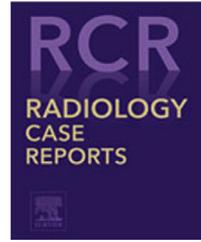


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Case Report

Endovascular treatment of patient with multiple extracranial large vessel stenosis and coexistent unruptured wide-neck intracranial aneurysm using a WEB device and Szabo-technique ☆,☆☆

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ABSTRACT

The coexistence of severe extracranial large vessel stenosis and unruptured intracranial aneurysms is not rare. There are different treatment approaches for these conditions, such as initial treatment of the aneurysm before revascularization of the stenosis; single-stage endovascular treatment of both lesions; stenosis eliminating followed by treatment of the aneurysm, or without treating the aneurysm. But, taking into account the risk of aneurysm rupture on the one hand and the risk of ischemic stroke on the other, it is sometimes difficult to choose the right management strategy. Despite this fact, there are still no guidelines or consensus on the management of these coexistent lesions. The article describes a clinical case of endovascular treatment of multiple extracranial stenosis and coexistent unruptured wide-neck aneurysm of the middle cerebral artery. The endovascular treatment of the carotid stenosis and aneurysm using a woven endobridge device was performed in

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one session; endovascular treatment of vertebral artery stenosis with Szabo technique was performed in another session.

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Introduction

The coexistence of severe extracranial large vessel stenosis and an unruptured intracranial aneurysms (UIAs) is not rare. According to different authors, the prevalence of such combination ranges from 1% to 14.2% of total number of patients with severe extracranial large vessel stenosis [1–6]. There are different approaches for treatment of extracranial large vessel stenosis and coexistent UIAs, such as initial treatment of the aneurysm before revascularization of the stenosis; single-stage endovascular treatment of both lesions; stenosis eliminating followed by treatment of the aneurysm, or without treating the aneurysm [7–19]. There are still no neither guidelines nor consensus on the management of these coexistent lesions. However, it is sometimes difficult to choose the right management strategy, taking into account the risk of aneurysm rupture on the one hand and the risk of ischemic stroke on the other. Cerebral artery revascularization causes hemodynamic changes, which could lead to the aneurysm rupture as a result of increased wall shear stress [18,20–22]. Vice versa, the risk of perioperative cerebral ischemia increases during and after cerebral aneurysm treatment without correction of significant extracranial large vessel stenosis. This risk is mainly caused by decreasing the intracranial hemodynamic reserve and reduction of perfusion pressure during anesthesia [3,5,23]. Moreover, endovascular aneurysm treatment in patients with carotid stenosis has its own risks [17,18]. The mechanical interaction between the access catheters and stenotic carotid plaque may increase the risk of thromboembolic complications [24].

The article describes a clinical case of endovascular treatment of multiple extracranial stenosis and coexistent unruptured bifurcation aneurysm (WNBA) of the middle cerebral artery (MCA). The endovascular treatment of the carotid stenosis and aneurysm using a woven endobridge device (WEB) was performed in one session; endovascular treatment of vertebral artery stenosis with Szabo technique was performed in another session.

Case report

Patient Ch., male, 72 years old, severe smoker, complaints on general weakness, headache, drop-attacks, severe dizziness, loss of balance and coordination.

The patient has a history of severe arterial hypertension. In March 2019, speech impairment, right extremities weakness, and numbness appeared and resolved within 2 hours. Patient visited hospital 2 days later: Signs of ischemic stroke was not defined on MRI. Duplex ultrasound scan (DU) revealed echolu-

cent plaque - type 1 in the bulb of left internal carotid artery (ICA), which causes stenosis up to 60% (according to NASCET criteria [25,26]), and subtotal stenosis in the ostium of right external carotid artery (ECA). Visualization of initial parts of both vertebral arteries (VA) was not successful due to the location behind the collarbones; however, linear blood flow velocity in both VA was significantly decreased (to 5 cm/sec). This finding indirectly indicates a probability of severe stenosis in the initial parts of both VA. Transient ischemic attack (TIA) was diagnosed. Acetylsalicylic acid (ASA) 100 mg and atorvastatin 40 mg were prescribed for stroke prevention. Endovascular neurosurgery was recommended for revascularization. But the patient refused it. In 2 month there were several consecutive episodes of vertigo and drop-attacks. In 3 month speech impairment and right extremities weakness appeared again and resolved in hour. Patient visited the neurologist in 2 days after this. MRI of brain did not determine any ischemic lesions. Results of repeated DU of extracranial large vessel were equivalent the results of previous DU. Repeated TIA affecting left carotid territory was diagnosed.

The patient admitted to neurosurgery department. Cognitive impairment (Montreal Cognitive Assessment test [MoCA] - 19 points [27]) and coordination disorder were found upon admission.

Total selective cerebral angiography (CAG) confirmed multifocal stenotic lesions of extracranial large vessels (Fig. 1): vulnerable plaque with ulceration in the bulb of left ICA, narrowing the artery lumen up to 60% (according to NASCET criteria), vulnerable plaque in lacerum, and cavernous segments of left ICA without significant stenosis, subtotal stenosis of the ostium of right ECA, subtotal stenosis of the ostium of both VA, 70% stenosis of the initial part of left SCA. Moreover, angiography demonstrated WNBA of M1-segment of left MCA. No coronary arteries stenosis has been identified on the single session coronarography. CT perfusion revealed significant differences in perfusion maps between right and left hemispheres with signs of hypoperfusion and prolonged transit time in the left ICA blood supply (Fig. 2).

