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The impact of post-dilatation on periprocedural outcomes during carotid artery stenting: A single-center experience

Feyzullah Besli[a,*], Fatih Gungoren[a], Ozcan Kocaturk[b], Zulkif Tanriverdi[a], Mustafa Begenc Tascanov[a]

[a] Department of Cardiology, Harran University Faculty of Medicine, Sanliurfa, Turkey
[b] Department of Neurology, Harran University Faculty of Medicine, Sanliurfa, Turkey

HIGHLIGHTS

- Carotid artery stenting is well known therapy modality in setting of carotid artery disease.
- Post-dilatation is not associated major adverse events at 30 days.
- Post-dilatation independent predictor of silent cerebral ischemia in patients undergoing CAS.
- Post-dilatation should be limited only in cases with severe residual stenosis after stenting during CAS as possible as.

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ABSTRACT

Background and aims: Carotid artery stenting (CAS) is an accepted treatment modality for carotid artery disease. However, CAS is associated with periprocedural embolic events, and the effect of balloon post-dilatation has not been sufficiently investigated in large studies. We assessed the effect of post-dilatation on periprocedural outcomes during CAS.

Methods: The study included 128 patients who underwent CAS. The patients were divided into groups according to whether post-dilatation was (post-dilatation [+], group 1) or was not (post dilatation [−], group 2) performed after stent deployment. Major adverse events were defined as death, minor or major stroke, and transient ischemic attack at 30 days. Silent ischemia was assessed using diffusion-weighted magnetic resonance imaging.

Results: No significant between-group differences were found in baseline characteristics, comorbid diseases, or lesion characteristics. The degree of stenosis and procedure duration was greater in group 1 than in group 2. The rate of major adverse events at 30 days was similar between the two groups (5.1% *vs.* 4.3%, $p = 0.844$). The silent ischemia rate and number of high-intensity signals were higher in group 1 than in group 2 (45.8% *vs.* 26.1%, $p = 0.020$ and 1.01 [1.2] *vs.* 0.42 [0.79], $p = 0.002$). Multivariate analysis revealed that post-dilatation was associated with a 2.4-fold increase in silent ischemia (95% confidence interval: 1.15–5.20, $p = 0.020$).

Conclusions: Although post-dilatation was not associated with an increase in major adverse events, it significantly increased the incidence of periprocedural silent ischemia. Therefore, post-dilation should be performed only in cases with severe residual stenosis after CAS.

1. Introduction

Carotid endarterectomy (CEA) and carotid artery stenting (CAS) are proven procedures for the treatment of symptomatic and asymptomatic carotid artery disease (CAD) [1]. Current guidelines recommend CEA as the first-line treatment for CAD in patients with average surgical risk [2]. Previous large randomized studies found that although CEA and CAS had similar long-term outcomes, in terms of stroke, death, and myocardial infarction rates, CAS was more strongly associated with periprocedural events [1,2]. Recently, the introduction of refined techniques and various new instruments, including atraumatic catheters, cell stents with various designs, embolic protection devices, and specialized wires, has reduced the rate of periprocedural embolic events [3]. In addition to these innovations, better patient selection, more experienced operators, and dual antiplatelet therapy have decreased the incidence of periprocedural events [4].

* Corresponding author.
E-mail address: feyzullahbesli@gmail.com (F. Besli).

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Several factors, including age, symptomatic status, use of proximal and distal embolic protection devices, stent type (open- and closed-cell and micromesh designs) and history of CAD have been studied in the context of the periprocedural outcomes of CAS and CEA [5–7]. It has also been suggested that development of hemodynamic instability (hyperperfusion, bradycardia and persistent hypo or hypertension) during CAS has been linked to the increased risk of cerebrovascular events by impairing cerebral perfusion and reducing the ability of washing out of microemboli [8,9].

The main objective of CAS is to stabilize the carotid plaque, rather than restore blood flow, because most strokes are embolic in nature. Predilatation, i.e., balloon angioplasty before stenting, involves preparation of a stenosed vessel for stent deployment, whereas post-dilatation, i.e., balloon angioplasty after stenting, is used to mitigate residual stenosis after stent deployment. Although the standard CAS procedure involves predilatation and post-dilatation, or a combination of the two, limited studies have investigated their effects on periprocedural outcomes. In this study, we aimed to assess the effect of post-dilatation on periprocedural outcomes in patients who underwent CAS.

