Analysis of Closed-Cell Intracranial Stent Characteristics Using Cone-Beam Computed Tomography With Contrast Material

Wataro TSURUTA,1 Yuji MATSUMARU,1 Yusuke HAMADA,2 Mikito HAYAKAWA,1 and Yuki KAMIYA1

Departments of 1Endovascular Neurosurgery and 2Radiology, Toranomon Hospital, Tokyo

Abstract

The intracranial nitinol stent named the Enterprise Vascular Reconstruction Device has poor radiographic visibility. The characteristics of closed-cell intracranial stents were investigated and the efficacy of intraoperative stent visualization examined with the 80 kV high-resolution XperCT protocol, which is a flat detector C-arm volume acquisition functionality system integrated with the angiography equipment. We treated 39 aneurysms with stent-assisted coil embolization. The aneurysms were located on the internal carotid artery in 24 cases, the anterior communicating artery (AcomA) in three, the basilar artery (BA) in 10, and the vertebral artery in two. Intraoperative 80 kV XperCT was performed in all cases after deposition of the stent. We evaluated the coverage of the aneurysm neck, incomplete stent apposition (ISA), and shift of vessels. Accurate stent visualization was achieved in 29 of the 39 cases without coil and delivery wire artifact. Coverage of the aneurysm neck succeeded in 28 cases; there was one case of BA top Y-configuration stenting in which the stent was dislocated into the aneurysm. ISA was detected in nine cases, including seven kinks and one flattening in the carotid siphon and one kink in the BA top. We detected linearization of vessels due to stent deployment in three AcomA cases and three BA top cases. We conclude that intraoperative 80 kV XperCT is an efficient modality for the evaluation of ISA. Stent kinking in the carotid siphon and linearization in distal vessels can be detected with this protocol.

Key words: intracranial stent, stent visualization, cone-beam computed tomography, coil embolization

Introduction

The endovascular treatment of cerebral aneurysms has been advanced by the development of intracranial stents. Intracranial stents are divided into two groups by cell type: open-cell and closed-cell. NeuroForm 1, 2, and 3 stents (Boston Scientific, Natick, Massachusetts, USA) and Wingspan stents (Boston Scientific) are open-cell designs with good conformability, even if the parent artery is bent. Closed-cell stents, which allow for resheathing following partial deployment, include the Enterprise (Codman Neurovascular, Raynham, Massachusetts, USA) and the LEO (Balt Extrusion, Montmorency, France). The Enterprise Vascular Reconstruction Device (Enterprise VRD) is the only approved intracranial stent in Japan as of September 2012. The evaluation of stent expansion and conformability to the vessel wall is important to prevent peri- and post-procedural complications. Incomplete coverage of the aneurysm neck results in the risk of coil protrusion. Stent kinking and incomplete expansion might create a risk of thromboembolic events. However, the condition of the Enterprise VRD stent is difficult to evaluate with multidetector-row computed tomography, magnetic resonance angiography, three-dimensional (3D) digital subtraction angiography, or 3D rotational angiography due to poor radiographic visibility. A new protocol for intracranial stent visualization has been investigated in our laboratory. The XperCT (Philips Medical Systems, Andover, Massachusetts, USA) is a flat
detector C-arm volume acquisition functionality system integrated with the angiography equipment. In this new protocol, intracranial stent visualization is achieved with the 80 kV high-resolution XperCT protocol, plus appropriate contrast material injection. With this protocol, the intraoperative evaluation of stent expansion and conformability to the vessel wall has become available.

The present study further explored the efficacy of 80 kV XperCT to establish the characteristics of closed-cell stents.

**Patients and Methods**

We treated 39 aneurysms in 37 patients (30 aneurysms in females, nine in males) with stent-assisted coil embolization at our institute. The Enterprise VRD stent was used in all cases. The aneurysms were located on the internal carotid artery (ICA) in 24 cases, the anterior communicating artery (AcomA) in three, the basilar artery (BA) in 10, and the vertebral artery in two.

