Utility of intravascular ultrasound in intracranial and extracranial neurointerventions: experience at University at Buffalo Neurosurgery–Millard Fillmore Gates Circle Hospital

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Intravascular ultrasound (IVUS) generates high-resolution cross-sectional images and sagittal reconstructions of the vessel wall and lumen. As a result, this imaging modality can provide accurate measurements of the degree of vessel stenosis, allow the detection of intraluminal thrombus, and analyze the plaque composition. The IVUS modality is widely used in interventional cardiology, and its use in neurointerventions has gradually increased. With case examples, the authors illustrate the utility of IVUS as an adjunct to conventional angiography for a wide range of intracranial and extracranial neurointerventions.

(Key Words • intravascular ultrasound • neurointervention • virtual histology)

Intravascular ultrasound is widely used in interventional cardiology. It is routinely used to assess proper stent apposition after coronary stent placement and to determine the most appropriate treatment for indeterminate lesions on the basis of conventional coronary angiography.2 Recently, IVUS assessment of coronary atherosclerotic plaque progression was used as a surrogate primary end point in large statin trials.10 Few reports have been published regarding the use of IVUS in neuroendovascular interventions. In this review, we discuss IVUS technology and our clinical experience with this modality over a wide range of extra- and intracranial neurointerventions, and we also present illustrative cases.

The IVUS Modality for Neurointerventions: Equipment, Technique, and Background

At Millard Fillmore Gates Circle Hospital, we use the 3.5 F 20-MHz Eagle Eye IVUS probe (Volcano Therapeutics) as an adjunct to conventional angiography for select neurointerventions. This cylindrical transducer sends ultrasound signals into the adjacent tissue and detects the reflected echoes. The reflected signals allow the generation of a cross-sectional image of the vessel wall and lumen at high resolution as a conventional gray-scale intravascular sonogram. Due to differences in reflected signals from different tissues, conventional gray-scale IVUS can distinguish normal vessel lumen and vessel wall from atherosclerotic plaque, intraluminal thrombus, and intimal dissection with high sensitivity.1 Within the atherosclerotic plaque, it can further identify the deposition of lipid (hypoechoic signal) and calcium (hyperechoic signal with distal shadowing). The probe is mounted near the tip of a monorail catheter that tracks over a 0.014-in guidewire (Fig. 1). All IVUS images are displayed and recorded using an IVUS workstation (Invision Imaging System, Volcano Therapeutics). Once the radiopaque probe is placed distal to the lesion of interest under direct fluoroscopic guidance, intravascular sonograms are generated by a continuous slow withdrawal of the catheter at approximately 1 mm per second. These live cross-sectional images are simultaneously converted into a continuous sagittal reconstruction of the vessel un-
The use of IVUS as an adjunct to CA interventions was first reported by Wilson et al.\(^4\) In that report, IVUS was used to evaluate the results of CAS quantitatively by measuring real-time luminal diameter. Several subsequent reports have supported the diagnostic utility of IVUS in CA disease. Tresukosol et al.\(^4\) reported on a patient who was found to have a 50% stenosis of the left CCA on conventional angiography, whereas IVUS subsequently revealed a 90% stenosis with complex superficial calcification. This patient subsequently underwent left CAS as a result. In an early CA study, Miskolezi et al.\(^4\) reported that IVUS may have a higher sensitivity than conventional angiography for detecting intimal thickening, concentric plaques, plaque surface ulceration, and calcifications. A recent case from our institution in which IVUS determined the degree of a stenosis on an ICA lesion that was indeterminate on conventional angiography is illustrated in Fig. 2.