2. Materials and methods

2.1. Study population

We retrospectively enrolled 128 patients who underwent CAS and diffusion-weighted magnetic resonance imaging (DWI/MRI) between January 1, 2016 and December 31, 2018. The patients were divided into two groups according to whether post-dilatation was (post-dilatation [+], group 1) or was not (post-dilatation [−], group 2) performed after stent deployment, with or without predilatation. The exclusion criteria included known acute kidney disease, previous history of heart failure, history of emergency catheterization, total occlusion of the target vessel, significant hypotension or severe anemia, the presence of an active infection or history of cancer, contraindications for anti-platelet and/or anti-coagulant therapy, and incomplete or missing data.

The indications for CAS were symptomatic 50–99% stenosis of the internal carotid artery (ICA) and asymptomatic 60–99% stenosis of the ICA, together with major clinical and/or imaging risk factors [2]. The percentage of ICA stenosis was determined by angiography according to the criteria of the North American Symptomatic Carotid Endarterectomy Trial [10]. A cerebrovascular team, including an interventional cardiologist, interventional neurologist, and cardiovascular surgeon assessed the treatment options for all patients. Moreover, the patients were included in the decision-making process regarding the optimal treatment. The study was approved by the local Institutional Ethics Committee and written informed consent was obtained from all patients.

2.2. Clinical data

The disease classifications, and periprocedural and 30-day follow-up CAS outcomes were derived from data collected by the investigators. Baseline clinical data were collected for all patients. Hypertension was defined as systolic blood pressure ≥140 mmHg, diastolic blood pressure ≥90 mmHg, and/or taking antihypertensive medication, and/or a history of diagnosed hypertension. Diabetes mellitus was defined as fasting serum glucose ≥126 mg/dL (7 mmol/L), non-fasting glucose ≥ 200 mg/dL (11.1 mmol/L), use of diabetic medications, or a previously established diagnosis. Hyperlipidemia was defined as low-density lipoprotein > 160 mg/dL, and/or taking a lipid-lowering agent.

2.3. CAS procedure

Oral acetylsalicylic acid and clopidogrel (75 mg/day) were prescribed 1 week before CAS and continued for at least 1 month after the procedure in all patients. The procedure was performed via the femoral artery under local anesthesia in all patients, with the exception of four cases in which the stent was introduced via the right radial artery. After a bolus injection of heparin (70–80 IU/kg), the common carotid artery was selectively cannulated with a 5-French Simmons, vertebral or right Judkins catheter, as appropriate. A 0.035-inch hydrophilic wire was introduced into the external carotid artery and then exchanged for a super-stiff wire. After a 7- or 8-French guiding catheter was advanced into the common carotid artery, the lesion was crossed using a 0.014-inch guidewire. Proximal protection with the Mo.Ma device (Medtronic Inc., Santa Rosa, CA, USA) was used in five patients; embolic protection could not be used in five other patients, and the Spider FX distal protection device (Medtronic, Minneapolis, MN, USA) was used in all remaining patients. CAS was performed using self-expandable stents including the Precise® Nitinol Stent (Cordis, Miami, FL, USA) and Protégé™ RX (Ev3 Inc., Plymouth, MN USA) open-cell stent. Atropine (0.5–1 mg) was administered intravenously in cases of hypotension and bradycardia during the procedure. An example of CAS procedure is shown in Fig. 1.

2.4. Major adverse events

Major adverse events were defined as death, minor or major stroke, and transient ischemic attack (TIA) at 30 days postoperatively. All patients were routinely assessed for silent cerebral ischemia. Neurological assessments were performed before, immediately after, 24 h and 30 days after the procedure. Post-procedural MRI, performed before the patients were discharged, was assessed by a neurologist with 10 years of experience, who was blinded to the procedure and clinical outcomes. The National Institutes of Health Stroke Scale (NIHSS) was used to assess neurological status [11]. A neurological deficit lasting

