INTRAVASCULAR ULTRASOUND-GUIDED INTERNAL CAROTID ARTERY STENTING

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Objective. The study was aimed at demonstrating efficacy and feasibility of intravascular ultrasound during internal carotid artery stenting for assessment of atheromatous plaque protrusion through a stent.

Patients and methods. Over the period from October to December 2018, the specialists of our Centre performed a total of 90 internal carotid artery stenting procedures in 83 patients (of these, 7 patients underwent bilateral staged stenting of both internal carotid arteries) using intravascular ultrasound in order to assess intraoperative protrusion of an atherosclerotic plaque through the implanted stent. The patients' age varied from 42 to 87 (mean 68.6±6.9) years. Symptomatic lesions of internal carotid arteries were revealed in 14 (16.9%) operated patients and asymptomatic lesions in 69 (83.1%). The degree of stenosis varied from 60% to 90% according to the findings of preliminary duplex ultrasonography and was subsequently confirmed by the results of multislice computed tomography or selective angiography.

The assessment of the patients' neurological status, as well as duplex ultrasonography of brachiocephalic arteries were performed at a scheduled follow-up visit on day 30 after discharge from hospital.

Results. The technical success of stenting was achieved in 100% of patients. According to the findings of intravascular ultrasound, plaque protrusion was observed in eight (8.8%) stented patients. Among them, six (6.6%) were free from angiographic signs of protrusion and only two (2.2%) had apparent angiographic signs of protrusion. During the early postoperative period, transient ischaemic attack was identified in four (4.4%) cases. One (1.1%) patient was found to develop ST-segment elevation acute myocardial infarction 24 hours after internal carotid artery stenting, followed by large hemispheric stroke on the side of stenting revealed on postoperative day 3. Nine (10%) patients according to the findings of intravascular ultrasound were diagnosed as having incomplete stent apposition after postdilatation, with the absence of such signs on angiography.

Conclusion. Intravascular ultrasound during carotid stenting provides a more accurate assessment of such an event as atherosclerotic plaque protrusion through a stent's cells. At the same time, IVUS-guided assessment of the intraoperative outcome may prevent the risk for the development of stroke in the early postoperative period. Besides, intravascular ultrasound allows a more detailed assessment of stent apposition and the degree of stent expansion in order to optimize and improve the remote results of the operation.

Key words: *carotid artery stenting, intravascular ultrasound, plaque protrusion.*

INTRODUCTION

Ischaemic stroke is a major complication during stenting of internal carotid arteries (ICAs), that can occur both intra– and postoperatively [1–5]. Prolapse of an atherosclerotic plaque (ATP) through the cell stent has been suggested as one of the main risk factors for the development of ischaemic stroke following carotid artery stenting (CAS), therefore the problem of additional methods of imaging is extremely important in this field of endovascular surgery [6–27]. Intravascular ultrasound (IVUS) provides high-resolution vessel imaging and makes it possible to obtain exhaustive information both at the stage of planning of the operation (initial arterial diameter, extension, degree of severity, as well as morphology of an atherosclerotic plaque) and at the stage of assessing the technical result of the operation (implanted stent apposition, presence of protrusions of the atheromatous component through the stent, and edge intimal dissections) [8–28].

Thus, advantages of using IVUS in diagnosis of protrusions were demonstrated in the article by Shinozaki N., Ogata N., Ikari Y. published in 2014 [27] and reporting the results of analysing a prospective register including a total of 77 patients subjected to ICA stenting. Of these, 68 patients underwent intraoperative IVUS (immediately after deployment of a device of cerebral protection from distal embolism and then again after the stage of stenting and confirmation

of optimal angiographic results). Six plaque protrusions (7.8%) through the stent struts were detected by IVUS but only 2 (2.6%) by angiography. Only one statistically significant independent predictor of plaque protrusion was preprocedural severe stenosis with flow delay. Once plaque protrusion was detected, the authors adhered to the following therapeutic policy: balloon technique as the first-line therapy in all six patients Additional postdilations (n=6) and stent-in-stent implantations (n=4) were performed to correct the plaque protrusions. Mention should be made that no late stroke was observed at 30 days after the procedure [9].

It is important that this study reporting the results of using IVUS showed higher frequency of detecting plaque protrusion than the results of an analogous study wherein plaque protrusion was diagnosed only in 4% of cases according to the results of angiography (M. Tsutsumi, H. Aikawa, M. Onizuka, M., et al., 2008) [10].