Given the obtained data: repeated TIAs; vulnerable plaque in the bulb of left ICA; WNBA of M1-segment of the left MCA; subtotal stenosis in the ostium of both VA; signs of hypoperfusion of left hemisphere CT perfusion; and old patient's age, endovascular treatment stage-by-stage was preferred.

After analysis of three dimension angiography, optimal WEB size SL 9 × 4 (MicroVention Inc., Aliso Viejo, CA) was selected. The patient was prescribed double antiplatelet therapy with ASA (100 mg/day) and clopidogrel (75 mg/day) a week before intervention.

The first session was performed under general anesthesia with vital signs continuous monitoring to prevent a drop of arterial pressure. During the intervention, 5000 IU of heparin was administered. A 6 Fr 90 cm Super Arrow-Flex Percuta-

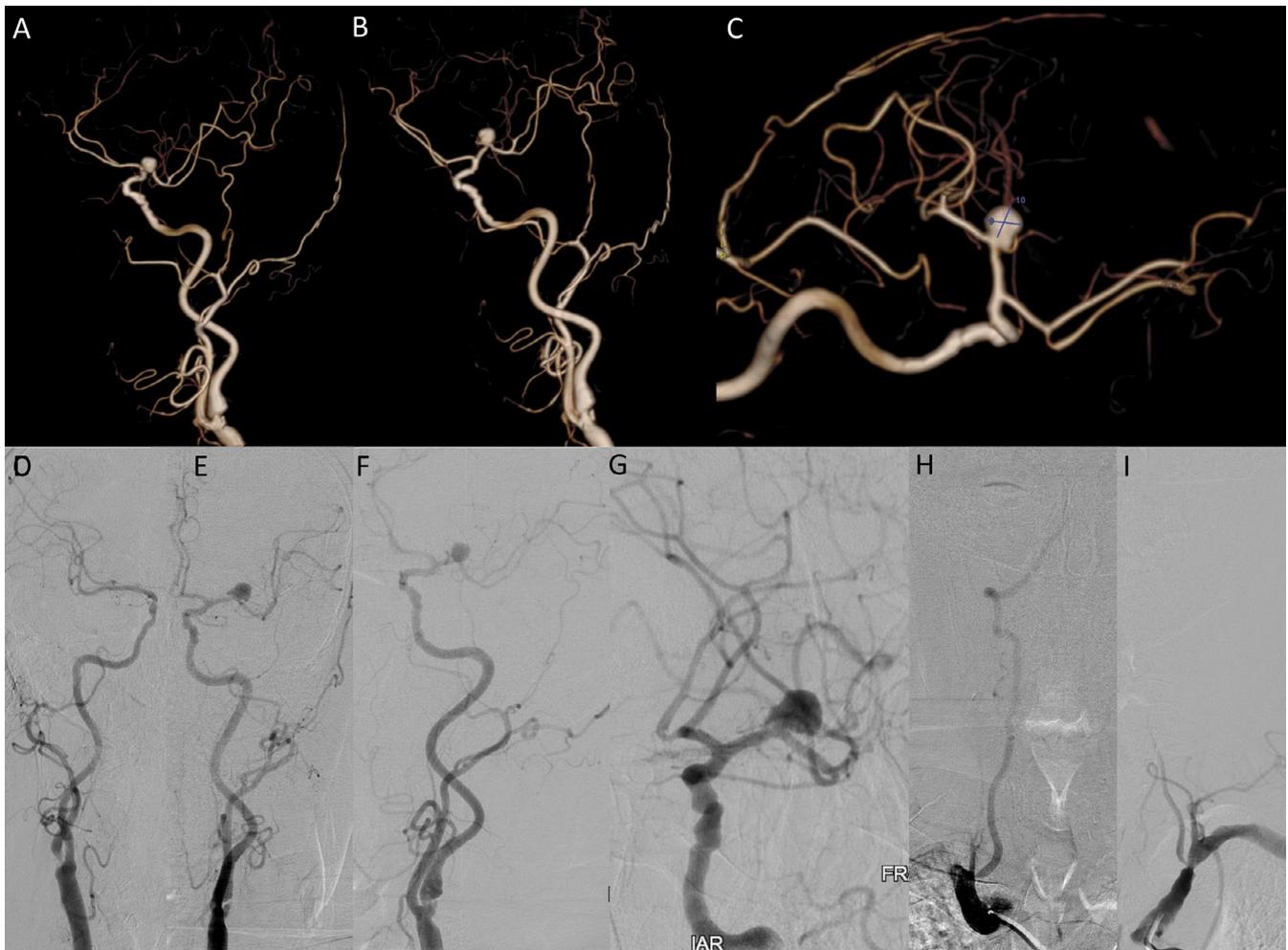


Fig. 1 – CAG revealed: Vulnerable plaque with ulceration in the bulb of left internal carotid artery, narrowing the artery lumen up to 60% (according to NASCET criteria) (A,B,C,E), wide neck bifurcation aneurysm in the M1-segment of left middle cerebral artery (A,B,C,E,F,G), subtotal stenosis of the ostium of right vertebral artery (H), subtotal stenosis of the ostium of right external carotid artery (D), hypoplasia of left vertebral artery and subtotal stenosis of its ostium, 70% stenosis of the initial part of left SCA (I).

