

Duplex-assisted carotid artery stenting without administration of contrast medium for patients with chronic kidney disease or allergic reaction

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Abstract

Introduction We aimed to investigate the safety and feasibility of duplex-assisted carotid artery stenting (CAS) without administration of contrast medium for the prevention of adverse reactions.

Methods Fifteen patients (9 % of all CASs) with severe carotid stenosis (≥ 70 %) associated with chronic kidney disease (CKD) (stage ≥ 3) or allergy to contrast medium underwent duplex-assisted CAS without administration of contrast medium over 4 years. The procedural success rate and perioperative complication rates were compared between the duplex-assisted CAS ($n = 15$) and conventional CAS ($n = 153$) groups.

Results The technical success rate was 100 % in both groups. Combined stroke or death rates during the post-procedural period did not differ significantly between the duplex-assisted CAS group (0/15, 0 %) and conventional CAS group (4/153, 2.6 %). None of the 14 patients with CKD in the duplex-assisted CAS group experienced further deterioration of renal function. The mean surface radiation dose of participants in the duplex-assisted CAS group ($n = 13$, 312 ± 131 mGy) was significantly lower than that of the conventional CAS group ($n = 31$, 1036 ± 571 mGy) ($p < 0.001$). The mean duration of CAS procedure was not significantly different between the duplex-assisted CAS group (156 ± 39.7 min) and the conventional CAS group (156 ± 37.4 min).

Conclusion Duplex-assisted CAS without administration of contrast medium could be an alternative option in selected patients deemed to be at high risk for renal failure from nephrotoxic contrast medium or who have an allergy to contrast medium.

Keywords Carotid stenosis · Duplex ultrasound · Carotid artery stenting · Contrast medium-induced nephropathy · Chronic kidney disease

Abbreviations

CAS	Carotid artery stenting
CEA	Carotid endarterectomy
CKD	Chronic kidney disease
CIN	Contrast medium-induced nephropathy
DM	Diabetes mellitus
eGFR	Estimated glomerular filtration rate
ICA	Internal carotid artery
PSV	Peak systolic velocity
EPD	Embolic protection device
FLAIR	Fluid-attenuated inversion recovery
DWI	Diffusion weighted imaging
MRA	Magnetic resonance angiography
CCA	Common carotid artery
IVUS	Intravascular ultrasound
DS	Duplex sonography
GC	Guiding catheter

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Introduction

Carotid artery stenting (CAS) has been reported to be a feasible alternative to carotid endarterectomy (CEA) in patients at

increased systemic or surgical risk in several studies [1, 2]. Injection of contrast medium is essential for visualizing the angio-architecture and therefore to performing carotid intervention. However, CAS with administration of contrast medium in patients with chronic kidney disease (CKD) or an allergy to contrast medium carries a significant risk of adverse reactions such as contrast medium-induced nephropathy (CIN) or an allergic reaction. The risk of CIN increases with higher doses of contrast medium, preexisting CKD, and diabetes mellitus (DM) [3, 4]. Even relatively small changes in renal function after administration of contrast medium are associated with substantial increases in mortality rates and length of hospital stay [5]. Furthermore, contrast medium-induced allergy is a condition that affects 3 % of patients undergoing angiography, with severe reactions occurring in 0.04 % [6]. These reactions are occasionally serious, potentially life-threatening reactions associated with the administration of contrast medium.

Duplex ultrasound is widely accepted as an accurate, safe, and noninvasive imaging modality in the diagnosis of carotid artery disease. By introducing this technique during carotid intervention, it would be possible to perform carotid revascularization safely without the use of contrast medium. To date, however, there have been few reports [7–9] regarding duplex-assisted CAS using ultrasound images as an alternative to fluoroscopy.

The objective of this study was to investigate the safety and feasibility of duplex-assisted CAS without administration of contrast medium for patients with CKD or adverse reactions associated with contrast medium in comparison with conventional CAS.

Materials and methods

Between January 2011 and June 2014, 168 consecutive patients underwent CAS in our hospital and related institutions. The patients who fulfilled the following criteria underwent duplex-assisted CAS without administration of contrast medium and were included in the present study. This study was designed as a retrospective multi-center study. The data of those patients who underwent conventional CAS were also collected for comparison with the duplex-assisted CAS. The local ethics committee approved this study, and informed consent was obtained from all subjects.