The 80 kV high-resolution XperCT evaluation was performed just after stent deployment in each patient. The digital subtraction angiography system was an Allura Xper FD20/20 (Philips Healthcare, Andover, Massachusetts, USA) with a flat detector (30 × 40 cm). Stent images were acquired in a 20.6-second rotational scan over 240° at 30 frames/sec using a 22-cm field of view, which resulted in approx. 620 projection images. The protocol has an approximate effective dose of 0.51 mSv.

Contrast material (iopamidol 300 mg/ml; Nihon Schering, Osaka) was seven-times diluted with saline for a total of 25 ml, and injected at the rate of 1 ml/sec, resulting in an actual contrast load of 3.5 ml. Evaluations of the coverage of the aneurysm neck, incomplete stent apposition (ISA), and shift of vessels were performed by two experienced neurosurgeons and one neurologist (each with >10 years of experience). The relationships between ISA and thromboembolic events and between ISA and in-stent stenosis were also analyzed.

In 22 of the aneurysm cases, the patients underwent follow-up angiography at one year post-stent implantation.

**Results**

Stent-assisted embolization was achieved in all cases. Accurate stent visualization was achieved in 29 of the 39 aneurysms (Fig. 1), and visualization was considered inadequate in 10 cases due to coil artifact in three and stent delivery wire artifact in seven. Coverage of the aneurysm neck succeeded in 28 cases; the exception was a case of BA top Y-configuration stenting dislocated into the aneurysm (Fig. 2). ISA was detected in nine of the 29 well-visualized cases, including seven kinks and one flattening in the carotid siphon (Fig. 3) and one kink in the BA top. Linearization of vessels (A1-A2) due to stent deployment was detected in all three of the AcomA cases just after deployment (Fig. 4).

Follow-up angiography at one year after stent deployment was performed in 22 of the 39 cases; the stents were patent in all 22 cases. Linearization of vessels (BA-P1) that had not been seen during the procedure was detected in all three of the BA top aneurysms. Intimal hyperplasia was detected in one
Fig. 3  A: Right carotid angiograms demonstrating a large paraclinoid aneurysm. The stent follows the outer contour of the curve with a consequent crimp on the inner curve (inner-curve incomplete stent apposition).  B: Right carotid angiogram demonstrating a large paraclinoid aneurysm. The stent follows the contour of the inner vessel curve, with poor contact on the outer curve (outer-curve incomplete stent apposition). In contrast, the microcatheter follows the outer contour of the curve.

Fig. 4  Right carotid angiograms of a broad-necked anterior communicating artery aneurysm located in the right A1-A2 junction (upper left). Linearization of deployed vessels was detected just after coil embolization (upper right) and on follow-up angiogram (lower left: digital subtraction angiogram, lower right: XperCT). Linearization had progressed and changed the angle between the parent artery and the aneurysm, while changing the terminal type aneurysm into a lateral type. Improvement of the anatomic status of the aneurysm was documented on the follow-up angiogram.

symptomatic patient who had interrupted antiplatelet therapy and suffered transient ischemic attack 2 months later (Fig. 5). Dual antiplatelet therapy was resumed, and this intimal hyperplasia in the carotid siphon was stable on the one-year follow-up angiogram without transient ischemic attack. ISA was not detected in this case.

Discussion

Stent visualization was achieved by the 80 kV high-resolution XperCT protocol more clearly compared to the 3D rotational angiography and prior XperCT protocols (Fig. 6). Intraoperative stent evaluation is useful to prevent peri- and post-procedural complications. In the past, cone-beam computed tomography (CBCT) was considered inferior to multidetector-row computed tomography regarding spatial resolution, and CBCT was used only to check for hemorrhagic complications after the procedure. CBCT imaging was eventually improved significantly by the introduction of flat panel detectors. Stent visualization with CBCT has been investigated focusing on the spatial resolution and the contrast resolution, and CBCT has become a useful modality for stent visualization with the new 80 kV high-resolution XperCT protocol, which provides improved spatial resolution and appropriate contrast material injection.

