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CASE REPORT

Double-barrel entanglement of intracranial Enterprise stents resulting from undetected incomplete stent apposition

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ABSTRACT

Objective Although intracranial stents have expanded the spectrum of aneurysms amenable to coiling, closed cell design variants can be prone to incomplete stent apposition around tightly curved arterial bends. A case is presented illustrating the technical ramifications of this phenomenon during subsequent treatment.

Clinical presentation A 49-year-old woman who had previously undergone Enterprise (closed cell design) stent mediated coiling of a wide necked ophthalmic carotid artery aneurysm was noted to harbor residual central filling on follow-up imaging, and was scheduled for additional embolization.

Intervention During retreatment, performed with a second concentrically placed Enterprise and further coil packing using the jailing technique, the proximal portion of the second Enterprise stent failed to expand as expected. C-arm cone beam CT (CBCT) revealed the second stent to have been navigated into and out of the orphaned lumen created by the incompletely apposed first Enterprise stent at the carotid siphon. This stent entanglement resulted in the formation of a trapped proximal double-barrel lumen in the curved segment and resolution to a single barrel lumen in the distal straight segment of the parent vessel facing the aneurysm neck.

Conclusion Caution is urged when navigating around curved vessel segments through previously deployed intracranial stents, which may be incompletely apposed to the vessel wall, to avoid deleterious and potentially catastrophic entanglement. CBCT imaging may be helpful in delineating the spatial relationship of previously deployed intracranial stents during subsequent endovascular navigation.

INTRODUCTION

The Enterprise stent (Codman, Raynham, Massachusetts, USA) has proven to be a versatile tool in the treatment of wide necked intracranial aneurysms.[1 2] This self-expanding nitinol stent features a closed cell design that has expanded the spectrum of aneurysms that can be treated by endovascular means.[3] The easy navigability of the Enterprise stent through tortuous anatomy is attributable to a low profile design and reliance on a small caliber 0.021 inch microcatheter. Nonetheless, its inherent closed cell design renders it prone to kinking and ovalization when deployed around sharply angled vessel segments. Recently, the Enterprise stent has also been shown to be associated with significant areas of incomplete stent apposition (ISA) to the vessel wall in even gently curved vessel segments.[4] In contrast with the documented risk of thromboembolic complications in cases of coronary stent ISA, little information is available on any long term clinical implications of poor wall apposition in intracranial aneurysm stent coiling although recent data suggest an association between ISA and periprocedural diffusion weighted imaging changes.[5] The use of high resolution angiographic C-arm cone beam CT (CBCT) has been previously shown to enable clear visualization of the relationship between intracranial stent struts and the parent vessel for both Neuroform[6] and Enterprise[5] stents. Here we present a case in which ISA is shown to have important implications for subsequent endovascular intervention necessitating microcatheter navigation across a previously deployed stent.

CASE REPORT

A 49-year-old woman found to harbor a wide necked, unruptured carotid ophthalmic intracranial aneurysm elected to undergo endovascular treatment with stent mediated coiling (figure 1A). This was performed using an Enteprise 4.5×22 mm stent via the jailing technique. The coiling portion of the procedure was felt to be suboptimal because of early kick back of the microcatheter and difficulty with repeat microcatheterization of the aneurysm for additional coiling (figure 1B). The procedure was tolerated well and the patient discharged without complications. One month follow-up MR angiography showed residual flow in the aneurysm dome (figure 1C) and a repeat embolization procedure was elected.

During the second procedure, an SL-10 microcatheter (Boston Scientific, Natick, Massachusetts, USA) was used to successfully catheterize the aneurysm residual and a Prowler Plus Select microcatheter (Codman) was navigated over a Synchro microwire (Boston Scientific) past the previously deployed Enterprise stent with mild difficulty selecting what was perceived as the central lumen of the previously deployed Enterprise stent under roadmap fluorography. The microcatheter was advanced without undue resistance and centered over the neck of the aneurysm (jailing technique). A second Enterprise 4.5×22 mm stent was centered and deployed across the neck of the aneurysm to increase neck coverage given the intent of using smaller coil size for the additional coil packing and the associated risk of flow induced migration.[7] On unsheathing of this second Enterprise stent, the distal markers were noted to open