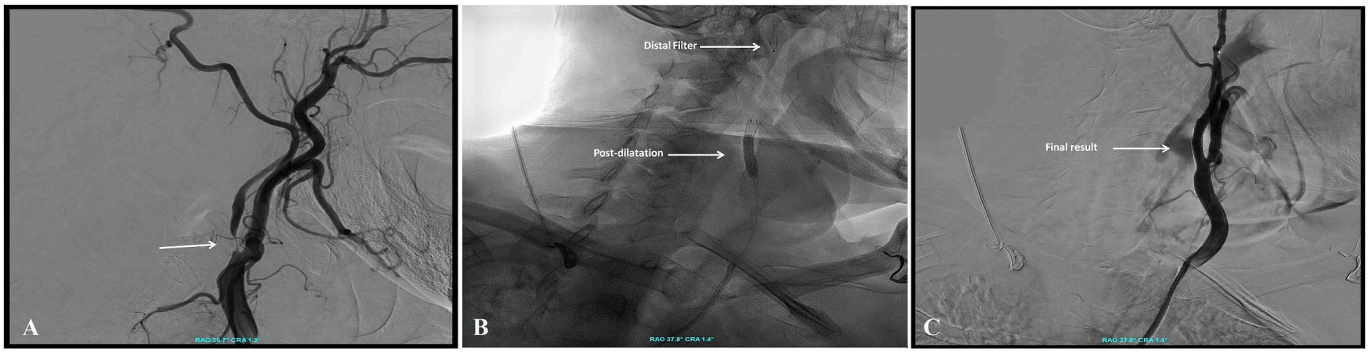

Fig. 1. A 68-year-old man who underwent carotid artery stenting with distal protection.
(A) Angiogram shows severe stenosis at the left internal carotid artery. (B) Post-dilatation after carotid artery stenting with distal filter. (C) Final result after balloon dilatation.

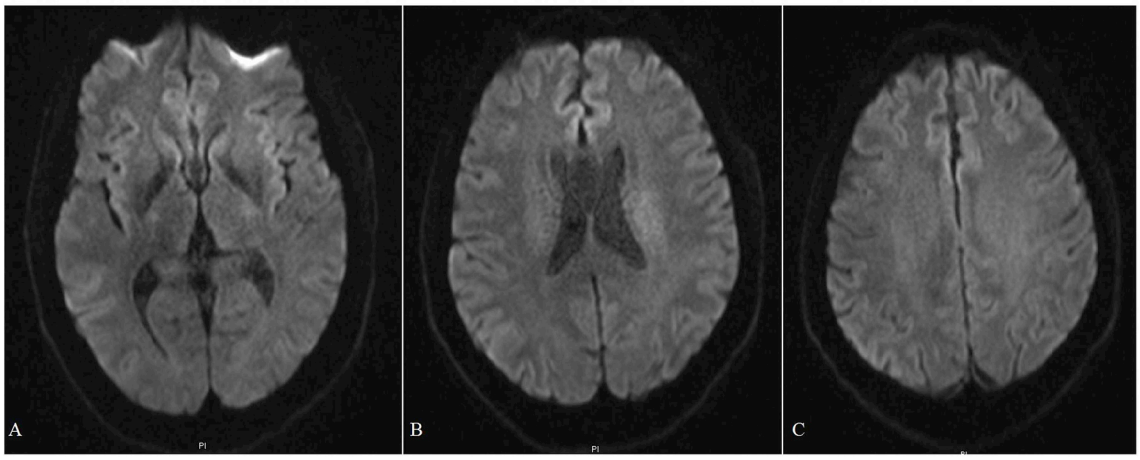

Fig. 2. No ischemic lesion is shown in bilateral cerebral hemispheres on the after-stenting diffusion weighted MR imaging in a patient.

more than 24 h, and with an NIHSS score > 4, was defined as a major stroke, whereas a focal neurological deficit lasting more than 24 h with an NIHSS score ≤4 was defined as a minor stroke. TIA was defined as a new neurological deficit lasting less than 24 h. Any new hyperintensity on DWI, and with correspondingly decreased diffusion on the apparent diffusion coefficient (ADC) map of the brain, was interpreted as silent cerebral ischemia (microembolic lesion) in the absence of neurological symptoms.

2.5. MRI acquisition and analysis

MRI was performed using a 1.5 T scanner (Magnetom Avanto; Siemens, Erlangen, Germany) using a dedicated head coil with patients in the supine position. The scanning protocol included DWI and ADC sequences at 5 mm sections. All MRI images and new high signal intensity were assessed by comparing preprocedural MRI images by a neurologist using a workstation (Leonardo; Siemens). Two example of MRI with and without ischemic lesions are shown in Figs. 1-3.

