Journal of Clinical Neuroscience 21 (2014) 1019–1023

Contents lists available at ScienceDirect

Journal of Clinical Neuroscience

journal homepage: www.elsevier.com/locate/jocn

Operative Technique

Double waffle-cone technique using twin Solitaire detachable stents for treatment of an ultra-wide necked aneurysm

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ARTICLE INFO

Article history:
Received 13 August 2013
Accepted 31 August 2013

Keywords:
Bifurcation-type aneurysm
Middle cerebral artery aneurysm
Solitaire stent
Waffle-cone technique
Wide neck
Y-stent technique

ABSTRACT

Several stent-supported coiling techniques have been devised for treating wide-necked bifurcation aneurysms including the Y-stent and waffle-cone constructs. The Y-stent technique is not technically possible with obtusely oriented daughter vessels, and the waffle-cone method is inadequate for aneurysms with necks exceeding the stent's maximal expansion diameter. We describe here the novel use of the Solitaire electrolytically detachable slotted stent (Solitaire, ev3, Irvine, CA, USA) featuring large-sized cells to fashion a concentric "double waffle-cone" construct. This method enabled the doubling of the neck coverage to treat an ultra-wide necked middle cerebral aneurysm with obtusely oriented daughter branches. The technique relies on the intra-cell crossing of the first stent using the second stent delivery microcatheter and fine tuning the relative position with the aid of cross-sectional cone-beam computed tomographic angiography to achieve optimal coverage of the neck prior to detachment of the stents in position. A retrievable stent with large cells such as the Solitaire device is optimal for this application given the need for relative adjustment of the deployment before final stent release to avoid under- or over-penetration of the distal stent struts into the aneurysm dome. An additional advantage of this approach over the kissing-stent technique is the absence of intraluminal stent struts, which was confirmed here by down-the-barrel cross-sectional imaging. The double waffle-cone construct enabled the successful coiling of the aneurysm with no post-procedural ischemic events detected on diffusion-weighted MRI and with stable complete embolization and no residual filling or in-stent stenosis at 6 month follow-up.

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1. Introduction

Wide-necked bifurcation aneurysms remain challenging for endovascular embolization as unassisted coiling risks coil mass herniation into the parent or daughter vessels. Stent supported coiling approaches include single-stent placement from the parent to one of the daughter vessels and Y-stenting with a stent in each daughter vessel with a common proximal concentric lumen [1]. Horizontal trans-circulation stenting relies on the presence of a prominent anterior or posterior communicating artery but is not relevant to end-territory lesions such as the middle cerebral artery bifurcation [2]. In cases of wide-necked lesions with daughter vessels at an angle not permitting microcatheter selection, the waffle-cone technique has been used to great effect to support the entire coil mass using a single stent deployed distally within the proximal dome and proximally in the parent vessel [3]. Nonetheless, ultra wide-necked bifurcation aneurysms are not amenable to any of these techniques. The maximal expansion diameter of available intracranial stents is 5 mm, so aneurysms with necks wider than this do not allow proper waffle-cone construction. Aneurysms in which the daughter branches originate at opposing ends of the proximal dome also have limitations for the waffle-cone method. We present here the novel use of the Solitaire (Solitaire, ev3, Irvine, CA, USA) electrolytically detachable slotted stent featuring large-sized cells to fashion a concentric coaxial double waffle-cone construct, to treat a 69-year-old woman with an ultra-wide necked middle cerebral artery aneurysm with obtusely oriented daughter branches. This technique was chosen after preoperative bench-top testing suggested clear-cut advantages in terms of intra-cell crossing, positional fine-tuning, lack of strut interlocking, and ability for complete capture before final electrolytically controlled detachment.