Increasing experience with IVUS during CA intervention led to its use as a tool for evaluation of plaque morphology and intramural lesions in addition to luminal diameters, often resulting in a change in the endovascular strategy and potentially reducing the risk of embolic strokes associated with CAS. In another case from our institution, IVUS accurately identified intraluminal thrombus after CA angioplasty (Fig. 3). The identification of intraluminal lesions allowed the alteration of the treatment strategy and guided the placement of an additional stent to trap the extruded thrombus prior to the removal of distal embolic protection. In fact, we have found the greatest utility with IVUS in assessing the extrusion of constrained plaque debris through the tines of the stent following CAS. Conventional angiography often will not allow detailed visualization of the small “cheese grated” material, which may flow downstream and cause an embolic stroke postprocedural. The IVUS modality reliably detects these excrescences, allowing for remedial measures prior to the removal of distal embolic filters. Perhaps this is of even greater value during procedures in which proximal occlusion with flow arrest or flow reversal during CAS is used. In these cases, the whole procedure is completed while avoiding anterograde angiography, which may push embolic debris intracranially. Use of IVUS allows assessment of the stent without a need for the injection of contrast material, such that flow reversal can be maintained until stent patency is confirmed by IVUS, and angiography is performed only after the flow reversal is withdrawn.

The IVUS modality can also optimize and direct the intervention by identifying residual stenosis, suboptimal plaque coverage, dissection, and poor wall apposition. In a series of 107 CAS procedures, Clark et al.\(^4\) reported that after a satisfactory result was determined by angiography,
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subsequent IVUS findings resulted in additional treatment in 9% of patients: 4 patients required poststent angioplasty, 3 required additional stents to achieve complete plaque coverage, and 3 were found to have malapposition of the stent.

Finally, IVUS can be very useful for the special circumstance of CCA origin stent insertion. Accurate stent placement at the CCA origin from the aortic arch is very challenging due to poor visualization of the CCA origin on conventional catheter-based angiography. With color-flow IVUS, the probe can detect an abrupt change in the size of the color flow once the transducer is moved from the stenosis into the aorta, enabling precise identification of the CCA origin and accurate stent placement.

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The utility of IVUS can extend to intracranial le-

Fig. 2. Case 1. This 78-year-old man with a history of right carotid endarterectomy and bilateral CAS with subsequent angioplasties for in-stent stenosis underwent routine transcranial Doppler studies that revealed right ICA velocities in the range of 500 cm/second. The patient subsequently underwent diagnostic angiography, and the result was equivocal (left, CCA injection, lateral cervical view). In-stent stenosis could not be excluded, and the apparent jet flow (arrow) suggested the presence of a high-grade stenosis. An IVUS study was then performed during the same procedure and revealed no significant in-stent stenosis (right), despite the high Doppler velocities. The patient was discharged without intervention. Repeat Doppler studies obtained at a different laboratory revealed right ICA velocities in the range of 140 cm/second.

Fig. 3. Case 2. This 70-year-old woman with a history of left carotid endarterectomy and subsequent left CAS for symptomatic restenosis presented with a left hemispheric transient ischemic attack 8 months after stent placement. Doppler imaging studies demonstrated velocities of 700 cm/second within the stent, suggestive of high-grade in-stent stenosis. Conventional angiography (A, AP view, left CCA injection) revealed 75% in-stent stenosis, and the patient underwent balloon angioplasty with no difficulties. However, the final angiographic run (B, AP view, left CCA injection) revealed a subtle lucency starting just proximal to the stent tines (arrow). An IVUS study was then performed (C), and the findings were consistent with an intraluminal thrombus within the proximal stent at the 5:30 o’clock position (arrow). An additional stent was then placed proximal to the existing stent, with some overlap. The final angiographic run showed good revascularization with no abnormalities (D, AP view, left CCA injection).
sions. Most importantly, it is the only imaging modality that details both the arterial wall and plaque composition of the intracranial circulation. We reported the first 2 successful applications of IVUS in intracranial interventions. One patient underwent intracranial stent insertion to treat an occlusive dissection of the left ICA (from the petrous segment to the cavernous segment) that occurred during arteriovenous malformation embolization. The other patient underwent stent placement for high-grade restenosis of the basilar artery. In the first patient, IVUS accurately identified the entire length of the dissection and prevented suboptimal stent coverage, which could potentially lead to recurrence. In addition, the color-flow feature of the IVUS equipment allowed the assessment of proper stent apposition by confirming the cessation of flow in the pseudolumen. In the second patient, IVUS gave insight into the composition and morphological features of the restenosis. The identification of a fibrous lesion after previous angioplasty suggested that the lesion was safe for stent placement. Moreover, IVUS provided us with a confirmatory set of measurements that allowed us to better choose our devices. Since our initial report, there have been other papers supporting the use of IVUS for intracranial lesions. Meyers et al. reported the use of IVUS to characterize both the degree of stenosis and plaque composition in a petrous ICA atherosclerotic lesion. The patient subsequently underwent successful stent placement.