neous Sheath (Teleflex Medical, Athlon, Ireland) was used for transfemoral access to the left common carotid artery. Coaxial catheter platform: distal access catheter Sofia 5F 125cm (MicroVention Inc., Aliso Viejo, CA), microcatheter VIA 27 (MicroVention Inc., Aliso Viejo, CA) was navigated on the Traxcess 14 Guidewire (MicroVention Inc., Aliso Viejo, CA) through the long sheath and through the stenotic lesion at the proximal ICA to the M1-segment of MCA. WEB SL 9 × 4 (MicroVention Inc., Aliso Viejo, CA) was implanted in the aneurysm of MCA with excellent filling of aneurysm sac and without stenosing of M1- and M2-segments on the control angiography (Fig. 3A-F). Then, a distal protection device Spider FX (Medtronic, Plymouth, MN), was held on the Traxcess 14 Guidewire (MicroVention Inc., Aliso Viejo, CA) to the ICA above the stenotic lesion and its filter was opened. A self-expanding double-mesh carotid stent Casper RX 8 mm × 30 mm (MicroVention Inc., Aliso Viejo, CA) was implanted across the ulcerated plaque with postdilatation from 6 mm × 20 mm bal-

loon catheter Submarine (Medtronic, Plymouth, MN). Follow-up angiography confirmed residual stenosis absence in the left ICA bulb (Fig. 3G-H), excellent position of the WEB in the aneurysm sac and revealed moderate contrast stagnation in the aneurysm. Hemostasis of the femoral artery puncture site was performed with Angio-Seal VIP Vascular Closure Device 6F (Terumo Medical Corporation, Somerset, NJ). There are no any new neurological deficits after procedure. A day later MRI confirmed the absence of “fresh” embolic foci of ischemia. The patient was discharged with recommendation to continue intake of ASA (100 mg/day), clopidogrel (75 mg/day), and atorvastatin (40 mg/day)

Drop-attacks, dizziness, balance, and coordination impairment continued after intervention, but there were no more TIA. In 3 months the patient was admitted for the second endovascular treatment session. The procedure was performed under conscious sedation and monitored by an anesthesiologist. During the intervention, 5000 IU of heparin was adminis-

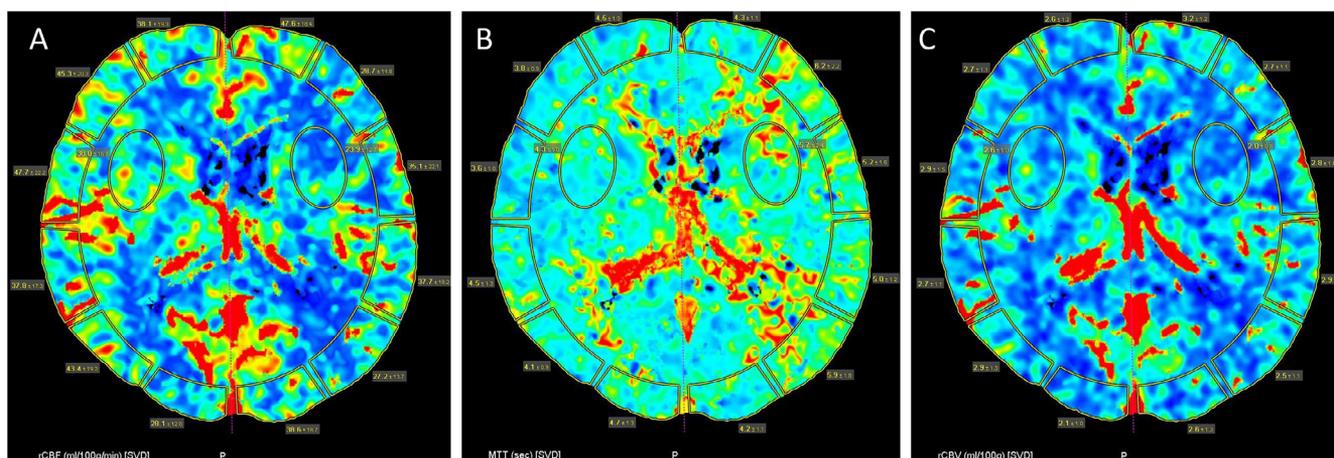


Fig. 2 – CT perfusion image shows marked reduction in blood flow to the left hemisphere: The difference in corresponding zones of right hemisphere reached 1.6 times (A). Mean transit time image of the CT perfusion study confirms markedly prolonged blood transit through brain tissue supplied by the left carotid artery (B). Cerebral blood volume remained within normal (C).