The inclusion criteria of the current study were the following: carotid stenosis of ≥ 70 % for symptomatic cases or progressive luminal narrowing (≥ 70 %) for asymptomatic cases; CKD stage ≥ 3 (defined as an estimated glomerular filtration rate [eGFR] < 60 mL/min/1.73 m²) [10] or allergy to contrast medium; and clear visualization of the luminal narrowing with minimal calcification on the longitudinal section of the duplex ultrasound sonography. The degree of internal carotid artery (ICA) stenosis was assessed using the North American Symptomatic Carotid Endarterectomy Trial (NASCET) [11]

method on the basis of peak systolic velocity (PSV). PSV greater than 200 cm/s was used as the most reliable predictor of ICA stenosis greater than 70 % in the current study [12]. Symptomatic patients were defined as those who had experienced amaurosis fugax, a transient ischemic attack, or a stroke in the territory of the ipsilateral carotid artery within the 6 months prior to study entry. In asymptomatic carotid stenosis, CAS was performed only for patients who had progressive stenosis more than 70 % despite medical treatment with antiplatelet and statin. The exclusion criteria were the following: severe tortuosity of the carotid artery, severely calcified carotid stenosis, near occlusion; an unstable or mobile plaque; major disabling stroke; or invisibility of the ICA lumen by duplex sonography. Fifteen patients (9 % of all 168 CASs) fulfilled the inclusion criteria and underwent duplex-assisted CAS.

The most important factor for the indication of duplex-assisted CAS was to obtain the clear visualization of the luminal narrowing with minimal calcification on the longitudinal section of the duplex ultrasonography (Fig. 1a); this factor was necessary for lesion cross of the embolic protection device (EPD) during the procedure. We excluded patients with near occlusion or severe tortuosity of the ICA because it is difficult to depict the total length of the plaque in the longitudinal section.

MR imaging protocol

MR imaging examinations were performed on an Achieva 3T system with Quasar Dual gradients (Philips Healthcare, Best,

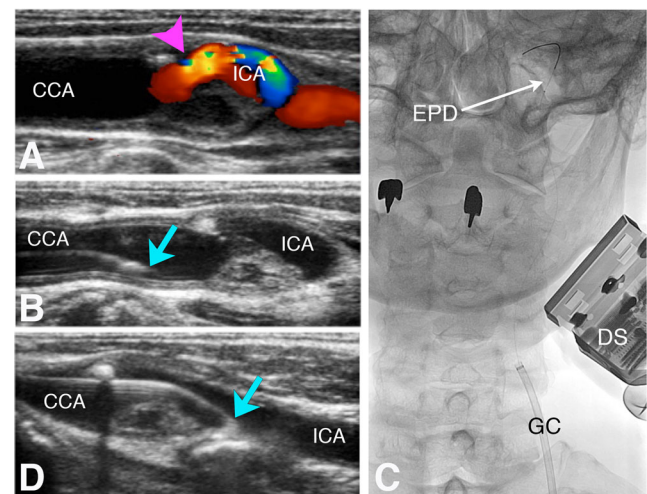


Fig. 1 Ultrasound images of duplex-assisted CAS in case 5. **a** Doppler color flow image demonstrates the severe carotid stenosis (pink arrowhead) without acoustic shadow. **b** The tip of the EPD (blue arrow) in the CCA just proximal to the carotid bifurcation is clearly visualized in the longitudinal section in gray-scale imaging. **c** Fluoroscopic anteroposterior view obtained after the EPD is advanced into the distal ICA. **d** The tip of the EPD (blue arrow) is advanced into the distal internal carotid artery by monitoring ultrasound images

the Netherlands). All patients underwent a baseline brain assessment including T1-weighted imaging, T2-weighted imaging, fluid-attenuated inversion recovery (FLAIR), and diffusion weighted imaging (DWI), and MR angiography (MRA) of the carotid and cerebral arteries before CAS. Cranial and cervical non-enhanced MRA was also used to obtain anatomical information. In addition, preoperative non-enhanced MRA of the aortic arch and iliac-femoral artery was performed for the evaluation of the access route.