2. Technical consideration

A 69-year-old woman presented to the hospital for evaluation of a near-syncopal event. Computed tomography angiography

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0967-5868/$ - see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.jocn.2013.08.029

revealed a large right middle cerebral artery bifurcation aneurysm along with severe bilateral vertebral artery origin stenosis. Cerebral angiography demonstrated an anteroinferiorly pointing saccular aneurysm at the bifurcation of the right middle cerebral artery measuring 8.2 mm deep by 7.4 mm wide, with a neck of 6.2 mm (Fig. 1). Surgical clipping was believed to carry a high risk because of concomitant vertebral artery stenosis and the patient's age. Endovascular embolization options were considered instead, including placing a stent from the inferior M2 segment to the M1 segment or using a kissing Y-stent construct to protect both M2 divisions. A single waffle-cone technique was unlikely to succeed given the width of the neck (Fig. 2A, "Waffle Cone"). We devised a novel double waffle-cone technique enabling protection of the origins of both M2 branches (Fig. 2A, "Double Waffle-Cone"). We considered constructing the waffle-cone with kissing stents, but felt that a coaxial, concentric arrangement would better limit metal in the vessel lumen (Fig. 2A, "Kissing Stent"). Bench-top planning was performed to assess feasibility (Fig. 2C, D). Cell-size analysis of the Solitaire stent, the Enterprise vascular reconstruction device (Codman Neurovascular, Raynham, MA, USA), and the Neuroform stent (Stryker Neurovascular, Fremont, CA, USA), revealed the Solitaire stent to have twice the cell area (Fig. 2B), providing the easiest intra-cell crossing by the second stent and the least limitation of second stent expansion. Additionally, the Solitaire device's 100% recoverability and electrolytically detachable design made it possible to readjust relative stent positioning before final deployment. The planned construct is detailed in sequential schematic form in Fig. 2E. The patient was started on aspirin 325 mg daily and clopidogrel (Plavix, Bristol-Myers Squibb, New York, NY, USA) 75 mg daily 6 days prior to the procedure. Platelet function tests obtained on the day of the procedure revealed optimally reduced platelet aggregation.

3. Technique

The procedure was performed under general anesthesia. An 8-French vascular sheath access was obtained in the right femoral artery and kept under continuous heparinized saline. A Guider Softip XF 7-French guide catheter (Boston Scientific, Natick, MA, USA) was loaded coaxially with a 5-French catheter and advanced to the proximal right internal carotid artery over a 0.035″ Glidewire (Terumo Interventional Systems, Tokyo, Japan). We attempted to deploy a stent spanning from the M1 to the inferior M2 using a Prowler Plus microcatheter (Codman Neurovascular) over a Synchro-2 Soft guide wire (Boston Scientific). Although it was possible to advance the wire from M1 into the distal portion of the inferior M2 division by deflection off the aneurysm dome, the microcatheter would not follow due to stenosis at the origin of the inferior M2 branch (Fig. 1D, arrow).

Instead, we proceeded with the plan to construct a double waffle-cone. We deployed a 4 mm × 20 mm Solitaire stent via a Prowler Plus Select microcatheter over a Synchro-2 Soft microwire using a push-pull technique with the distal end of the stent opening into the aneurysm and the proximal end in the M1 (Fig. 3A).

Next, another Prowler Plus Select microcatheter was advanced into the inferior aspect of the aneurysm, crossing a distal cell of the first stent (Fig. 3B). We deployed a 4 mm × 15 mm Solitaire stent with the distal end in the aneurysm and the proximal end in the M1 segment (Fig. 3C). Cone-beam computed tomographic