The use of IVUS also makes it possible to improve the technical results of stenting [8–26]. In their study, Clark D.J., et al. by an example of ICA stenting with intraoperative IVUS in 97 patients (107 arteries) reported that IVUS detected stent malapposition in 11%, which required additional postdilatation in order to achieve complete stent apposition. They also demonstrated that calcium ICA lesions associated with high risk of postoperative complications were detected in more arteries with IVUS than angiography (61 vs. 46%, P<0.05) [11].

Bandyk D.F., et al. in a retrospective review of their carotid stent registry (n=306) identified 220 CAS procedures performed with either a digital C-arm fluoroscopy alone (n=110) or in conjunction with IVUS (n=110). IVUS usage resulted in lower (P<0.05) contrast agent volumes. IVUS imaging resulted in the use of larger diameter balloons (typically 6 mm) and identified more residual stent abnormalities (plaque protrusion) (P<0.01) [12].

The purpose of our study was to improve the results of treatment in patients with haemodynamically significant atherosclerotic ICA lesions by means of intravascular ultrasound-guided endovascular angioplasty and stenting.

PATIENTS AND METHODS

Over the period from October to December 2018, the specialists of the Medical and Rehabilitation Centre performed a total of 90 ICA stenting procedures in 83 patients (among them, 7 patients underwent bilateral CAS in a staged fashion) using IVUS in order to assess intraoperative protrusion of an atherosclerotic plaque through the implanted stent. Seventy-two (80%) patients underwent IVUS prior to stent implantation for plaque characterization, determining the degree of atherosclerotic lesions and performing virtual histology (iMap). IVUS after stent implantation and postdilatation was performed in all 90 (100%) cases in order to verify atheromatous component protrusion and stent apposition. All interventions were carried out under local anaesthesia. All 83 (100%) patients received dual antiplatelet therapy.

The patients' age varied from 42 to 87 (mean 68.6±6.9) years. There were 59 (71.1%) men and 24 (28.9%) women. All 83 (100%) patients suffered from hypertension, 53 (63.8%) had ischaemic heart disease, and 29 (34.9%) had diabetes mellitus. Symptomatic ICA lesions were revealed in 14 (16.9%) operated patients, asymptomatic – in 69 (83.1%). Lesions of the right ICA were detected in 26 (31.3%), of the left ICA – in 50 (60.3%), and bilateral lesions – in 7 (8.4%) patients. The stenosis degree ranged from 60% to 99% according to the findings of preliminary examinations (Doppler ultrasonography), which was later on confirmed by the results of multislice computed tomography or direct angiography. All patients before and after stenting underwent assessment of the neurological status using the NIHSS (National Institutes of Health Stroke Scale) and mRS (modified Rankin Scale).

The femoral approach was used in 87 (96.7%) cases, the right radial access in 2 (2.2%) cases, and the right brachial approach – in 1 (1.1%) case. Distal cerebral embolic protection was used in 69 (76.6%) patients by means of the following devices: FilterWire EZ™ (Boston Scientific, USA), SpiderFX Embolic Protection Device (Medtronic, USA), Emboshield NAV6 Embolic Protection System (Abbott Vascular, USA), Cordis ANGIOGUARD® RX Guidewire System (USA), whereas proximal protection was used in 21 (23.4%) patients by means of the Mo.Ma Ultra (Medtronic, (USA). Twenty-nine (32.2%) patients required predilatation of the lesion, with stent postdilatation performed in 90 (100%) cases. The dual layer MicroNet mesh stent (CGuard™ InspireMD, Israel) was implanted in 42 (46.7%) cases, whereas such previous-generation stents as the Protégé™ RX carotid stent system (Medtronic, USA), Cordis PRECISE PRO RX® Carotid Stent System (USA), Carotid WALLSTENT (Boston Scientific, USA) were implanted in the remaining 48 (53.3%) cases. All IVUS procedures were performed using the OPTICROSS™ catheter (Boston Scientific, USA). Within the time frame of the study, the following parameters were assessed:

- prior to stenting: degree and pattern of stenosis, extension of the lesion; virtual histology of atherosclerotic plaque (iMap), true arterial diameter;
- after stenting and postdilatation: protrusion of the atheromatous component through stent cells, stent apposition degree, and the presence of intimal edge dissection.

All patients for 24 postoperative hours were monitored in the intensive care unit, to be then transferred to the general ward. Assessment of the operated patients' neurological status, as well as Doppler ultrasonography of brachiocephalic arteries were performed at a scheduled follow-up visit on day 30 after discharge from hospital.

RESULTS

The technical success was achieved in 100% of patients, with no lethal outcomes observed.

