-Institution Retrospective Study

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■ OBJECTIVE: **Although carotid artery stenting (CAS) has been gaining popularity as an alternative to carotid endarterectomy (CEA), perioperative stroke rate following contemporary CAS remains significantly higher than stroke rate after CEA. The purpose of this study was to assess perioperative (within 30 days) therapeutic results in patients with carotid stenosis (CS) after introduction of preoperative carotid magnetic resonance imaging plaque evaluation in a single center performing both CEA and CAS.**

■ METHODS: **Based on prospectively collected data for patients with CS who were scheduled for carotid revascularization, retrospective analysis was conducted of 295 consecutive patients with CS. An intervention was selected after consideration of periprocedural risks for both CEA and CAS. Concerning risk factors for CAS, results of magnetic resonance imaging plaque evaluation were emphasized with a view toward reducing embolic complications.**

■ RESULTS: **CAS was performed in 114 patients, and CEA was performed in 181 patients. Comparing baseline characteristics of the 295 patients, age, T1 signal intensity of plaque, symptomatic CS, urgent intervention, and diabetes mellitus differed significantly between CAS and CEA groups. Among patients who underwent CAS, new hyperintense lesions on diffusion-weighted imaging were confirmed in 47 patients. New hyperintense lesions on diffusion-weighted imaging were recognized in 21.4% of patients who underwent CEA ($n = 39$), significantly less frequent than in patients who underwent CAS.**

■ CONCLUSIONS: **The overall short-term outcome of CEA and CAS is acceptable. Preoperative carotid magnetic resonance imaging evaluation of plaque might contribute to low rates of ischemic complications in CAS.**

INTRODUCTION

Carotid stenosis (CS) is a major cause of cerebral infarction and can be treated with medical therapy alone or in combination with carotid interventions. Although carotid endarterectomy (CEA) remains the gold standard of carotid revascularization for moderate-grade to high-grade CS,[1-3] carotid artery stenting (CAS) has been gaining popularity as an alternative to CEA since several randomized trials demonstrated the noninferiority of CAS to CEA.[4-6] Under circumstances in which patients with CS have options for revascularization, choosing the treatment modality is of great importance in considering the advantages and disadvantages of each intervention.

Ischemic stroke resulting from distal embolization is a devastating complication of carotid revascularization, particularly in CAS. More recent studies have demonstrated that the

Key words
- Carotid artery stenting
- Carotid endarterectomy
- Carotid plaque
- Magnetic resonance imaging
- Perioperative complication

Abbreviations and Acronyms
CAS: Carotid artery stenting
CEA: Carotid endarterectomy
CS: Carotid stenosis
DWI: Diffusion-weighted imaging
MRI: Magnetic resonance imaging
roSI: Relative overall signal intensity

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characteristics of carotid plaque could greatly influence the perioperative risk of new brain ischemia.[7,8] Although carotid plaque is generally assessed using ultrasound, magnetic resonance imaging (MRI) has been gaining importance in the evaluation of carotid atherosclerosis owing to technologic developments in MRI equipment and image sequencing.[9] MRI of carotid plaque can diagnose plaque histologic components[10] that are associated with embolic complications after CAS or CEA.[11] MRI evaluation of carotid plaque was adopted for preoperative imaging in our institute in 2002 and is used as 1 of the selection criteria for carotid intervention.[10] The purpose of the present study was to assess the incidence of perioperative (within 30 days) complications, with special focus on ischemic complications, at a single center performing both CEA and CAS to treat CS after the introduction of MRI assessment of carotid plaque.

MATERIALS AND METHODS

The local institutional review board approved this study, and all patients provided written informed consent to participate in all procedures associated with the study. Based on prospectively collected data for patients with CS who were scheduled for CEA or CAS, we analyzed 297 consecutive patients with CS who underwent carotid revascularization at our institute between 2004 and 2013 after the introduction of MRI carotid plaque evaluation. After excluding 2 patients with CS for whom MRI was contraindicated because of pacemaker implantation, 181 patients who underwent CEA and 114 patients who underwent CAS were analyzed in this study. Inclusion criteria for CEA and/or CAS generally included ≥70% asymptomatic CS and ≥50% symptomatic stenosis. For symptomatic low-grade stenosis (<50%) refractory to intensive medical treatment, we considered CEA when patients presented with >2 recurrences, had no other general problems, and consented to surgical intervention.[12] Severity of CS was evaluated using digital subtraction angiography with the criteria defined by the North American Symptomatic Carotid Endarterectomy Trial Collaborators.[13]