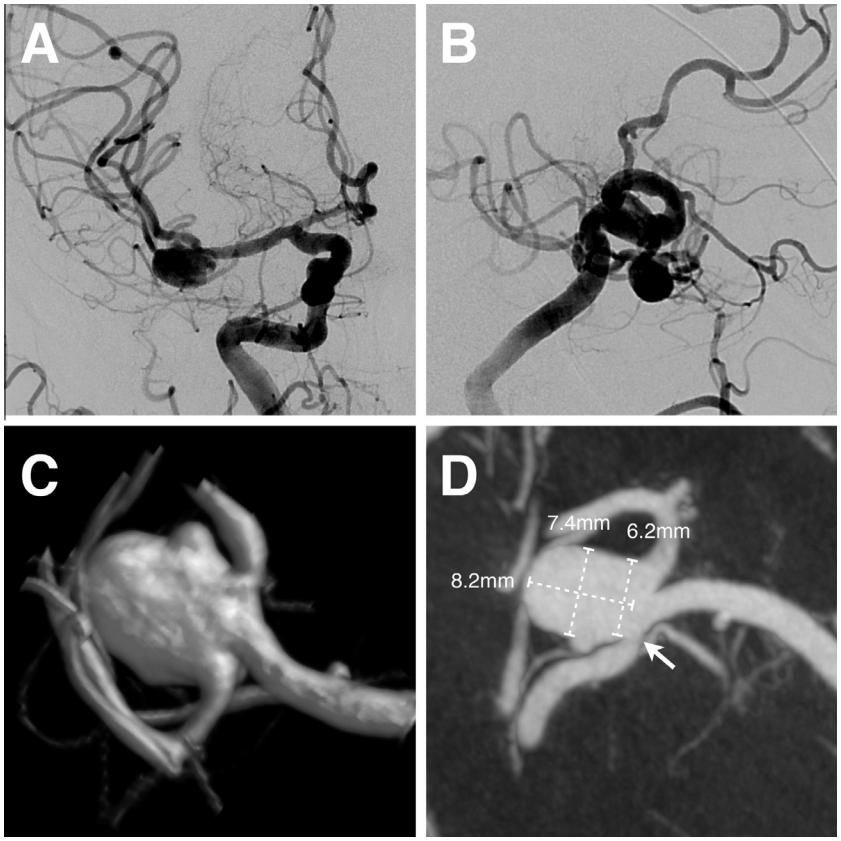


Fig. 1. (A, B) Right internal carotid artery injection digital subtraction angiography anteroposterior (A) and lateral-oblique (B) projections demonstrating a large middle cerebral artery bifurcation aneurysm. (C, D) Cone-beam computed tomography angiography three-dimensional (C) and axial (D) reconstructions demonstrating a wide neck and obtuse angles of the distal branches, with a stenotic area at the proximal segment of the inferior division (arrow).