The IVUS findings demonstrated plaque protrusion in eight (8.8%) stented patients (all protrusions in the stents without double-layer mesh design). Of these, six (6.6%) were free from angiographic signs of protrusion and only two (2.2%) had clear-cut angiographic evidence of protrusion. All these patients underwent repeat stent dilatation using a balloon catheter, in five (5.5%) of them after repeat dilatation with a balloon catheter of the same diameter, no protrusion was revealed by IVUS, and the remaining three (3.3%) patients required dilatation with a balloon catheter of a larger diameter (0.5–1.0 mm more than the initial one). The stent-in-stent technique was not used because of complete disappearance of protrusion signs after repeat balloon dilatation of the stent (Fig. 1, 2).

One (1.1%) of these patients after repeat dilatation with a balloon catheter of a larger diameter was found to have total arrest of blood flow through the entire ICA due to massive embolism into the cerebral distal protection system, removal of which resulted in normal blood flow through the ICA (Fig. 3). However, this patient demonstrated intraoperative focal neurological symptomatology, completely regressing within 24 hours. The findings of magnetic resonance imaging (MRI) of the brain, carried out 48 hours postoperatively revealed no signs of acute impairment of cerebral circulation (AICC) in this patient, with the condition regarded as transient ischaemic attack (TIA).

Fig. 1. IVUS-guided stenting of the right ICA: a – baseline selective angiogram of the right carotid basin with haemodynamically significant stenosis (indicated by the arrow) of the right proximal portion of the ICA; b – angiogram after stent implantation and balloon postdilatation in the ICA stenosis zone

Although no in-depth analysis of the morphology of atherosclerotic plaques was envisaged in this article was, it is important to mention that according to the findings of intravascular virtual histology (iMap) obtained in every procedure of IVUS, the main component (approximately 50% of the total mass of the plaque) was a fibrous one with inclusions of necrotic (about 20%), lipid (about 10%), and calcified (about 10%) components (Fig. 4).

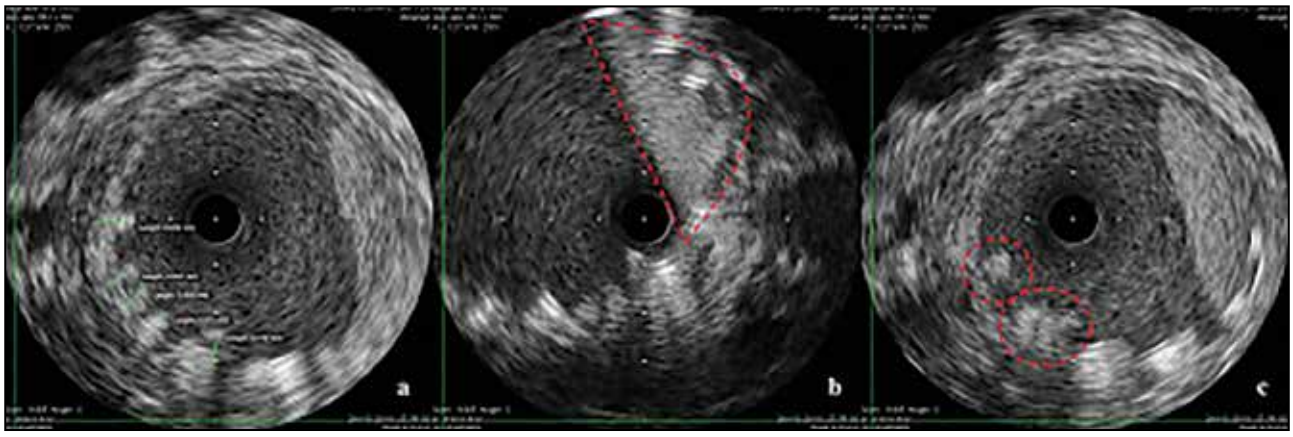

Fig. 2. Example of IVUS with atheromatous plaque protrusion through the stent's cells: a – shown are the protrusion dimensions by the IVUS data, measuring from 0.6 to 0.8 mm in length; b – the dashed line indicates the zone of the contrast agent collecting in the ICA's lumen (due to the "no-flow" effect) resulting from accumulation of atherosclerotic plaque fragments in the filter (see Figures 3 and 4); c – the dashed lines encircle large protrusions of atheromatous masses through the implanted stent's cells

Fig. 3. A series of angiograms: a – ICA stenosis (encircled by the dashed line) prior to stenting; b – arrow indicates the location of the protective filter basket, evident is the absence of opacification distally to the filter – the "no-flow" effect); c – final angiogram of the ICA after stenting, with the blood flow restored (description in the text)

Depending on the increase of the fraction of each morphological component, the plaque's behaviour during stenting changed either upward or downward. Thus, the main predictor of malapposition of the stent after implantation was an increase in the calcified component by more than 20% of the total mass, which, in turn, might immediately suggest an idea to use a larger-diameter balloon catheter during postdilatation for better stent expansion. An increase in the necrotic and lipid components in the total mass of the plaque is a predictor of instability and possible protrusion during stenting. It is feasible to implant double-layer design stents into such stenoses for minimization of embolic complications.