2.6. Reproducibility

Intra-observer variability was calculated for the neurologist who assessed the recorded images (offline) of 20 randomly selected patients showing new high signal intensity on DWI. The measurements were repeated after 2 weeks. Mean percent error was calculated as the absolute difference divided by the average of the two observations.

2.7. Statistical analysis

All statistical tests were performed using SPSS statistical software (version 23.0; SPSS Inc., Chicago, IL, USA). The data are presented as percentages for dichotomous variables, and as means ± standard deviations or medians with 25–75 interquartile range for continuous variables, according to the distribution of the data. Continuous data with a normal distribution were compared using Student's *t*-tests, whereas skewed data were compared using the Mann–Whitney *U* test. Categorical variables were assessed using the Chi-square test. Stepwise logistic regression analysis with backward elimination was used to evaluate the independent relationship between post-dilatation and periprocedural outcomes. All probabilities were two-tailed, and *p*-values less than 0.05 were considered statistically significant.

3. Results

The study included 128 patients (65.6% males) with a mean age of 71.6 (7.7) years. The majority of patients were symptomatic for CAD (79.7%), and 59 (46.1%) underwent post-dilatation due to residual stenosis after stenting.

The baseline clinical, demographic, and lesion characteristics are shown in Tables 1 and 2. We found no significant differences in baseline characteristics, comorbid diseases, or lesion characteristics between the two groups. However, the degree of stenosis was significantly greater (95% [80–98%] *vs.* 90% [80–95%], $p = 0.023$) and procedure duration

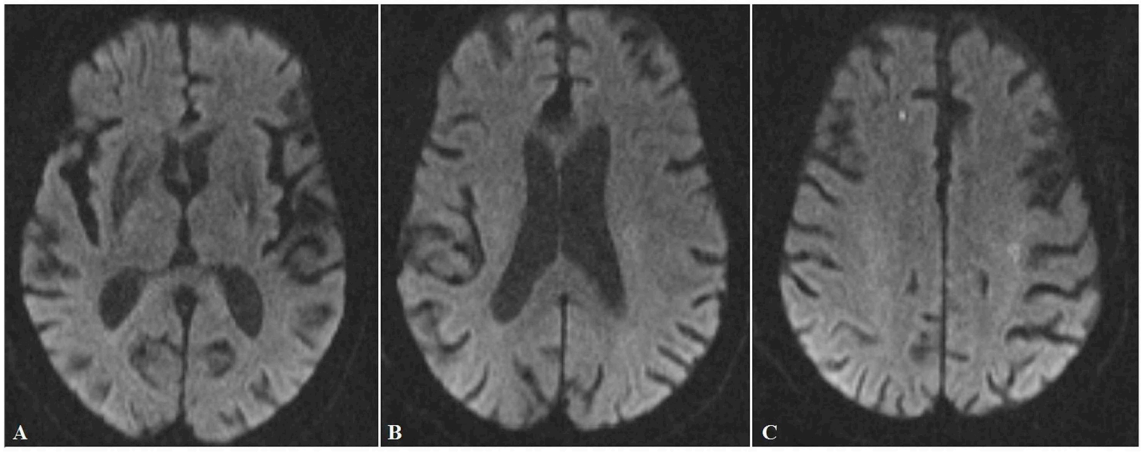

Fig. 3. Single small new hyperintensities are shown on the post-stenting diffusion-weighted MR imaging in a patient.

Table 1
Basal demographic and clinic features of the patients.

Variables	Group 1 (n = 59)	Group 2 (n = 69)	*p* value
Age, years	71.7 (8.1)	71.5 (7.4)	0.875
Male gender, n (%)	36 (61)	48 (69.6)	0.310
Body mass index (kg/m^2)	26.4 (2.2)	26.7 (2.3)	0.463
Symptomatic carotid stenosis, n (%)	47 (79.7)	55 (79.7)	0.995
Asymptomatic carotid stenosis, n (%)	12 (20.3)	14 (20.3)	
Intervention day for symptomatic patients	10 (7–15)	8 (7–10)	0.193
Systolic blood pressure (mmHg)	132.4 (17.2)	131.6 (16.4)	0.453
Diastolic blood pressure (mmHg)	71.4 (9.6)	70.2 (8.8)	0.521
Risk factors, n (%)			
Hypertension	42 (71.2)	47 (68.1)	0.707
Diabetes mellitus	24 (40.7)	21 (30.4)	0.226
Hyperlipidemia	24 (40.7)	30 (43.5)	0.749
Current smoker	9 (15.3)	9 (13)	0.720
Coronary artery disease	16 (27.1)	19 (27.5)	0.958

Table 2
Procedural characteristics of the study group.