tered. With usage of right-side transradial access through 6 Fr 10 cm Radifocus Introducer II (Terumo Medical Corporation, Somerset, NJ) guiding catheter Launcher 6F 100 cm (Medtronic, Plymouth, MN) was introduced to the right SCA on the level of VA ostium. During scinting of ostium stenosis, for accurate stent positioning the special anchor stenting technique (Szabo technique) [28,29] was used. PT2 wire (Boston Scientific, MA) was introduced in the right VA as a target wire for the balloon-expandable stent and “anchor” wire – Cougar XT (Medtronic, Plymouth, MN) was introduced through the right subclavian artery to the aortic arch for the Szabo technique. The VA ostium lesion was predilated routinely with the Sprinter Legend RX Balloon 3 mm × 10 mm (Medtronic, Plymouth, MN). Then, one strut segment of the proximal stent cell of drug-eluting balloon-expandable stent Onyx Resolute 5 mm × 12 mm was gently flared by forceps. The outside end of the “anchor” wire was introduced through the flared strut of the stent, and then the lifted strut was pressed back into place. The target wire was introduced through the stent/balloon system in the usual way. The stent/balloon system was advanced into the initial part of VA until the “anchor” wire stopped advancing. The stent was deployed at a low pressure (6 atmospheres). Then, after the balloon deflating and marker wire was withdrawn, the stent was finally postdilated at a high pressure (10–12 atmospheres) (Fig. 4A–D). Follow-up angiography demonstrated complete luminal reestablishment of VA with precise stent positioning without exceeding prolapse to the SCA and good filling of vertebrobasilar basin arteries including retrograde filling of left V4-segment through the vertebrobasilar junction (Fig. 4E–F), left ICA without stenosis, left MCA aneurysm complete occlusion (Fig. 4G–H). Hemostasis of the radial artery puncture site was performed with TRAcetlet Transradial Compression Device (Medtronic, Plymouth, MN). There are no any new neurological deficits after procedure. A day later MRI confirmed the absence of “fresh” embolic ischemic foci. The patient was discharged with recommendation to continue intake of ASA (100 mg/day), clopidogrel (75 mg/day), and atorvastatin (40 mg/day). The patient was examined in

3 months after intervention: drop-attacks, dizziness, balance and coordination impairment regressed, TIAs were not observed. Cognitive functions much improved (MoCA - 26).

The coexistence of severe extracranial large vessel stenosis and an unruptured intracranial aneurysms

Discussion

Management of the patients with severe extracranial large vessel stenosis and an unruptured intracranial aneurysms associated with the risk of aneurysm rupture and with the risk of ischemic stroke during and after intervention.

On the one hand, hemodynamic changes after cerebral artery revascularization could increase aneurysmal wall stress and lead to the aneurysm bleed. On the other hand, the risk of perioperative cerebral ischemia increases during and after cerebral aneurysm treatment without correction of significant extracranial large vessel stenosis. In the cases of microsurgical treatment it can due to the decreased intracranial hemodynamic reserve and a temporary reduction in perfusion pressure during anesthesia [18,20–22]. Risk of cerebral ischemia increases in the cases of endovascular treatment of an aneurysm through untreated carotid stenosis due to need for traverse of stenotic lesion and mechanical interaction between the access catheters and stenotic plaque [17,18,24].

There are different treatment approaches for treatment of coexisting of extracranial large vessel stenosis and UIAs, but there is no definite consensus on the management of these coexistent pathology [7–19].

Therefore, the development of treatment strategy for patients with such combined pathology is a difficult task. An integrated approach with involvement of highly qualified multidisciplinary team and using the latest developments of interventional medicine is necessary.