Postoperative DWI was performed in all patients within 24 h following the procedure. On postoperative DWI, any new ipsilateral hyperintense lesions were regarded as ischemic lesions associated with the procedure, and these lesions were counted.

Duplex imaging analysis

All preoperative and intraoperative duplex carotid mapping was performed by one author (H.H.) to investigate the following factors: the measurements of the degree of narrowing based on PSV for the indication of carotid revascularization; the lumen diameter of the common and internal carotid artery (CCA and ICA) for reference of device size; the plaque morphology in the longitudinal and transverse sections; and the vascular tortuosity and calcification.

Procedures of duplex-assisted CAS

All patients were treated with dual antiplatelet agents for at least 5 days before the procedure. All procedures were performed under local anesthesia with systemic heparinization in doses between 5000 and 10,000 IU. The basic trans-femoral approach was utilized in 12 patients. The trans-brachial approach was selected in three patients because of problems in the femoral access such as aortic aneurysm or severe arteriosclerosis obliterans. All procedures were performed by one author (A.F.) having more than 300 conventional CAS experiences.

The duplex scanner was positioned ipsilateral to the carotid lesion, and the operator was positioned on the same side wearing radiation-resistant gloves. The duplex monitor images were directly transferred to a conventional angiographic reference monitor. From the groin or brachial artery puncture to the common carotid artery engagement, the guiding catheter was navigated only fluoroscopic-guidance. Duplex scanning was started to navigate the guide wire into the external carotid artery when introducing the guiding catheter into the CCA. The EPD placed in the CCA was clearly visible on the longitudinal section (Fig. 1b) and was then advanced into the ICA by duplex-guidance (Fig. 1c, d). Balloon protection was selected when the status of flow arrest of the targeted vessel (ICA) was easily confirmed. Because of the lack of the preoperative angiographical assessment of collateral circulation, we substitute the MRA findings of Willis' circle for

it. We used filter protection in patients with suspected insufficient cerebral collateral (i.e., lack of ipsilateral both A1 and P1 segment).

The pre-dilatation was performed under duplex-guidance, which was followed by placement of a stent across the lesion and deployment under duplex monitoring (Fig. 2a). Stent diameter and length were chosen according to the proximal and distal arterial diameters and the lesion length as measured by preoperative and intraprocedural duplex mapping. Post-dilatation was performed after the stent deployment if enough expansion of the carotid artery was not achieved (Fig. 2b, c). Technical success was confirmed by duplex images and intravascular ultrasound (IVUS) including appropriate stent apposition against the arterial wall, wide patency of the native and stented CCA and ICA segments, and the absence of plaque protrusion through stent struts and thrombus and flaps within stent. Dual antiplatelet therapy was maintained for at least 6 months postoperatively.

Radiation exposure of patients and duration of procedure

A biplane flat detector rotational fluoroscopy and angiography unit (Artis Zee BA Twin; Siemens, Erlangen, Germany) was used for 13 patients who underwent the duplex-assisted CAS and 31 patients who underwent the conventional CAS. Data on radiation dose during the duplex-assisted CAS were extracted from reports obtained with commercially available dose monitoring software (Care; Siemens). For comparison, data on radiation dose were obtained for the patients who underwent conventional CAS using the same angiography unit. CAS duration was also collected from the same two groups.

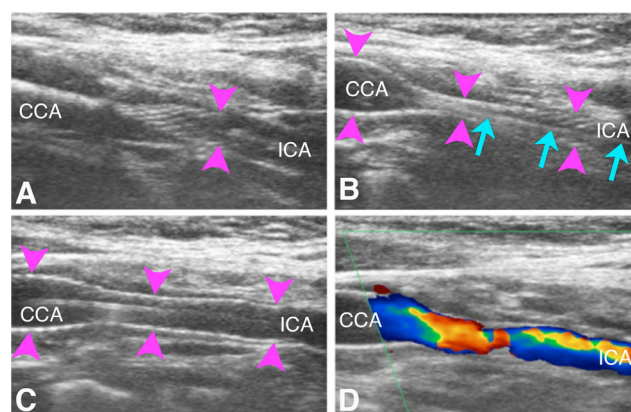


Fig. 2 Serial duplex images obtained during delivery of the stent in case 11. **a** When starting the delivery of the stent, the position of the distal stent end (pink arrowheads) is confirmed by duplex monitoring. **b** After completion of stent deployment, inadequate stent opening is shown (pink arrowheads). Note that the wire of the EPD (blue arrows) is inside the stent. **c** Additional balloon angioplasty results in the wide opening of the placed stent (pink arrowheads). **d** Doppler color flow image demonstrates excellent flow after CAS