During the early postoperative period, there were 4 (4.4%) cases of TIA, completely resolving within 24 hours. According to the findings of cerebral MRI performed at 48–72 hours postoperatively these patients were free from signs of AICC, with no evidence of plaque protrusion through the stent observed in 3 of these patients.

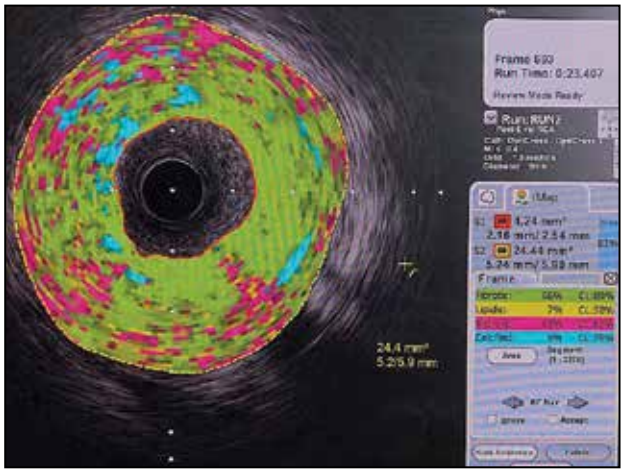

Fig. 4. Intravascular ultrasound-derived virtual histology of an atherosclerotic plaque. The degree of stenosis amounts to 83%. Seen is predominance of the fibrous (68% with reliability of 80%) and necrotic (19% with reliability of 61%) components, with the lipid and calcified inclusions amounting to 7% and 5%, respectively

Twenty-eight (31.1%) patients were found to have the presence of the atheromatous component in the basket of the filter of distal protection after its retrieval (Fig. 5). All 28 patients received stents without double-layer mesh design. And, vice versa, all 42 patients undergoing implantation of dual layer design stents (CGuard) appeared to have no atheromatous contents in the filter basket after its retrieval.

One (1.1%) patient was found to develop ST-segment elevation acute myocardial infarction (STEAMI) 24 hours after ICA stenting with acute circulatory arrest, followed by appropriate resuscitation measures taken. This patient underwent emergency stenting of the anterior interventricular artery (AIVA). However, on the background of dual antiplatelet therapy, 48 hours thereafter there occurred thrombosis of the implanted AIVA stent, managed by repeat percutaneous coronary intervention and balloon angioplasty. 12 hours after repeat intervention on the AIVA, this patient was found to have acute neurological symptomatology with the development of large hemispheric AICC, as identified by the findings of brain MRI on the ipsilateral side of the previously stented ICA. Doppler ultrasound revealed no evidence of ICA stent thrombosis in this patient.

Nine (10%) patients during IVUS were found to have incomplete stent apposition after postdilatation, without apparent angiographic signs thereof. Notably, in these patients according to the findings of virtual histology (iMap) calcium was always a prevailing component of an atherosclerotic plaque. All patients underwent repeat stent dilatation using a larger-diameter balloon catheter, with a satisfactory result according to the findings of repeat IVUS.

The findings of IVUS revealed no signs of intimal edge dissection.

On day 30 after discharge from hospital we performed control examination and Doppler ultrasonography of brachiocephalic arteries in 79 (95.1%) operated patients. According to the findings of Doppler ultrasound, all stents were patent, with no evidence of significant restenosis. No 30-day strokes were observed in this patient cohort.

Four (4.4%) operated patients failed to visit our clinic after 30 days for health-unrelated reasons. Therefore, they were reached by phone, with all four self-assessing their health status as satisfactory.

CONCLUSION

The use of IVUS during ICA stenting undoubtedly provides more extensive determination of the event of atherosclerotic plaque protrusion through stent's cells during surgery, which far from always can be seen angiographically, and more importantly, makes it possible to correct this dangerous situation, preventing thereby the risk for the development of stroke in the early postoperative period. Besides, it gives a possibility of a more detailed assessment of stent apposition and the degree of stent expansion, which certainly plays an important role in the immediate outcome of the performed intervention and its remote results, increasing safety and efficacy of carotid stenting.

Further application of intravascular imaging techniques, as well as the use of dual layer design stents during ICA stenting will, in our opinion, make this method of prevention of ischaemic stroke even more efficient and safer.

Conflict of interest: none declared.

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Fig. 5. Filter with atheromatous content

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