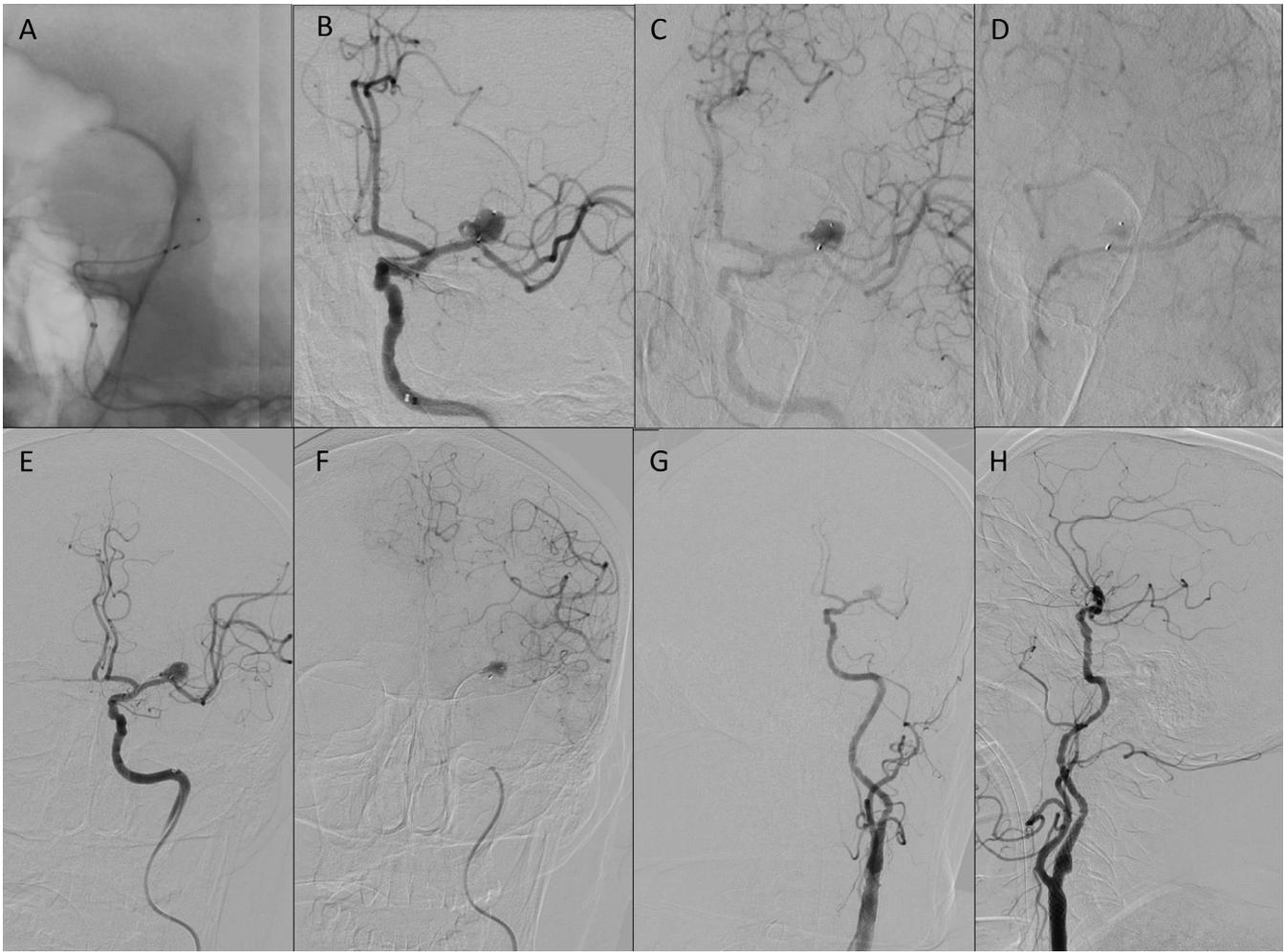


Fig. 3 – The first session of endovascular treatment.

Woven Endobridge Intrasaccular Device (WEB SL 9 × 4) (MicroVention Inc., Aliso Viejo, CA) was implanted in the aneurysm of left MCA with excellent filling of aneurysm sac and without stenosing of M1- and M2-segments of MCA. Contrast stagnation in the aneurysm sac was determined (A-F)

A self-expanding double-mesh carotid stent Casper RX 8 mm × 30 mm (MicroVention Inc., Aliso Viejo, CA) was implanted across the ulcerated plaque in the left ICA with a distal protection device Spider FX (Medtronic, Plymouth, MN), and postdilatation from a 6 mm × 20 mm balloon catheter Submarine (Medtronic, Plymouth, MN). Follow-up angiography demonstrated optimal luminal reestablishment of the left carotid artery (G-H).

Considering the high risk of hyperperfusion during stenting of both carotid and vertebral arteries in single session, it is reasonable to start from one artery stenting (ICA in our case) with initial endovascular treatment of the aneurysm in the same session to prevent bleeding.

WNBA is treatment challenge with either endovascular or open surgical methods. Two variants of endovascular WNBA treatment were considered. First variant, stent- and balloon-assistant coiling techniques with jailing of microcatheter for coiling, could be technically difficult and required to pass the stenosis with a large-bore access catheters, what could increase the risk of thromboembolic complications. Second treatment variant, the use of intrasaccular device developed specifically for the treatment of WNBA - WEB. It is significantly more safe than other WNBA treatment approaches [30]. Besides, for this method, coaxial catheter platform with

minimal outer diameter is required. This is allow to decrease the mechanical interaction between the access catheters and stenosing plaque, as a result, the risk of thromboembolic complications is reduced. Therefore, in the presented case, we gave preference and successfully applied this method.

Carotid artery stenting was performed in the same session, after WEB was implanted in the aneurysm. The double mesh carotid stent with distal embolic protection device was used. Because the use of double mesh designed stent decreases the risk of periprocedural and postprocedural distal embolism in the cases of high-risk plaque. The ICA plaque in our patient considered high-risk due to ultrasound characteristics: echolucent ulcerated vulnerable plaque [31].

Considering that stenosis of both VA remained and the lack of blood supply persisted after the initial intervention, as evi-