Radiation exposure of the duplex operator

The data regarding the external radiation exposure were obtained from the dosimeter outside the radiation protection glove; after collection, the findings were analyzed.

Statistical analysis

Descriptive statistics are presented as the mean $\pm$ SD. Differences in the continuous clinical and laboratory variables were compared using Student's unpaired or paired *t* test. The categorical variables were compared using Fisher's exact tests. Repeated-measures analysis of variance (ANOVA) and paired *t* tests with corrections for multiple testing by the Holm method were used to investigate the change in renal function before and after the duplex-assisted CAS. Values of $p < 0.05$ were reported to be significant. Statistical analysis was performed with free open-source software (R3.0; R Foundation for Statistical Computing, <http://www.r-project.org>).

Results

A total of 153 patients underwent conventional CAS because they had normal renal function and no allergic reaction to the contrast medium (Table 1). In the duplex-assisted CAS group, 14 patients presented with CKD (eGFR 25.6 ± 9.9 mL/min/1.73 m²) and only 1 patient presented with a previous anaphylactoid reaction from contrast medium.

The patients' baseline characteristics are summarized in Table 1. In univariate analysis, the demographic and clinical characteristics did not differ significantly between the duplex-assisted CAS and conventional CAS groups, except in the incidence of DM, preoperative eGFR and the preoperative degree of stenosis (Table 1).

The mean age of patients in the duplex-assisted CAS group was 71.9 ± 7.9 years (range, 60–86 years). Fourteen patients were men, and one was a woman. Four patients were symptomatic, and 11 were asymptomatic. The lesion was on the right side in 9 (60 %) cases. Balloon protection was utilized in 13 (87 %) cases. The trans-femoral approach was selected in 12 (80 %) cases. The technical success rate in the duplex-assisted CAS group was 100 %, which was the same as in the conventional CAS group. During procedure, there was no plaque protrusion detected by both duplex images and IVUS in the duplex-assisted CAS group. On the other hand, 11 cases of plaque protrusion (7.2 %) were detected by IVUS in the conventional CAS group. Among them, there were four cases where plaque protrusion was not detected by conventional angiography. The IVUS-based detection rate of the plaque protrusion was higher than angiography alone (7.2 versus 4.6 %). Improvements in the hemodynamic parameters in the ICA (i.e., PSV decrease below 150 cm/s) were confirmed at the end of the procedure in all participants in the duplex-assisted CAS group (Tables 1 and 2).

Postoperative complications

No stroke or death occurred in the duplex-assisted CAS group during the post-procedural period (within 30 days).

Table 1 Baseline characteristics of patients who underwent conventional or duplex-assisted CAS

	Conventional CAS (<i>n</i> = 153)	Duplex-assisted CAS (<i>n</i> = 15)	<i>p</i> value
Age	73.2 $\pm$ 7.7	71.9 $\pm$ 7.9	0.5367
Male	137 (90 %)	14 (93 %)	1.00
Vascular risk factors			
Hypertension	112 (73.2 %)	14 (93 %)	0.119
Hyperlipidemia	70 (45.6 %)	10 (67 %)	0.1752
DM	113 (73.9 %)	7 (46 %)	0.0361
IHD	45 (29.4 %)	8 (53 %)	0.0791
ASO	27 (17.65 %)	3 (20 %)	0.7334
Preoperative eGFR (mL/min/1.73 m ²)	67.3 $\pm$ 17.9	25.6 $\pm$ 10.3	<0.001
Symptomatic stenosis	59 (38.6 %)	4 (27 %)	0.4171
Preoperative degree of stenosis (%)	81.1 $\pm$ 10.8	77.3 $\pm$ 4.6	0.0155
Postoperative degree of stenosis (%)	9.2 $\pm$ 7.8	14 $\pm$ 8.5	0.05045
Ischemic high signal on postoperative DWI	53 (38 %)	7 (47 %)	0.4022
Postoperative stroke or death rate (within 30 days)	4 (2.6 %)	0	1.00