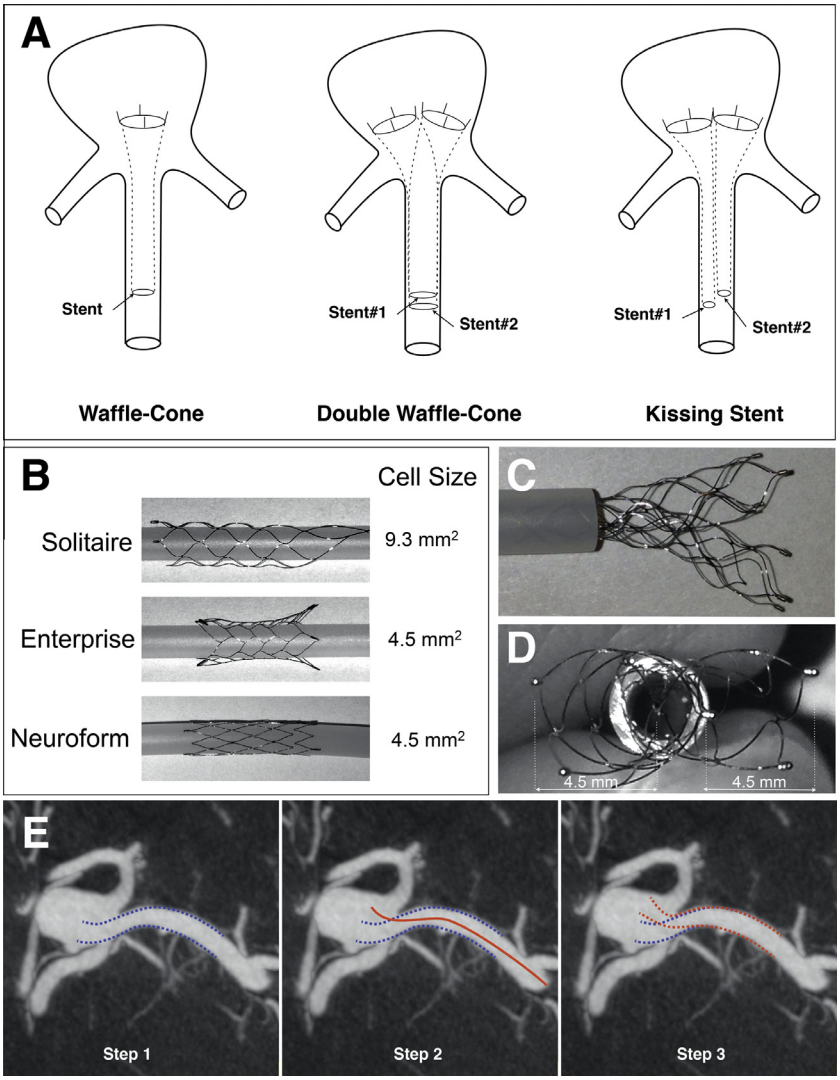


Fig. 2. Preoperative bench-top planning and schematic diagrams of the double waffle-cone stent construct. (A) Schematic diagram demonstrating three possible stent configurations with the distal end of the stents within the aneurysm dome. The double waffle-cone allows for protecting a much wider neck than the single waffle-cone technique. As opposed to the kissing-stent configuration, the double waffle-cone maintains a strut-free intraluminal space. (B) Photographs of the Solitaire (Solitaire, ev3, Irvine, CA, USA), Enterprise (Codman Neurovascular, Raynham, MA, USA), and Neuroform (Stryker Neurovascular, Fremont, CA, USA) stents demonstrating their differing architecture and the surface area of their respective cells. (C, D) Photographs of the side-view and end-on view of the proposed double waffle-cone construct demonstrating the effective doubling of the cone size by using two stents, with the stent crossing point theoretically within the aneurysm. (E) Schematic drawing superimposed on cone-beam computed tomography angiography axial reconstructions denoting the steps of creating the construct. In step 1, a stent is placed with the distal end within the dome of the aneurysm. In step 2, a microcatheter is navigated through a distal cell of the first stent chosen to cover the contralateral obtuse daughter branch. In step 3, the second stent is deployed in crossing fashion, resulting in the double waffle-cone, with the stent crossing point inside the dome of the aneurysm.

angiography confirmed protection of the inferior M2 segment by the distal struts (Fig. 3D). There were no struts crossing the lumen of the M1 segment in lateral or down-the-barrel projections (Fig. 3E, F).

Concentric stents deployed in the relatively narrow M1 segment potentially elevated the risk of thromboembolic events, so we elected to allow for stent endothelialization before proceeding with coil embolization. Postoperative MRI demonstrated no evidence of infarct following this procedure. Coil embolization was performed 17 days later. Under general anesthesia, a 6-French guide catheter (Codman Neurovascular) was placed in the internal carotid artery from a femoral approach. An SL-10 microcatheter (Stryker Neurovascular) was advanced over a Synchro-2 Soft microwire to the dome of the aneurysm through the double waffle-cone. We deployed a Target 360 Soft 7 mm × 15 cm (Stryker Neurovascular) to serve as a framing coil (Fig. 3G). Additional coiling was performed using a combination of soft coils and Hydrogel-coated coils (Terumo) to achieve complete embolization (Fig. 3H, I). Diffusion-weighted MRI demonstrated no evidence of infarct (Fig. 4A).

Follow-up angiography at 3 months demonstrated a stable construct with preservation of distal middle cerebral artery flow. The patient was weaned off clopidogrel and tapered to 81 mg of aspirin daily (Fig. 4B). Magnetic resonance angiography at 6 month follow-up demonstrated no infarction, and persistent filling of the distal middle cerebral artery branches (Fig. 4C). The patient remained neurologically intact and asymptomatic on 6 month follow-up.

4. Discussion

Treatment of ultra wide-neck bifurcation-type aneurysms with obtusely angled daughter vessels poses a particular challenge by demanding protection of two efferent vessels while concomitantly