Use of IVUS in Venous Interventions

Compared with arterial neurointerventions, the clinical application of IVUS in the management of cerebral venous circulation disease is less well established. In the venous system, IVUS offers similar advantages of high-resolution cross-sectional images and accurate measurements of the degree of stenosis, detection of intraluminal thrombus, and venous wall thickness. However, compared with the arterial circulation, the venous system consists predominantly of vessels with a large diameter and less resistance, thus enabling navigation through a significant portion of the intracranial venous vasculature, including the transverse, sigmoid, and superior sagittal sinuses.

At Millard Fillmore Gates Circle Hospital, IVUS is routinely used in conjunction with angiography to evaluate diseases of cerebral venous outflow obstruction, including dural sinus thrombosis and pseudotumor cerebri. In both cases, IVUS can provide critical confirmatory information, such as the presence of intraluminal thrombus in dural sinus thrombosis and the accurate assessment of the degree of stenosis and its response to angioplasty or stent insertion in the transverse sinus in patients with pseudotumor cerebri. For patients with pseudotumor cerebri who undergo angioplasty or stent insertion in the transverse sinus, follow-up information regarding the location, degree, and morphological features of the restenosis or any in-stent stenosis can also be readily identified by IVUS. In Fig. 4, a case from our institution is illustrated in which IVUS confirmed the persistent right-sided transverse sinus stenosis following balloon angioplasty, which led us to perform the subsequent stent placement procedure.

Apart from cerebral venous occlusive disease, successful application of IVUS has also been reported in other venous interventions. Shindo et al. reported the use of IVUS-assisted transvenous embolization of a dural arteriovenous fistula. In that case, IVUS was used to map the exact fistulous sites formed to guide the transvenous embolization.

Future IVUS Applications in Neurointerventions

The main restriction of IVUS for neurointerventional applications at present is its use in the intracranial circulation. This is related to limited navigability because of the tortuosity and small luminal diameter of the distal intracranial circulation as well as the limited flexibility and relatively large diameter of the IVUS catheter. With smaller and softer catheters to improve navigability, the use of IVUS could extend beyond the conditions discussed in this review. For example, in acute ischemic stroke, IVUS can delineate the composition of the culprit lesion (calcific vs soft), which in turn would help to guide the intervention (angioplasty or stent insertion for calcific/atherosclerotic lesion and thrombolysis, thrombectomy, and thrombectomy.

Fig. 4. Case 3. This 27-year-old woman with a history of benign intracranial hypertension presented with worsening headache and blurry vision. Despite long-term medical treatment with acetazolamide and topiramate, as well as serial lumbar punctures, her headache continued to worsen, and neurological examination revealed severe papilledema. Computed tomography venography showed bilateral transverse sinus stenosis, and the patient underwent angiography for further evaluation of the degree of stenosis and possible stent placement. Diagnostic angiography confirmed severe transverse sinus stenosis bilaterally. The patient underwent multiple balloon angioplasty attempts in the right and left transverse sinuses, without any significant improvement on the right. A postangioplasty IVUS recording confirmed persistent severe stenosis of the transverse sinus on the right (see arrow in cross-sectional IVUS image). The patient subsequently underwent successful stent treatment of the right transverse and sigmoid sinuses. Postoperatively, her headaches and vision improved significantly.
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or clot retrieval for soft embolus). With respect to aneurysms, IVUS could be used to define the neck better and to understand aneurysm wall composition and intraaneurysmal contents, such as thrombus.15

Conclusions

The IVUS modality is a valuable adjunct to conventional angiography in the treatment of extra- and intracranial arterial and venous diseases. Through technical advances in different IVUS modalities and availability of smaller and softer catheters, its use could extend to diseases that involve more distal arterial and venous vascularatures. Continued application of this underutilized diagnostic tool is important to accumulate a larger experience of IVUS in the clinical setting of neurointervention.

Disclosure

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References