CAS carotid artery stenting, DM diabetes mellitus, IHD ischemic heart disease, ASO arteriosclerosis obliterans, eGFR estimated glomerular filtration rate, DWI diffusion weighted imaging

Table 2 Summary of patients undergoing duplex-assisted carotid artery stenting

Case	Age/sex	Symptom	Side	Risk for CEA	EPD	Approach	Stenosis (%) pre./post.	Postop. HI on DWI
1	70/M	–	R	High position	B	Femoral	80/10	–
2	67/M	–	L	High position	B	Femoral	80/10	–
3	75/M	–	L	Heart failure	B	Femoral	80/15	–
4	62/M	–	R	High position	B	Brachial	80/10	+
5	80/M	–	L	Advanced age	B	Femoral	80/10	+
6	64/M	+	L	Heart failure	B	Femoral	70/10	–
7	69/M	–	R	High position	F	Femoral	70/20	+
8	71/M	+	R	High position	B	Femoral	70/0	+
9	79/M	–	R	Advanced age	B	Brachial	70/30	–
10	86/M	–	L	Advanced age	B	Femoral	80/30	+
11	77/M	+	R	Advanced age	B	Femoral	80/10	+
12	62/M	+	R	High position	B	Femoral	80/10	–
13	60/M	–	R	Heart failure	F	Brachial	80/10	+
14	76/M	–	L	High position	B	Femoral	80/25	–
15	80/M	–	R	Advanced age	B	Femoral	80/10	–

M male, *F* female, *R* right, *L* left, *CEA* carotid endarterectomy, *EPD* embolic protection device, *B* balloon protection, *F* filter protection, *pre.* preoperative, *post.* postoperative, *postop.* HI on DWI postoperative hyperintensity on diffusion weighted imaging

Combined stroke or death rates during the post-procedural period did not differ significantly between duplex-assisted CAS group (0 %) and conventional CAS group (4/153, 2.6 %).

New hyperintense DWI lesions were recognized on the post-treatment scan in 7 patients (47 %) in the duplex-assisted CAS group and 58 (38 %) of 153 patients in the conventional CAS group. No significant difference was observed between the incidences of the new hyperintense DWI lesions of the two groups.

In the duplex-assisted CAS group, one patient underwent the second CAS 7 months later because of the shortening of closed cell stent leading the malposition into the proximal common carotid artery. This was caused by the inappropriate stent size selection.

In the conventional CAS group, one patient underwent the second CAS 11 days later because of acute stent occlusion after the first emergency CAS for crescendo TIA. No significant difference was observed between the incidences of the second CAS of the two groups.

Renal function

None of the 14 patients with CKD in the duplex-assisted CAS group experienced further deterioration of renal function. Repeated-measures ANOVA and paired *t* tests with corrections for multiple testing by the Holm method demonstrated that no significant changes were observed in the eGFR before CAS (25.6 ± 9.9 mL/min/1.73 m²), 7 days after and 1 month after CAS (27.4

± 10.3 and 26.8 ± 11.0 mL/min/1.73 m², respectively) ($p = 0.19$) (Fig. 3).

Radiation exposure and duration of procedure

In 31 conventional CAS cases and 13 duplex-assisted CAS cases, the radiation doses and duration of CAS were measured with the same fluoroscopy and angiography unit. The mean surface radiation dose of participants in the duplex-assisted CAS group (312 ± 131 mGy) was significantly lower than that of the conventional CAS group (1036 ± 571 mGy) ($p < 0.001$). The mean duration of CAS was not significantly different between the duplex-assisted CAS group (156 ± 39.7 min) and the conventional CAS group (156 ± 37.4 min).