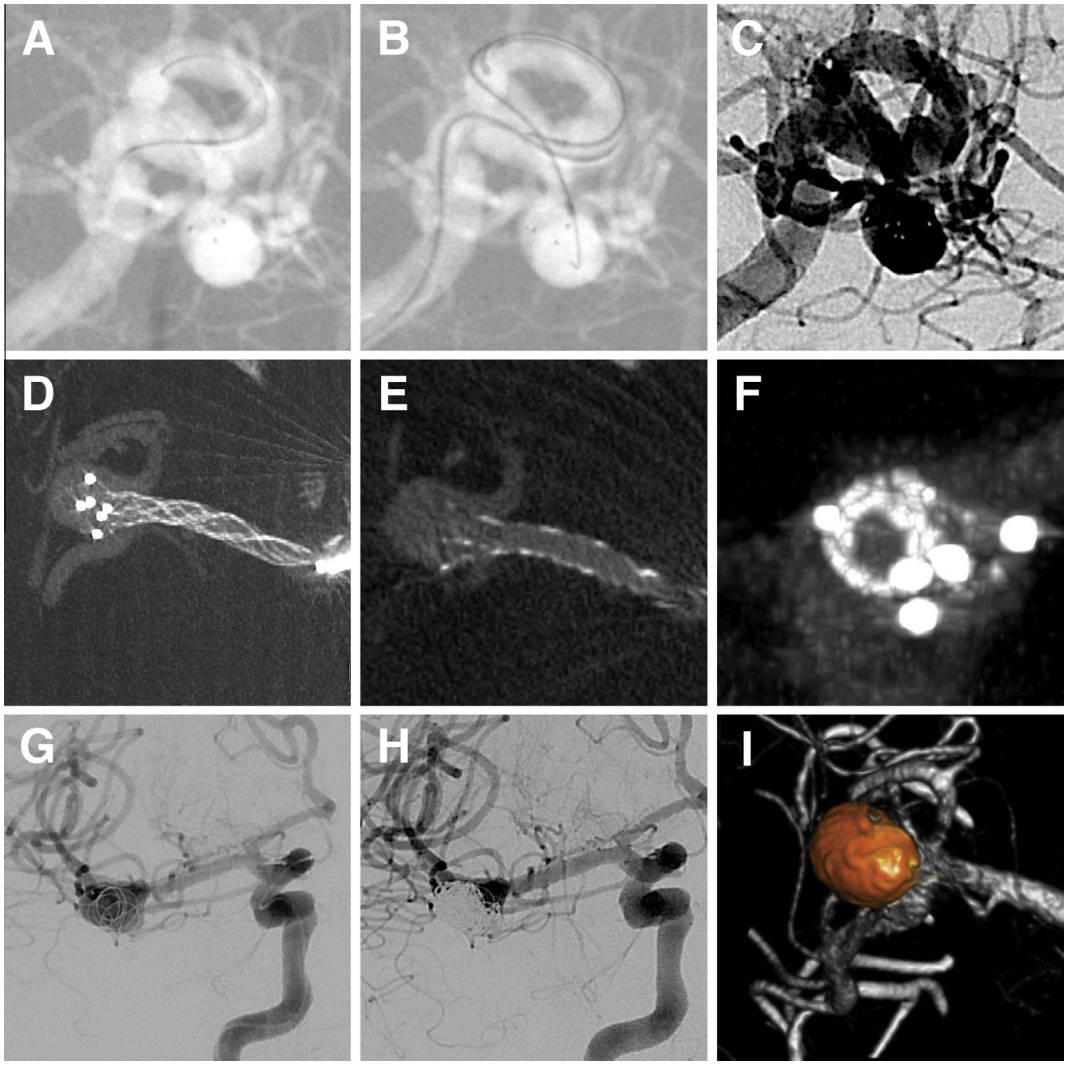


Fig. 3. Therapeutic procedure. (A) Digital subtraction angiography (DSA) roadmap demonstrating placement of the first stent. (B) DSA roadmap after a microwire has been advanced through the distal cell of the first stent and into the aneurysm dome. (C) DSA demonstrating the two stents deployed, protecting both distal branches and creating a support for the coil-pack. (D) Cone beam computed tomographic angiography (CBCT-A) axial maximum intensity projection showing the double waffle-cone deployed within the aneurysm dome. (E) CBCT-A thin-slice axial reconstruction showing the stent cross-point within the aneurysm dome and no intertwined stent struts within the lumen of the proximal vessel. (F) CBCT-A maximum intensity projection down the barrel of the entire stent, again demonstrating no metal within the vessel lumen. (G, H) DSA anteroposterior right internal carotid artery injections after the framing coil has been placed, and after complete embolization with coils. (I) Three-dimensional dual-volume reconstruction rotational angiography showing the final coil-pack and patent distal vessel.