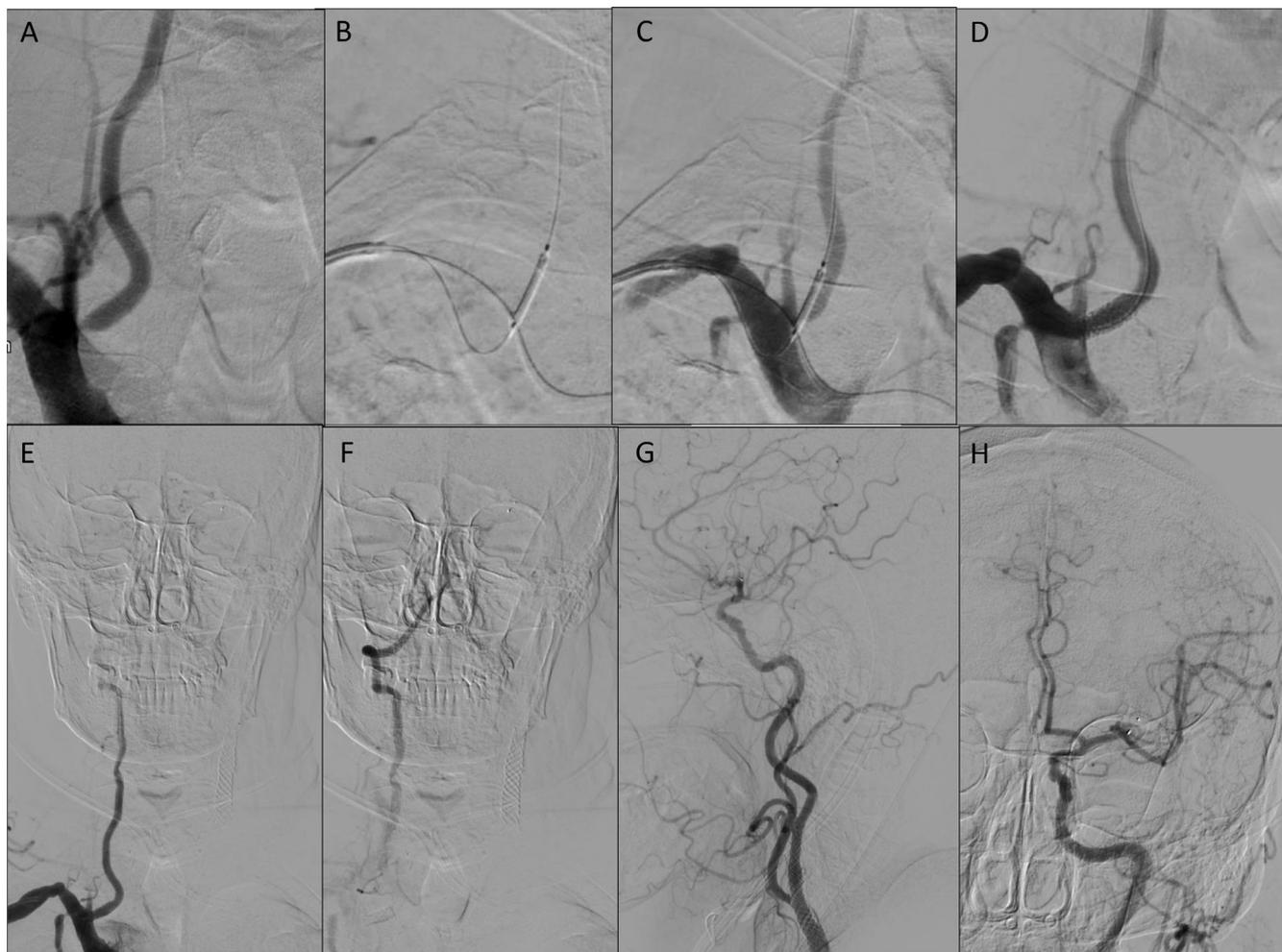


Fig. 4 – The second session of endovascular treatment.

Intraoperative angiographic images: (A) subtotal stenosis in the ostium of right VA (A), Onyx Resolute 5 × 15 mm drug-eluting coronary stent (white arrow) was positioned in V1-segment of the right VA from its ostium using the Szabo technique: after placing a target wire (red arrows) in the distal vertebral artery, the anchor wire (black arrows) is positioned in the SCA, with the proximal end passing through the last cell of the stent as a retention marker to anchor the stent in position (B,C). Stent is implanted into initial part of VA without excessive protrudes into the SCA, without obvious deformation (D). Follow-up angiography demonstrated complete luminal reestablishment of VA with good filling of vertebrobasilar basin arteries including retrograde filling of V4-segment of left VA through vertebrobasilar junction (E-F) Control left carotid angiogram shown left ICA patency without stenosis, left MCA aneurysm complete occlusion (G-H).

denced by the presence of drop attacks, dizziness, imbalance, and coordination, it was decided to perform stenting of dominant VA.

Although VA ostium stenting is considered to be a safe treatment option, high rates of restenosis and delayed stent fractures remained [32–36]. Using of drug eluting stents decrease neointimal hyperplasia related in-stent restenosis in VA. Using of the special anchor stenting technique (Szabo technique) provides optimal plaque coverage, without exceeding prolapse of stent struts to the SCA, what decreased the risk of delayed stent fracture [37]. Consequently, stenting of VA stenosis was performed with usage of above options as part of the second phase of the intervention.

Conclusion

The proposed concept of endovascular treatment of multiple extracranial large vessel stenosis and coexistent unruptured WNBA allows to reduce perioperative risks and delayed risks coming from each of coexistent pathology. All interventions were performed successfully, the patient condition significantly improved.

In the cases of coexistence extracranial stenosis and WNBA, usage of WEB device for aneurysm treatment with follow carotid stenting in one session could be the method of choice. Further stenting should be performed in the case of persisting clinical symptoms indicating insufficient blood

supply to the brain. Using the Szabo technique with short drug-eluting balloon-expandable coronary stent for precise VA ostium stenting and prevention delay in-stent restenosis and stent fracture is quite encouraging.