Variables	Group 1 (n = 59)	Group 2 (n = 69)	*p* value
Lesion localization, n (%)			
Right internal carotid artery	29 (49.2)	30 (43.5)	0.521
Left internal carotid artery	30 (50.8)	39 (56.5)	
Degree of stenosis, %	95 (80–98)	90 (80–95)	**0.023**
Length of lesion, mm	25 (15–25)	25 (20–25)	0.723
Protection device, n (%)			
Proximal protection	2 (3.4)	3 (4.3)	
Distal protection	54 (91.5)	64 (92.8)	0.791
None	3 (5.1)	2 (2.9)	
Stent diameter	7.1 (0.4)	7.1 (0.7)	0.764
Stent length, mm	40 (30–40)	40 (30–40)	0.318
Mean duration of procedure (min)	42 .5 (4.5)	37.1 (4.2)	**0.038**

Bold values show statistical significance with p-value <0.05.

was significantly longer (42.5 [4.5] min *vs.* 37.1 [4.2] min, $p = 0.038$) in group 1 than in group 2.

The impact of post-dilatation on periprocedural outcomes is listed in Table 3. The incidence of major adverse events, including TIA, minor and major stroke, and death at 30 days, was similar between the two groups (5.1% *vs.* 4.3%, $p = 0.844$). However, silent cerebral ischemia rate and number of high-intensity signals were significantly higher in group 1 than in group 2 (45.8% *vs.* 26.1%, $p = 0.020$ and 1.01[1.2] *vs.* 0.42 [0.79], $p = 0.002$, respectively). Stepwise multivariate logistic regression analysis with backward elimination was performed to identify independent predictors of silent cerebral ischemia, and revealed that post-dilatation was the only independent predictor, and was associated with a 2.4-fold increase in the incidence of silent cerebral ischemia (95% CI: 1.15–5.20, $p = 0.020$) (Table 4).

Table 3
Peri-procedural and 30-day outcomes of the study group.

Variables	Group 1 (n = 59)	Group 2 (n = 69)	*p* value
Major advers events, n (%)	3 (5.1)	3 (4.3)	0.844
TIA, n	1	1	
Minor stroke, n	1	1	
Major stroke, n	0	1	
Mortality, n	1	0	
Silent ischemia n (%)	27 (45.8)	18 (26.1)	**0.020**
The number of high signal intensities, n	1.01 (1.2)	0.42 (0.79)	**0.002**

Bold values show statistical significance with p-value <0.05.

Table 4
Independent predictor of silent cerebral ischemia in multivariate logistic regression analysis.

Variables	B	S.E.	Wald	Odds ratio	95% C.I.	*p*
Post-dilatation	0.895	0.385	5.412	2.447	1.151–5.202	**0.020**

B: β coefficient, S.E: standard error, C.I.: confident interval, CAD: carotid artery disease.
Entered variables: post-dilatation, age, symptomatic CAD, diabetes mellitus, hypertension and degree of stenosis.
Bold values show statistical significance with p-value <0.05.

3.1. Reproducibility

The intra-observer mean percent error for the new high signal intensity on DWI was 2.4 ± 1.1%.

4. Discussion

We investigated the effect of balloon post-dilatation on periprocedural outcomes in patients who underwent CAS. Our major finding was that although post-dilatation did not increase the rate of major adverse events at 30 days, it was an independent predictor of silent cerebral ischemia.

CAS has gradually become accepted as an alternative to CEA for the treatment of CAD. The introduction of refined CAS techniques and new device technologies, including various-cell stent designs, embolic protection devices, and atraumatic catheters, together with better patient selection, has improved periprocedural outcomes. Despite this, CAS is associated with a higher rate of periprocedural events than CEA [12]. Several large studies and meta-analyses have evaluated the possible factors associated with periprocedural outcomes of CAS [13–16]; in particular, the use of embolic protection devices is found to be related to less periprocedural events during CAS [13].