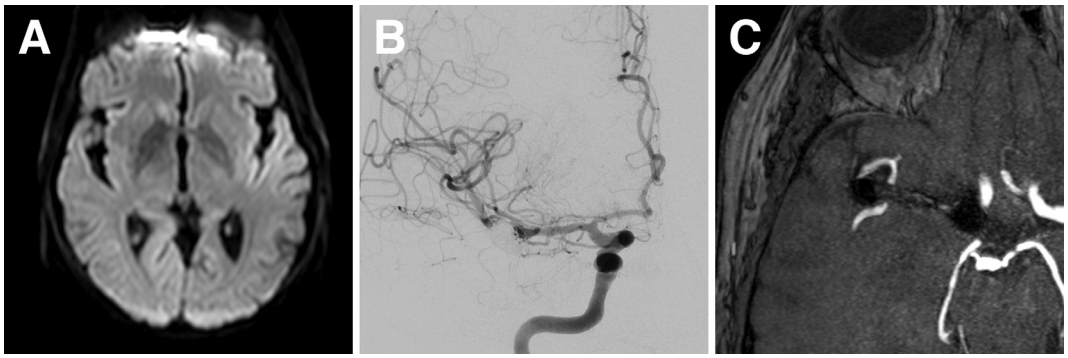


Fig. 4. Follow-up imaging. (A) Diffusion-weighted axial MRI after the coil embolization procedure demonstrating no evidence of acute cerebral infarction. (B) Follow-up right internal carotid artery injection digital subtraction angiography confirms long-term patency of the stents and distal vasculature, along with complete occlusion of the aneurysm. (C) 6 month follow-up axial magnetic resonance angiography showing blood flow in both inferior and superior divisions of the middle cerebral artery and no flow within the aneurysm. Susceptibility artifact from the stent limits visualization of proximal middle cerebral artery blood flow.

providing optimal coil mass support in the face of an aneurysm which may be wider than it is deep. Wide-neck bifurcation aneurysms may be treated with a single stent spanning from the parent to one daughter vessel, or by the dual Y-stent technique. Chow et al. described the first use of dual stents in a Y-shaped construct (using Neuroform stents) thereby ensuring the patency of the efferent vessels as well as optimally protecting the coil mass from herniation into the parent vessel [1]. The Y-stent construct cannot readily be deployed if the daughter branches cannot be successfully catheterized as in the case described above; furthermore, all currently available stents exhibit unacceptable kinking and ovalization in the case of closed-cell design or cell widening in the case of open-cell design resulting in decreased coil support and risk of parent vessel occlusion. The waffle-cone technique introduced by Horowitz et al. allows treatment of bifurcation aneurysms with wide necks where efferent branches may not be amenable to the Y-stent configuration [3]. This technique, however, is limited to aneurysms with a neck width of less than 5 mm, the maximum diameter of the currently available intracranial stents. These limitations prompted the development of the dual-waffle cone technique described here.

The Solitaire stent incorporates a large cell, slotted design with retrievability and electrolytic detachment, allowing it to be repositioned multiple times prior to deployment [4]. The slotted design is intended to minimize the incomplete wall apposition around tight radius bends [5]. The device has been successful in assisting coil embolization of wide-neck aneurysms with encouraging follow-up results [6]. Sychra et al. showed feasibility of deploying the Solitaire stent in eight patients in a waffle-cone construct with excellent follow-up results [7]. In addition, Sobri Muda et al. demonstrated the successful use of the Solitaire stent in a Y-configuration for treatment of wide neck basilar apex aneurysms [8]. These authors note the advantages of the large cell size when expanding one stent within the next in the Y-configuration. Despite its closed-cell design, the large cell size may be less protective of coil herniation when used as a coil-assisting device. In the double waffle-cone technique (similarly to the Y-stent technique), this characteristic allowed expansion of one stent as it crosses the first stent. As demonstrated in Figure 2, the cell size in the completely unrestrained stent is twice as large in the Solitaire as in the other available intracranial devices. This becomes more critical when the stents are constrained by partial deployment within smaller distal branches.

Multiple retrievability proved to be critical in enabling the fine-tuning and repositioning necessary for each stent to construct the double waffle-cone in this complex aneurysm. In contrast, the Neuroform stent cannot be re-sheathed or recovered after deployment, and the Enterprise stent allows recovery only if partially deployed. In this regard, it is important to stress the need for first re-sheathing the second stent in the construct before repositioning or re-sheathing the first stent to avoid undesirable strangulation or "bow-tieing" the second stent by the constricting cell of the first stent.