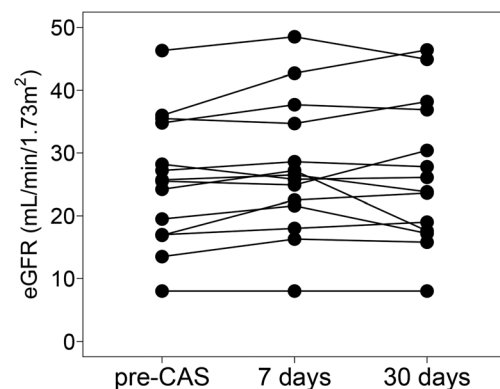


Fig. 3 The changes in the eGFR before, 7 days after, and 1 month after CAS. There is no significant difference among the eGFR values of each time point in repeated-measures analysis of variance and paired *t* tests with corrections for multiple testing by the Holm method

Radiation exposure level of the duplex operator

In 13 patients treated by the duplex-assisted CAS, the mean external radiation exposure level of the duplex operator was 0.246 mSv.

Discussion

The current results demonstrated the safety of duplex-assisted CAS without administration of contrast medium. All duplex-assisted CAS were successfully performed without severe perioperative complications. There was no significant difference in the incidence of post-procedural complications or new hyperintense DWI lesions between the duplex-assisted CAS group and conventional CAS group in the current study. Additionally, no significant deterioration of renal function was observed after duplex-assisted CAS.

Duplex carotid sonography is effective for evaluating the presence and severity of carotid stenosis to minimize risks of cerebral angiography [12]. Modern duplex scanners provide excellent images and reliable hemodynamic parameters of the carotid arteries and have increasingly been used as the sole preoperative method to evaluate the exact location, degree, and extent of a carotid lesion in the neck [12, 13]. Accordingly, it is reasonable to assume that duplex methods can also be used to visualize guide wires, sheaths, balloons, and stents during the performance of CAS. In fact, real-time hemodynamic parameters such as PSV obtained by Doppler color flow imaging were very useful in revealing the function of filter protection devices in the current study.

Recently, some authors have recognized the potential of duplex-assisted CAS in guiding endovascular therapy for cervical artery stenosis. Ascher et al. reported duplex-assisted carotid artery balloon angioplasty and stent placement for 18 patients with minimal or no contrast medium. However, they required an aortic arch angiogram in 22 % patients [8]. Varcoe et al. compared the results of the 12 duplex-assisted CAS cases and the 11 conventional CAS cases. However, they still performed the selective carotid angiogram with contrast medium in the case of severe stenosis [9]. Kocak et al. used the smallest amount of contrast medium (less than 10 mL), and the renal function disorder did not occur in the conventional CAS [14]. Although using the smallest amount of contrast medium with adequate hydration may decrease the relative risk of CIN, CAS without the administration of contrast medium would be the best way to prevent adverse reactions, as in the current study. Instead of an aortic arch angiogram with contrast medium, we routinely used MRA of the aortic arch. In addition, MRA of the iliac-femoral artery helps achieve confirmation of the access route. The preoperative duplex scanning, IVUS [13], and intraoperative X-ray image are enough for placement of the EPD,

although duplex insonation of the distal extracranial carotid segment is difficult. According to our experience of conventional CAS cases, IVUS could detect plaque protrusion better than conventional angiography. IVUS could be a reliable method for the detection of the plaque protrusion during duplex-assisted CAS. Therefore, conventional angiography in duplex-assisted CAS is not necessary unless a neurologic abnormal finding appears [8]. In fact, no patients presented any neurologic change during and after duplex-assisted CAS.

Regarding CAS using gadolinium contrast medium, a number of case reports and case series have reported a strong association of nephrogenic systemic fibrosis with exposure to gadolinium contrast medium in the setting of severe or end-stage renal disease [15]. Therefore, we think that the usage of gadolinium contrast medium should also be avoided in the case of CAS for patients with renal failure.

Any prophylactic treatment cannot prevent an allergic reaction [6]. Therefore, the approach of performing local anesthetic CAS without administration of contrast medium was reasonable for the prevention of these adverse reactions.

Regarding the complication rates of CEA in patients with renal dysfunction, the adjusted hazard ratios for cardiovascular death and myocardial infarction in patients with an eGFR 30–59 were 2.22 (1.27 to 3.89) and 1.90 (1.04 to 3.47) compared with patients with an eGFR ≥ 60 , respectively [16]. In contrast, no complication (stroke, myocardial infarction, or death) was observed after duplex-assisted CAS for patients with eGFR < 60 mL/min/1.73 m² in the current study. The absence of renal function deterioration and lack of serious complications in the current study demonstrated the safety of the duplex-assisted CAS.