Our preclinical investigation revealed that both the stent struts and vessel lumen were well visual-
ized in the cases in which contrast material diluted 30 times with saline was injected. The concentration of contrast material is diluted by 28 times (nearly 30) in the ICA when seven times-diluted contrast material is injected at the rate of 1 ml/sec from the guiding catheter, given that blood flow in the ICA is 4 ml/sec.\textsuperscript{14} We therefore used seven times-diluted contrast material for stent visualization in our clinical study.

CBCT with intravenous administration of contrast material for stent visualization provides noninvasive follow-up imaging without intra-arterial catheterization.\textsuperscript{2,18} In comparison, XperCT using intra-arterial administration requires a smaller amount of contrast material; approx. ten times the amount of contrast material is needed for CBCT with intravenous administration compared to intra-arterial administration. For intraoperative evaluations, keeping the amount of contrast material as low as possible is very important to prevent renal dysfunction.

ISA was detected in nine of the 29 well-visualized cases in our series (eight in the carotid siphon and at the BA top). Evaluation of the relationship between geometric features of the parent vessel at the stent deployment site and the prevalence of ISA detected a unique crescent flow pattern on 3 T magnetic resonance angiography, which was confirmed by flat panel computed tomography as indicating ISA.\textsuperscript{7} Further multivariate analysis revealed that the crescent flow pattern correlated with small vessel-curvature radius, large stent-subtended angle, and large parent vessel diameter.\textsuperscript{7} Two patterns of ISA of the Enterprise VRD were also reported in an in vitro stent deployment study.\textsuperscript{6} Using a microcatheter pull-back technique, the stents tended to follow the contour of the inner vessel curve, with poor contact on the outer curve (outer curve ISA). Use of a microwire push technique resulted in the stents following the outer contour of the curve during their deployment, with a consequent crimp on the inner curve (inner curve ISA).\textsuperscript{6}

In the present series, we identified seven cases of stent kinking in the carotid siphon as inner curve ISA and only one case of flattening as outer curve ISA. This might be because operators tend to push the microwire at the deployment, preventing the stent from slipping down to the proximal side in tortuous vessels. In a paraclinoid ICA case in our series, the aneurysm neck was partially located in the inner curve, though mainly located in lateral wall. XperCT after coil insertion detected partial stent coverage of the aneurysm neck due to inner incomplete stent apposition (arrowheads).

A kinked or flattened stent does not fit with the vessel wall but rather protrudes into the inner lumen. Therefore, ISA might prevent neointimal proliferation and be a factor in in-stent thrombosis. Some studies have investigated the relationship be-
tween thromboembolic complications and ISA. For example, ISA was associated with peri-procedural ipsilateral hyperintense lesions on diffusion-weighted imaging.⁸ In the present series, there were three cases of thromboembolic complication in the perioperative and follow-up periods; ISA was not detected by XperCT in any of these cases. As our case series was limited to patients with continuing dual antiplatelet therapy, it is not clear whether ISA is associated with thromboembolic complications.

We detected linearization of deployed vessels in all three of the AcomA aneurysms just after deployment and in all three of the BA top aneurysms on follow-up angiography. Distal markers of the stent in the BA top cases seemed to have dug into the vessel wall on the follow-up angiograms. Linearization of parent vessels changes the anatomical structure and causes vessel wall stress, and may also increase the risk of in-stent stenosis or small vessel laceration, although we have never encountered such sequelae.

The flow-diverting effect that promotes further occlusion of an incompletely coiled aneurysm was analyzed by comparing the follow-up angiographic outcomes of stented versus non-stented incompletely coiled aneurysms.⁹ Stent-assisted coiling may have caused progression of an occlusion due to the flow-diverting effect.⁹ Linearization of a deployed vessel changes the angle between the parent artery and the aneurysm, changing a terminal-type aneurysm into a lateral type. Coil compaction occurs most frequently in terminal aneurysms, and this might be a reflection of differences in the inflow pattern at the ostium.⁹ Therefore, the flow-diverting effect might be enhanced by linearization. In an AcomA case in our series where linearization was detected on follow-up angiography, improvement of anatomic status was also documented (Fig. 4).