The main objective of CAS is not to increase cerebral blood flow by decreasing the degree of stenosis in the carotid artery, but rather to stabilize the carotid plaque, trapping it between the stent and vessel wall. Predilatation facilitates lesion preparation and stent access and deployment, whereas post-dilatation facilitates stent expansion toward the vessel wall when residual stenosis is present. However, cerebral embolic events commonly occur during the post-dilatation stage. Possible mechanisms precipitating embolic events include i) plaque protrusion, which may occur if the balloon pushes the stent struts against the atheromatous plaque, ii) interruption of cerebral flow and hypotension caused by stimulation of the carotid baroreceptors during balloon inflation, and iii) increased procedure duration [17].

The degree of stenosis was greater, and the duration of the procedure was longer in group 1 than in group 2, possibly because stents do not fully expand in arteries with a high degree of stenosis such that operators tend to perform balloon post-dilatation which prolongs the procedure.

Previous studies found that CAS without post-dilatation was feasible, safe, and associated with a low incidence of adverse periprocedural outcomes [18,19]. Conversely, Obeid et al. [4] reported that post-dilatation was linked to an increase in periprocedural stroke and death rates in patients undergoing CAS. However, these studies did not assess silent ischemia on DWI. We investigated the rate of silent ischemia and major adverse events associated with post-dilatation. We found that the incidence of major adverse events was similar between two groups, which may be explained by our relatively small sample size. In contrast, silent cerebral ischemia was detected primarily in the group 1. Also, the number of high signal intensity was significantly greater in the group 1. Thus, our findings suggest that post-dilatation is associated with increased rates of adverse events and silent cerebral ischemia.

Indeed, the incidence of silent cerebral ischemia is higher than

deemed, and has been reported to range from 22% to 54% in some studies [20–22]. Although both ultrasound and DWI imaging techniques can detect silent cerebral ischemia (microemboli), DWI is more commonly used to detect silent ischemia [22–24]. The clinical significance of silent cerebral ischemia has not been fully understood, though previous studies have shown that silent ischemia is independently associated with cerebral deficits, deterioration of cognitive function, and memory loss [25–28]. Thus, we think that our study is valuable because it demonstrates post-dilatation increased silent cerebral ischemia.

Atherosclerotic particles and debris causing cerebrovascular events can be embolized during catheter manipulation or cannulation of the aortic arch, while deploying the wire at the lesion site or placing and removing a filter. Furthermore, balloon predilatation, post-dilatation, and stent deployment may dislodge debris. Several studies have shown that cerebral embolic protection devices and closed-cell and double-layer stent designs minimize distal emboli during CAS [13,29,30]. However, filter systems can only entrap embolic materials that are larger than their pore size. Moreover, trapped materials can spill out into the carotid artery during retrieval of the filter system. The majority of atherosclerotic particles can cause silent cerebral ischemia. In our study, the overall incidence of silent cerebral ischemia was 35%, which was consistent with previous findings. The fact that most of our study population had symptomatic CAD, and that open-cell stents and distal filter systems were used in nearly all of the patients, may have influenced our findings. However, multivariate analysis revealed that post-dilatation was the only independent predictor of silent cerebral ischemia, and was associated with a 2.4-fold increase in the incidence of the condition.

Our study had several limitations. First, it was conducted in a single center and the sample size was relatively small. A larger study including more cases, and using closed-cell or double-layer stent designs and proximal protection devices, would provide more generalizable findings. Second, although the groups were similar in terms of baseline characteristics and procedural characteristics, the retrospective design was a limitation. Larger studies are needed to clarify the prognostic role of post-dilatation in periprocedural outcomes of CAS.

4.1. Conclusions

Post-dilatation was associated with an increased incidence of silent cerebral ischemia in patients who underwent CAS. Therefore, post-dilatation should be limited to cases with severe residual stenosis after CAS.

Conflict of interest

The authors declared they do not have anything to disclose regarding conflict of interest with respect to this manuscript.

Author contributions

F. Besli, Z. Tanriverdi, and F. Gungoren were involved in the conception, design, or planning of the study. F. Besli, O. Kocaturk, Z. Tanriverdi, F. Gungoren and MB Tascanov were involved in the acquisition of data. F. Besli, Z. Tanriverdi and MB Tascanov were involved in the analysis of data. O. Kocaturk, F. Gungoren and MB Tascanov were involved in the interpretation of results. F. Besli, O. Kocaturk, Z. Tanriverdi, F. Gungoren and MB Tascanov substantially contributed to drafting of the manuscript.