Regarding CEA as the first-line choice, CAS was performed in patients deemed high-risk candidates for CEA or patients expressing preferences for CAS after evaluating the procedural risks for CAS (**Figure 1**). Risk factors for CAS were defined as chronic renal failure with estimated glomerular filtration rate <30 mL/min/1.73 m^2, severe atherosclerosis extending the entire length of the aorta, carotid plaques with dense near-circumferential calcification, and carotid plaques with high-intensity signal on T1-weighted MRI of plaque for which the relative overall signal intensity (roSI) was >1.5.[10] The roSI was calculated using the following formula[10]: roSI = SI whole plaque/SI sternocleidomastoid muscle, where roSI indicates relative overall plaque signal intensity, and SI is signal intensity.

Risk factors for CEA were defined as highly positioned CS, in which the distal plaque end reached the upper part of the axis on lateral projection angiogram; contralateral carotid artery occlusion; cardiac or lung failure as risk factors for morbidity in general anesthesia; and history of neck surgery and/or irradiation. Concerning coronary ischemic heart disease, all patients except emergent cases were checked by a cardiologist, and coronary percutaneous interventions were performed before CEA or CAS when needed.

Regarding risk factors for CS, hypertension and dyslipidemia were by definition restricted to patients using blood pressure–lowering drugs and statins, respectively. Diabetes mellitus was defined as use of insulin or oral glucose inhibitors. Ischemic heart disease was defined as angina or prior myocardial infarction. All postoperative events occurring within 30 days were recorded and analyzed. Postoperative symptomatic stroke was defined as a new lesion confirmed on computed tomography and/or MRI with neurologic deterioration lasting >24 hours. Regardless of the presence or absence of postoperative neurologic symptoms, all patients were evaluated for asymptomatic infarction with diffusion-weighted imaging (DWI) within 3 days after the intervention.

MRI Protocol

A 1.5T, whole-body MRI scanner (Gyroscan Intera; Philips Healthcare/Philips Medical Systems B.V., Eindhoven, The Netherlands) with an 8-cm surface coil was used to image the carotid arteries. Plaque characteristics were precisely evaluated using 2-dimensional spin echo black-blood MRI. Using axial MRI of areas with the highest rate of stenosis, roSI was measured and compared with MRI plaque signals as described.[10] Plaque distribution was evaluated using long-axis 3-dimensional inversion recovery turbo field echo black-blood MRI.[14] The parameters of axial plaque images, long-axis plaque images, and brain diffusion images were as follows:

- Axial black-blood T1-weighted imaging (2-dimensional double inversion recovery turbo spin echo): field of view, 150 mm; matrix size, 256 × 256; repetition time/echo time, 700–1000 (1 cardiac cycle)/12 ms; flip angle, 110°; slice thickness, 3.0 mm
- Long-axis T1-weighted imaging (3-dimensional inversion recovery turbo field echo): field of view, 150 mm; matrix size, 320 × 512; repetition time/echo time/inversion time, 10/2.7/500 ms; flip angle, 35°; slice thickness, 1.6 mm
- DWI (single-shot echo planar imaging): field of view, 250–280 mm; matrix size, 128 × 256; repetition time/echo time, 3500–5000/90 ms; flip angle, 90°; slice thickness, 4–5 mm; and b-factor, 1600.

Technique of CEA

CEA in this study was performed by 9 neurosurgeons (S.Y., M.C., O.N., T.S., K.Y., N.S., M.K., Y.K., and K.T.). Preoperatively administered antithrombotics were not interrupted during the perioperative period, and single antiplatelet therapy was generally continued after CEA.

Technique of CAS

CAS in this study was performed by 4 neurosurgeons (A.H., K.Y., M.K., and Y.K.). Dual antiplatelet treatment was started before CAS. Precautions against cerebral embolism during CAS were taken for almost all patients (n = 112) with distal balloon protection for 39 cases, distal filter protection for 70 cases, and proximal protection for 3 cases.