Taking into account the positive results obtained, it is necessary to conduct larger studies to create recommendations on the tactics of management such coexistent pathology.

REFERENCES

- [1] Khan UA, Thapar A, Shalhoub J, Davies AH. Risk of intracerebral aneurysm rupture during carotid revascularization. *J Vasc Surg* 2012;56:1739–47.
- [2] Yang X, Lu J, Wang J, Wang L, Qi P, Hu S, et al. A clinical study and meta-analysis of carotid stenosis with coexistent intracranial aneurysms. *J. Clin. Neurosci.* 2018;52:41–9.
- [3] Ballotta E, Da GG, Manara R, Baracchini C. Extracranial severe carotid stenosis and incidental intracranial aneurysms. *Ann Vasc Surg* 2006;20:5–8.
- [4] Griffiths PD, Worthy S, Gholkar A. Incidental intracranial vascular pathology in patients investigated for carotid stenosis. *Neuroradiology* 1996;38:25–30.
- [5] Kappelle LJ, Eliasziw M, Fox AJ, Barnett HJ. Small, unruptured intracranial aneurysms and management of symptomatic carotid artery stenosis // North Am Symptomatic Carotid Endarterectomy. *Trial Group Neurol* 2000;55:307–9.
- [6] Héman LM, Jongen LM, van der Worp HB, Rinkel GJ, Hendrikse J. Incidental intracranial aneurysms in patients with internal carotid artery stenosis: a CT angiography study and a metaanalysis. *Stroke* 2009;40:1341–6.
- [7] Iwata T, Mori T, Tajiri H. Successful staged endovascular treatment of a symptomatic cervical carotid bifurcation stenosis coupled with a coincidental unruptured cerebral aneurysm in the carotid distal segment. *AJNR Am J Neuroradiol* 2008;29:1948–50. <http://dx.doi.org/10.3174/ajnr.A1172>.
- [8] Kann BR, Matsumoto T, Kerstein MD. Safety of carotid endarterectomy associated with small intracranial aneurysms. *South Med J* 1997;90:1213–16. <http://dx.doi.org/10.1097/00007611-199712000-00010>.
- [9] Ladowski JS, Webster MW, Yonas HO, Steed DL. Carotid endarterectomy in patients with asymptomatic intracranial aneurysm. *Ann Surg* 1984;200:70–3. <http://dx.doi.org/10.1097/0000658-198407000-00012>.
- [10] Orecchia PM, Clagett GP, Youkey JR, Brigham RA, Fisher DF, Fry RF, et al. Management of patients with symptomatic extracranial carotid artery disease and incidental intracranial berry aneurysm. *J Vasc Surg* 1985;2:158–64. <http://dx.doi.org/10.1067/mva.1985.avs0020158>.
- [11] Suh BY, Yun WS, Kwun WH. Carotid artery revascularization in patients with coexistent carotid artery stenosis and asymptomatic un-ruptured intracranial artery aneurysm. *Ann Vasc Surg* 2011;25:651–5. <http://dx.doi.org/10.1016/j.avsg.2011.02.015>.
- [12] Navaneethan SD, Kannan VS, Osowo A, Shrivastava R, Singh S. Coexistent intracranial aneurysm and carotid artery stenosis: a therapeutic dilemma. *South Med J* 2006;99:757–8. <http://dx.doi.org/10.1097/01.smj.0000217190.93989.c9>.
- [13] Pappadà G, Fiori L, Marina R, Vaiani S, Gaini SM. Management of symptomatic carotid stenoses with coincidental intracranial aneurysms. *Acta Neurochir (Wien)* 1996;138:1386–90. <http://dx.doi.org/10.1007/BF01411116>.
- [14] Carvi Y, Nievas MN, Haas E, Höllerhage HG. Unruptured large intracranial aneurysms in patients with transient cerebral ischemic episodes. *Neurosurg Rev* 2003;26:215–20.
- [15] Borkon MJ, Hoang H, Rockman C, Mussa F, Cayne NS, et al. Coexistent unruptured intracranial aneurysms and carotid artery stenosis: an institutional review of patients undergoing carotid revascularization. *Ann Vasc Surg* 2014;28:102–7. <http://dx.doi.org/10.1016/j.avsg.2013.06.013>.
- [16] Park JC, Kwon BJ, Kang HS, Kim JE, Cho YD, Han MH, et al. Single-stage extracranial carotid artery stenting and intracranial aneurysm coiling: technical feasibility and clinical outcome. *Interv Neuroradiol* 2013;19:228–34.
- [17] Badruddin A, Teleb MS, Abraham MG, Taqi MA, Zaidat OO. Safety and feasibility of simultaneous ipsilateral proximal carotid artery stenting and cerebral aneurysm coiling. *Front Neurol* 2010;1:120. <http://dx.doi.org/10.3389/fneur.2010.00120>.
- [18] Gallego León JI, Concepción Aramendía L, Ballenilla Marco F, Vázquez Suárez JC. Coexistent endovascular treatment of coexistent extracranial carotid stenosis and intracranial aneurysm. Our experience. *Interv Neuroradiol.* 2009;15: 53–59.