We detected stent dislocation into the aneurysm in one of our BA top Y-configuration cases. The first stent seemed to be lifted up when the second stent was delivered and deployed through the cell of the first stent. Nine Y-configuration stenting cases included five patients (55.6%) in whom the hybrid technique (Neuroform, Enterprise VRD) and three patients (33.3%) in whom a non-hybrid (two Enterprise VRDs) technique was used.¹ Stent protrusion into the aneurysm occurred in one of the non-hybrid cases (11.1%).³ With regard to the prevention of stent slip, deployment of a second stent in another session might be effective.¹⁷ The other two Y-configuration cases in our series underwent a second intervention for stabilization of the first stent, and we were able to deploy the second stent at the appropriate position.

The closed-cell stents tend to be linearized and are also easily kinked by force.⁴ The factor causing kinking in the carotid siphon is the undeformable anatomical curve of the ICA fixed by the dura. In contrast, with stent deployment in distal vessels such as the anterior cerebral artery or posterior cerebral artery which are not fixed by the dura, the vessels are displaced gradually by the stent linearization.

We detected in-stent intimal hyperplasia in one symptomatic patient in whom antiplatelet therapy was interrupted. The intimal hyperplasia was observed in the carotid siphon without ISA. In previous reports, in-stent stenosis after the deployment of an intracranial stent occurred in about 5% of cases.⁵,¹⁰,¹² Conservative antiplatelet therapy might be effective, because many patients are asymptomatic and demonstrate partial or complete resolution at follow-up. In the clinical course of 219 aneurysms treated with the Enterprise VRD, 3% of cases demonstrated significant (≥ 50%) in-stent stenosis or occlusion.¹²,¹³ Delayed thrombotic events occurred in seven cases (3%), and all delayed events were concomitant to cessation of dual-antiplatelet therapy.¹²,¹³ The factors that contribute to the risk of in-stent stenosis are not established, and it is not clear whether ISA is associated with in-stent stenosis or how long dual antiplatelet therapy should be continued in the postoperative period. Further evaluations of in-stent thrombosis and stenosis with XperCT may help answer these questions.

In the present series, complete stent visualization failed in 10 cases (three cases due to coil artifact and seven due to artifact caused by the stent delivery wire). The problem of metal artifacts in the reconstruction due to coils and stent delivery wire remains unresolved.¹⁵,¹⁶ The stent delivery wire should be out of the field of view before conducting an XperCT study. The part of the stent adjacent to the coil mass might not be visualized after coil insertion due to the artifact caused by platinum coils. The efficacy of XperCT is limited to the evaluation of stent conditions such as kinking, flattening, and conformability to the vessel before coil insertion. Evaluation of in-stent stenosis or the presence of thrombus in the aneurysm neck is difficult on follow-up angiography, although it is possible in the stent lumen apart from the coil mass.

The present study found that intraoperative 80 kV XperCT is an efficient modality for the evaluation of intracranial stents, although the problem of metal artifacts in the reconstruction due to coil and stent delivery wire remains unresolved. ISA in the carotid siphon and linearization in distal vessels such as the anterior cerebral artery or posterior cerebral artery can be detected by 80 kV XperCT after the deployment of an intracranial closed-cell stent.
Conflicts of Interest Disclosure

The authors report no conflict of interest relevant to the research. All authors who are members of The Japan Neurosurgical Society have registered online Self-reported COI Disclosure Statement Forms.

References


Address reprint requests to: Dr. Wataro Tsuruta, Department of Neurosurgery, Institute of Clinical Medicine, Graduate School of Comprehensive Human Sciences, University of Tsukuba, 2-1-1 Amakubo, Tsukuba, Ibaraki 305-8576, Japan.

e-mail: wataro@cf6.so-net.ne.jp

Neurol Med Chir (Tokyo) 53, June, 2013