References

[1] A. Lamanna, J. Maingard, C.D. Barras, H.K. Kok, G. Handelman, et al., Carotid artery stenting: current state of evidence and future directions, Acta Neurol. Scand. 139 (4) (2019) 318–333.

[2] A.R. Naylor, J.B. Ricco, G.J. de Borst, S. Debus, J. de Haro, et al., Management of atherosclerotic carotid and vertebral artery disease: 2017 clinical practice guidelines of the European society for vascular surgery (ESVS), Eur. J. Vasc. Endovasc. Surg. 55 (2018) 3–81.

[3] D. Mukherjee, M. Roffi, Minimizing distal embolization during carotid artery stenting, JACC Cardiovasc. Interv. 12 (4) (2019) 404–405.

[4] T. Obeid, D.J. Arnaoutakis, I. Arhuidese, U. Qazi, C.J. Abularrage, et al., Poststent ballooning is associated with increased periprocedural stroke and death rate in carotid artery stenting, J. Vasc. Surg. 62 (3) (2015) 616–623.e1.

[5] J.H. Voeks, G. Howard, G.S. Roubin, M.B. Malas, D.J. Cohen, et al., Age and outcomes after carotid stenting and endarterectomy: the carotid revascularization endarterectomy versus stenting trial, Stroke 42 (2011) 3484–3490.

[6] E. Tatli, A. Tokatli, M.B. Vatan, M.T. Agac, H. Gunduz, et al., Comparison of closed-cell and hybrid-cell stent designs in carotid artery stenting: clinical and procedural outcomes, Postep. Kardiol. Interwencyjnej 13 (2) (2017) 135–141.

[7] A.S. Dhillon, S. Li, J.P. Lewinger, D.M. Shavelle, R.V. Matthews, et al., Comparison of devices used in carotid artery stenting: a vascular quality initiative analysis of commonly used carotid stents and embolic protection devices, Cathet. Cardiovasc. Interv. 92 (4) (2018) 743–749.

[8] F.M. McKevitt, A. Sivaguru, G.S. Venables, T.J. Cleveland, P.A. Gaines, et al., Effect of treatment of carotid artery stenosis on blood pressure: a comparison of hemodynamic disturbances after carotid endarterectomy and endovascular treatment, Stroke 34 (11) (2003) 2576–2581.

[9] P. Lavoie, J. Rutledge, M.A. Dawoud, M. Mazumdar, H. Riina, et al., Predictors and timing of hypotension and bradycardia after carotid artery stenting, AJNR (Am. J. Neuroradiol.) 29 (10) (2008) 1942–1947.

[10] G.G. Ferguson, M. Eliasziw, H.W. Barr, G.P. Clagett, R.W. Barnes, et al., the North American symptomatic carotid endarterectomy trial: surgical results in 1415 patients, Stroke 30 (1999) 1751–1758.

[11] T. Brott, H.P. Adams Jr., C.P. Olinger, J.R. Marler, W.G. Barsan, et al., Measurements of acute cerebral infarction: a clinical examination scale, Stroke 20 (1989) 864–870.

[12] A. Lamanna, J. Maingard, C.D. Barras, H.K. Kok, G. Handelman, et al., Carotid artery stenting: current state of evidence and future directions, Acta Neurol. Scand. 139 (4) (2019) 318–333.

[13] J. Omran, E. Mahmud, C.J. White, H.D. Aronow, D.E. Drachman, et al., Proximal balloon occlusion versus distal filter protection in carotid artery stenting: a meta-analysis and review of the literature, Cathet. Cardiovasc. Interv. 89 (5) (2017) 923–931.

[14] K.I. Paraskevas, E.L. Kalmykov, A.R. Naylor, Stroke/death rates following carotid artery stenting and carotid endarterectomy in Contemporary Administrative Dataset Registries: a systematic review, Eur. J. Vasc. Endovasc. Surg. 51 (2016) 3–12.

[15] D.V. Heck, G.S. Roubin, K.G. Rosenfield, W.A. Gray, C.J. White, et al., Asymptomatic carotid stenosis: medicine alone or combined with carotid revascularization, Neurology 88 (21) (2017) 2061–2065.

[16] CAVATAS investigators, Endovascular versus surgical treatment in patients with carotid stenosis in the Carotid and Vertebral Artery Transluminal Angioplasty Study (CAVATAS): a randomised trial, Lancet 357 (9270) (2001) 1729–1737.