One challenge for the waffle-cone approach is to gauge the depth at which the stent needs to be deployed into the dome to allow for sufficient flaring of the stent to cover the neck of the aneurysm while simultaneously avoiding deployment too deep into the dome. Failure to do so could hinder complete coil embolization by compartmentalizing the dome. The Enterprise stent flares more than the Solitaire stent, but the flared portion possesses little stiffness to compression upon framing coil deployment. This results in the need for deeper dome penetration and may not be possible in shallower domes.

An advantage of the double waffle-cone construct over the kissing or crossing Y-stent technique is the lack of metal stent struts within the lumen of the proximal vessel, as we demonstrated in our bench-top assessment (Fig. 2C) and final result (Fig. 3E, F). Eliminating intraluminal struts has theoretical benefits in terms of limiting shear-rate dependent platelet activation. This is predicted by fluid dynamics of parabolic flow profile with central luminal velocity being highest compared to close to the vessel wall; a long segment of metal within the central lumen of the parent vessel, such as seen in the kissing stent construct, would lead to the highest shear rates in that region with possible platelet activation. Reducing the intraluminal metal burden, such as achieved by the double waffle-cone construct, may play an important role in mitigating this risk [9].

In this patient, we established the utility of a double waffle-cone construct in securing a complex ultra-wide neck middle cerebral artery bifurcation aneurysm and outlined several advantages of using the Solitaire detachable stent device for this application. This technique offers unique advantages to the kissing-stent technique in that it enables freedom of intraluminal central strut impingement while offering stable wide-based coil support in cases where Y-stenting is not feasible because of obtuse daughter vessel angulation.

Conflicts of Interest/Disclosures

The senior author (A.M. Malek) has received unrestricted research funding from Codman Neurovascular, Microvention, Stryker Neurovascular, Siemens, Ansys, and CD-Adapco for research that is unrelated to the submitted work.

The other authors declare that they have no financial or other conflicts of interest in relation to this research and its publication.

References

[1] Chow MM, Woo HH, Masaryk TJ, et al. A novel endovascular treatment of a wide-necked basilar apex aneurysm by using a Y-configuration, double-stent technique. AJNR Am J Neuroradiol 2004;25:509–12.
[2] Cross 3rd DT, Moran CJ, Derdeyn CP, et al. Neuroform stent deployment for treatment of a basilar tip aneurysm via a posterior communicating artery route. AJNR Am J Neuroradiol 2005;26:2578–81.
[3] Horowitz M, Levy E, Sauvageau E, et al. Intra/extra-aneurysmal stent placement for management of complex and wide-necked-bifurcation aneurysms: eight cases using the waffle cone technique. Neurosurgery 2006;58:ONS-258–62 [discussion ONS-262].
[4] Doerfler A, Becker WP, Wanke I, et al. A novel flexible, retrievable endovascular stent system for small-vessel anatomy: preliminary in vivo data. AJNR Am J Neuroradiol 2005;26:862–8.
[5] Krischek O, Miloslavski E, Fischer S, et al. A comparison of functional and physical properties of self-expanding intracranial stents [Neuroform3, Wingspan, Solitaire, Leo+, Enterprise]. Minim Invasive Neurosurg: MIN 2011;54:21–8.
[6] Yavuz K, Geyik S, Pamuk AG, et al. Immediate and midterm follow-up results of using an electrodetachable, fully retrievable SOLO stent system in the endovascular coil occlusion of wide-necked cerebral aneurysms. J Neurosurg 2007;107:49–55.
[7] Sychra V, Klisch J, Werner M, et al. Waffle-cone technique with Solitaire AB remodeling device: endovascular treatment of highly selected complex cerebral aneurysms. Neuroradiology 2011;53:961–72.
[8] Muda AS, Ralib AR, Yaacob Y, et al. Y-stent-assisted coil embolisation of wide-necked aneurysms using a new fully retrievable and detachable intracranial stent: report of two cases. Malays J Med Sci: MJMS 2011;18:91–7.
[9] Kanaan H, Jankowitz B, Aleu A, et al. In-stent thrombosis and stenosis after neck-remodeling device-assisted coil embolization of intracranial aneurysms. Neurosurgery 2010;67:1523–32 [discussion 1532–3].