Radiation exposure and duration of procedure

Although the mean fluoroscopy time was not significantly different, surface radiation exposure doses were significantly lower in the duplex-assisted CAS group than in the conventional CAS group. Regarding the additional radiation exposure for the duplex operator, the level of mean external radiation dose at his hand reached 0.246 mSv. The International Commission on Radiological Protection (ICRP) limits for occupational workers are 100 mSv over a period of 5 years with the further provision that the dose should not exceed 50 mSv in any single year [17]. The effective dose of radioactivity will surpass 50 mSv after approximately 200 cases a year in this technique. We introduced this technique for specifically selected patients. Accordingly, only 15 of 168 patients (9 %) underwent duplex-assisted CAS for 3 years. Consequently, the radiation exposure for the duplex operator was far lower than the ICRP limit in the current study. In the ICRP recommendation, particular attention is paid to circulatory disease and cataracts because of recent evidence of higher incidences of injury than expected after lower doses; hence, threshold

doses appear to be lower than previously considered [18]. In the context of protection, the lower the radiation exposure, the lower are the observation rates of early and late effects.

It was likely that it took a longer time to perform the duplex-assisted CAS than the conventional CAS because angiography was not used in the former. In fact, there was no significant difference in the duration of the procedure between the conventional CAS and duplex-assisted CAS. Therefore, the duration of the procedure is not a problem for duplex-assisted CAS if a skillful duplex operator is present. Because almost only disadvantage of duplex-assisted CAS is additional radiation exposure to the duplex operator, intermittent duplex monitoring should be used as much as possible. We think the duration of duplex assist can be made shorter except for the lesion cross by repeating the case.

Asymptomatic and elderly cases with CKD

The Asymptomatic Carotid Atherosclerosis Study (ACAS) [19] and the Asymptomatic Carotid Surgery Trial (ACST) [20] demonstrated that marginal but definite benefit for CEA in reducing the risk of stroke after 5 years when compared with “best” medical therapy alone. On the other hand, it has been established that patients with CKD have a shortened life span. Men and women aged 70 years had a mean life expectancy of 3.9 and 4.1 years, respectively, at an eGFR 15–29 [21]. Then, what was the justification for treating patients with asymptomatic carotid stenosis who had CKD? According to ACST [20] subgroup analysis, the incidence of ipsilateral events was four times higher for a stenosis that had progressed by two categories than a stenosis that had remained unchanged and was seven times higher for a stenosis that had progressed by three categories [22]. However, because change to one category higher or to any number of categories lower was not associated with an increased incidence of ipsilateral neurological events [22], the case of the slight progressive luminal narrowing may have been observed. Silvestrini et al. reported that annual risks changed from 1.1 % for stable stenosis to 8.3 % for progressing stenosis [23]. Taken together, we think treating asymptomatic patients who had CKD would be justified only if the carotid stenosis shows progression as in the current study.

Limitations

Our study has some limitations. First, this study was based on retrospective and single-centered (single hospital and related facilities) methods, which might influence the bias control. Second, the small sample size and thus the imprecision of the statistical analysis are a main limitation of the current study. Third, this method needs a skillful operator of the duplex ultrasound sonography under radiation exposure during

CAS. Fourth, there was no comparison between CEA and duplex-assisted CAS in the current study.

Conclusions

In the current study, duplex-assisted CAS achieved excellent anatomic and hemodynamic improvement of carotid stenosis without any major complications or deterioration of renal function. Therefore, this method seemed to be a safe and effective treatment for patients with CKD or an allergy to contrast medium. A larger number of cases would be required to establish the safety and effectiveness of this approach.

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Compliance with ethical standards We declare that all human studies have been approved by the institutional review board and have therefore been performed in accordance with the ethical standards laid down in the 1964 Declaration of Helsinki and its later amendments. We declare that all patients gave informed consent, or consent was given by the patient's nearest relatives in the event patients did not have the capacity to consent, prior to inclusion in this study.

Conflict of interest We declare that we have no conflict of interest.

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