[17] J.J. Vitek, N. Al-Mubarak, S.S. Iyer, G.S. Roubin, Carotid artery stenting: technical considerations, AJNR (Am. J. Neuroradiol.) 21 (2000) 1736–1743.

[18] A. Ogata, M. Sonobe, N. Kato, T. Yamazaki, H. Kasuya, et al., Carotid artery stenting without post-stenting balloon dilatation, J. Neurointerventional Surg. 6 (7) (2014) 517–520.

[19] M. Maynar, S. Baldi, R. Rostagno, T. Zander, M. Rabellino, et al., Carotid stenting without use of balloon angioplasty and distal protection devices: preliminary experience in 100 cases, AJNR (Am. J. Neuroradiol.) 28 (7) (2007) 1378–1383.

[20] H.G. Roh, H.S. Byun, J.W. Ryoo, D.G. Na, W.J. Moon, et al., Prospective analysis of cerebral infarction after carotid endarterectomy and carotid artery stent placement by using diffusion-weighted imaging, AJNR (Am. J. Neuroradiol.) 26 (2005) 376–384.

[21] H. Poppert, O. Wolf, M. Resch, W. Theiss, T. Schmidt-Thieme, et al., Differences in number, size and location of intracranial microembolic lesions after surgical versus endovascular treatment without protection device of carotid artery stenosis, J. Neurol. 251 (2004) 1198–1203.

[22] H.J. Jaeger, K.D. Mathias, R. Drescher, E. Hauth, G. Bockisch, et al., Diffusion-weighted MR imaging after angioplasty or angioplasty plus stenting of arteries supplying brain, AJNR (Am. J. Neuroradiol.) 22 (2001) 1251–1259.

[23] R.G. Ackerstaff, C. Jansen, F.L. Moll, F.E. Vermeulen, R.P. Hamerlijinck, et al., The significance of microemboli detection by maens of transcranial Doppler ultrasonography monitoring in carotid endarterectomy, J. Vasc. Surg. 21 (1995) 963–969.

[24] G. Orlandi, S. Fanucchi, C. Fioretti, G. Acerbi, M. Puglioli, et al., Characteristics of cerebral microembolism during carotid stenting and angioplasty alone, Arch. Neurol. 58 (2001) 1410–1413.

[25] M. Cosottini, M.C. Michelassi, M. Puglioli, G. Lazzarotti, G. Orlandi, et al., Silent cerebral ischemia detected with diffusion-weighted imaging in patients treated with protected and unprotected carotid artery stenting, Stroke 36 (11) (2005) 2389–2393.

[26] O. Wolf, P. Heider, M. Heinz, H. Poppert, T. Schmidt-Thieme, et al., Frequency, clinical significance and course of cerebral ischemic events after carotid endarterectomy evaluated by serial diffusion, Eur. J. Vasc. Endovasc. Surg. 27 (2) (2004) 167–171.

[27] R.G. Ackerstaff, M.J. Suttorp, J.C. van den Berg, T.T. Overtoom, J.A. Vos, et al., Antonius Carotid Endarterectomy, Angioplasty, and Stenting Study Group. Prediction of early cerebral outcome by transcranial Doppler monitoring in carotid

bifurcation angioplasty and stenting, J. Vasc. Surg. 41 (4) (2005) 618–624.
[28] S.J. Fearn, R. Pole, K. Wesnes, E.B. Faragher, T.L. Hooper, et al., Cerebral injury during cardiopulmonary bypass: emboli impair memory, J. Thorac. Cardiovasc. Surg. 121 (2001) 1150–1160.
[29] A.S. Dhillon, S. Li, J.P. Lewinger, D.M. Shavelle, R.V. Matthews, et al., Comparison of devices used in carotid artery stenting: a vascular quality initiative analysis of commonly used carotid stents and embolic protection devices, Cathet. Cardiovasc. Interv. 92 (4) (2018 Oct 1) 743–749.
[30] E. Stabile, G. de Donato, P. Musialek, K. De Loose, R. Nerla, et al., Use of dual-layered stents in endovascular treatment of extracranial stenosis of the internal carotid artery: results of a patient-based meta-analysis of 4 clinical studies, JACC Cardiovasc. Interv. 11 (23) (2018 Dec 10) 2405–2411.