- [19] Kaçar E, ÖF Nas, Erdoğan C, Hakyemez B. Single-stage endovascular treatment in patients with severe extracranial large vessel stenosis and coexistent ipsilateral unruptured intracranial aneurysm. *Diagn Interv Radiol* 2015;21(6):476–82. doi:10.5152/dir.2015.15092.
- [20] Zhu G-Y, Wei Y, Su Y-L, Yuan Q, Yang C-F. Impacts of internal carotid artery revascularization on flow in anterior communicating artery aneurysm: a preliminary multiscale numerical investigation. *Appl Sci* 2019;9:4143.
- [21] Shakur SF, Amin-Hanjani S, Bednarski C, Du X, Aletich VA, Charbel FT, et al. Intracranial blood flow changes after extracranial carotid artery stenting. *Neurosurgery* 2015;76:330–6.
- [22] Shakur SF, Hrbac T, Alaraj A, Du X, Aletich VA, Charbel FT, et al. Effects of extracranial carotid stenosis on intracranial blood flow. *Stroke* 2014;45:3427–9.
- [23] Tallarita T, Sorenson TJ, Rinaldo L, Oderich GS, Bower TC, Meyer FB, et al. Management of carotid artery stenosis in patients with coexistent unruptured intracranial aneurysms. *J. Neurosurg.* 2019;18:1–4.
- [24] Campos JK, Lin L, Beaty NB, Bender MT, Jiang B, Zarrin DA, et al. Tandem cervical carotid stenting for stenosis with flow diversion embolisation for the treatment of intracranial aneurysms. *Stroke Vasc Neurol* 2019;4. doi:10.1136/svn-2018-000187.
- [25] North American Symptomatic Carotid Endarterectomy Trial Collaborators. Beneficial effect of carotid endarterectomy in symptomatic patients with high-grade carotid stenosis. *N Engl J Med* 1991;325:445–53. <http://dx.doi.org/10.1056/NEJM199108153250701>.
- [26] Serena J, Irimia P, Calleja S, Blanco M, Vivancos J, Ayo-Martín Ó, et al. Cuantificación ultrasonográfica de la estenosis carotídea: recomendaciones de la Sociedad Española de Neurosonología. *Neurología* 2013;28:435–42.
- [27] Chiti G, Pantoni L. Use of Montreal Cognitive Assessment in patients with stroke. *Stroke* 2014;45:3135–40. doi:10.1161/STROKEAHA.114.004590.
- [28] Szabo S, Abramowitz B, Vaitkus P. New technique for aorto-ostial stent placement. *Am J Cardiol* 2005;96:212H.
- [29] Kern MJ, Ouellette D, Frianeza T. A new technique to anchor stents for exact placement in ostial stenoses: the stent tail wire or Szabo technique. *Catheter Cardiovasc Interv* 2006;68:901–6.
- [30] Arthur AS, Molyneux A, Coon AL for the WEB-IT Study investigators. The safety and effectiveness of the Woven EndoBridge (WEB) system for the treatment of wide-necked bifurcation aneurysms: final 12-month results of the pivotal WEB Intra-saccular Therapy (WEB-IT) Study. *J Neurointerv Surg* 2019;11:924–30. doi:10.1136/neurintsurg-2019-014815.
- [31] Stabile E, Donato G, Musialek P, Loose KD, Nerla R, Sirignano P, 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. Eugenio Stabile, Gianmarco de Donato, Piotr Musialek, Koen De Loose, Roberto Nerla, Pasqualino Sirignano, Salvatore Chianese. *JACC Cardiovasc Interv* 2018;11(23):2405–11. doi:10.1016/j.jcin.2018.06.047.
- [32] Broussalis E, Kunz AB, Luthringshausen G, Klein S, McCoy R, Trinka E, et al. Treatment of vertebral artery origin stenosis with a Pharos stent device: a single center experience. *Interv Neuroradiol* 2011;17:316–22.
- [33] Kim SR, Baik MW, Yoo SH, Park IS, Kim SD, Kim MC, et al. Stent fracture and restenosis after placement of a drug-eluting device in the vertebral artery origin and treatment with the stent-in-stent technique. Report of two cases. *J Neurosurg* 2007;106:907–11.
- [34] Tsutsumi M, Kazekawa K, Onizuka M, Kodama T, Matsubara S, Aikawa H, et al. Stent fracture in revascularization for symptomatic ostial vertebral artery stenosis. *Neuroradiology* 2007;49:253–7.
- [35] Teraa M, Moll FL, van der Worp BH, Lo RT, de Borst JJ, et al. Symptomatic vertebral artery stent fracture: a case report. *J Vasc Interv Radiol* 2010;21:1751–4.
- [36] Lu J, Liu J, Wang D, Wang S, et al. Stent fracture and occlusion after treatment of symptomatic vertebral artery ostium stenosis with a self-expanding device. *Intervent Neuroradiol* 2014 Published Online First: 1 January 2014. doi:10.15274/INR-2014-10068.
- [37] Tang F, Wang Q, Hu C, Li P, Li L, et al. Use of the Szabo technique to guide accurate stent placement at the vertebral artery ostium. *J Endovasc Ther* 2013;20(4):554–60. doi:10.1583/13-4298.1.