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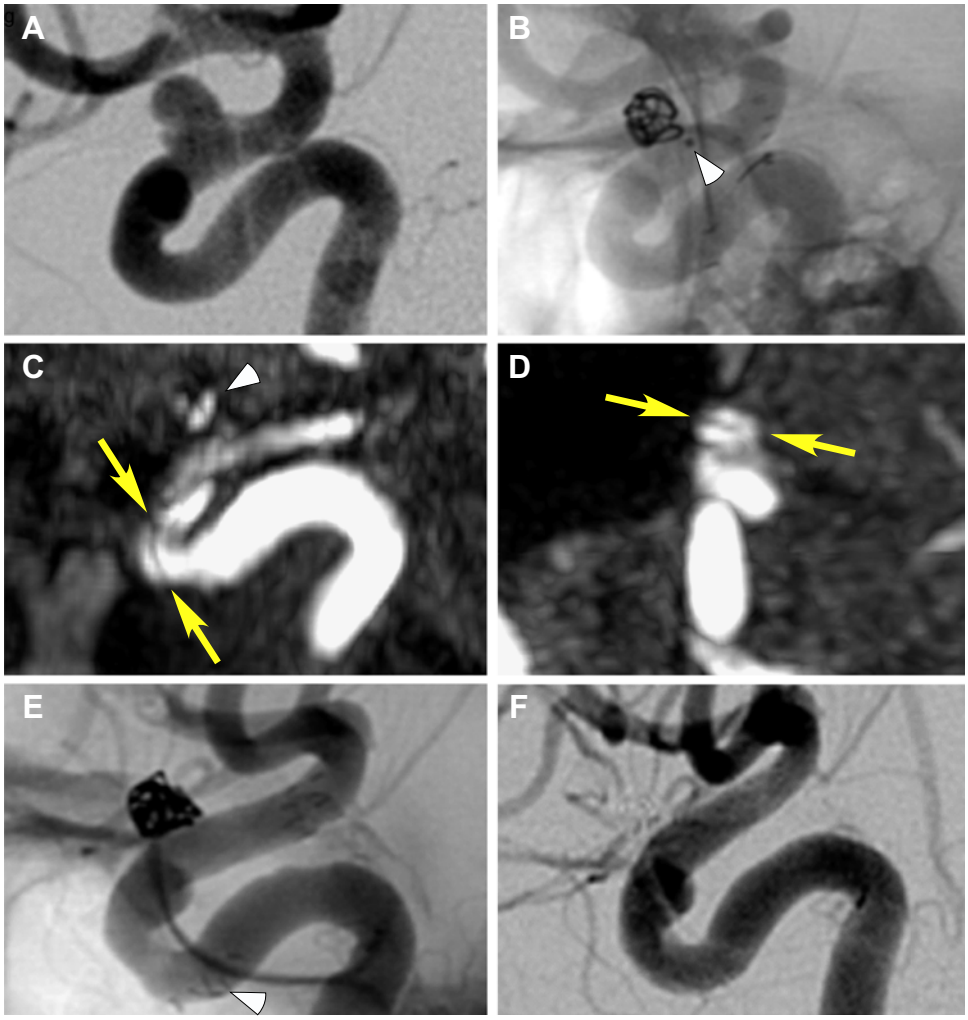


Figure 1 Preoperative digital subtracted angiography (DSA) of a wide necked ophthalmic internal carotid artery aneurysm (A), and following initial Enterprise stent coiling (B), showing ejected distal tip of microcatheter (arrowhead) with inability to reaccess the dome through the stent struts. 3 T MR angiography multiplanar reconstructions at the 1 month mark (C, sagittal; D, axial) showing residual filling in the dome. Note the crescent shaped orphaned lumen separated by stent induced artifact (arrows). Successful second stent coiling procedure with further coil packing of the dome and additional concentric stent deployment after traversing the initial Enterprise stent (E) with poor proximal strut expansion of the second Enterprise stent (arrowhead). DSA 4 months later shows angiographic obliteration of the aneurysm (F).

completely but the proximal markers remained constrained and incompletely expanded; the stent delivery microwire was retrieved without difficulty. The procedure was well tolerated and the residual aneurysm was angiographically obliterated. The patient was kept on clopidogrel/aspirin for 3 months and then maintained on 81 mg of acetylsalicylic acid subsequently. At the 1 year clinical follow-up, the patient complained of bilateral arm paresthesias and visual migraines for which she underwent follow-up angiography after an MRI showed no infarcts.

Angiography and CBCT enabled the in vivo high resolution visualization of the two deployed stents (figure 2). CBCT was performed using the standard 20 s acquisition using a flat panel angiography system (Axiom Artis VB22N; Siemens AG, Forchheim, Germany) while injecting 1 ml/s of 1:6 dilute contrast agent mixture with normal saline (Isovue-250; Bracco Imaging SpA, Milano, Italy), and x-ray duration 22 s with an x-ray delay of 2 s. Dataset reconstruction was performed on the dedicated Syngo workstation and exported for imaging using Osirix software (64 bit V.3.8; Pixmeo, Bernex, Switzerland). The multiplanar reconstruction of the CBCT revealed the first stent to have severe mid-section crimping as well as ISA on both the inner and outer curves of the carotid siphon. In addition, it revealed the second stent to have been partially deployed into the orphaned lumen created by the outer curve ISA in the carotid siphon. Orthogonal section CBCT showed the proximal markers of stent No 2 to be unexpanded up to the mid-siphon region of the ICA. From there, stent No 2 crosses back into the true lumen and becomes concentric with stent No 1, as is confirmed by the doubling of strut density in slices 4 and 5 (figure 2C). Analysis of the images suggests that the microwire used to advance the Prowler Plus microcatheter during the second procedure entered the orphaned lumen of the outer region of ISA created by the ovalization and crimping of the first Enterprise stent (figure 2D). Accordingly, the proximal half of the second Enterprise stent was trapped in a twin-barrel configuration in this orphaned ISA induced lumen, as evidenced by the unexpanded proximal markers.

DISCUSSION

The Enterprise stent is a closed cell design, self-expanding nitinol stent that has proven to be useful in assisting the endovascular treatment of wide necked aneurysms previously not amenable to coil embolization.[3] The closed cell design has been noted for its superior ability to provide a stable scaffold across the neck of aneurysms,[1] preventing coil herniation into the parent vessel, as well as the greater flexibility of its delivery system, thus allowing easier maneuverability through the intracranial circulation.[8]

Previous evaluation of the in vitro architecture of the Enterprise stent showed it to exhibit kinking when bent after deployment to more acute angles.[9] This finding was replicated with retrospective in vivo analysis of stent conformation, which showed that the Enterprise stent was more susceptible to central ovalization and subsequent ISA in larger diameter vessels with

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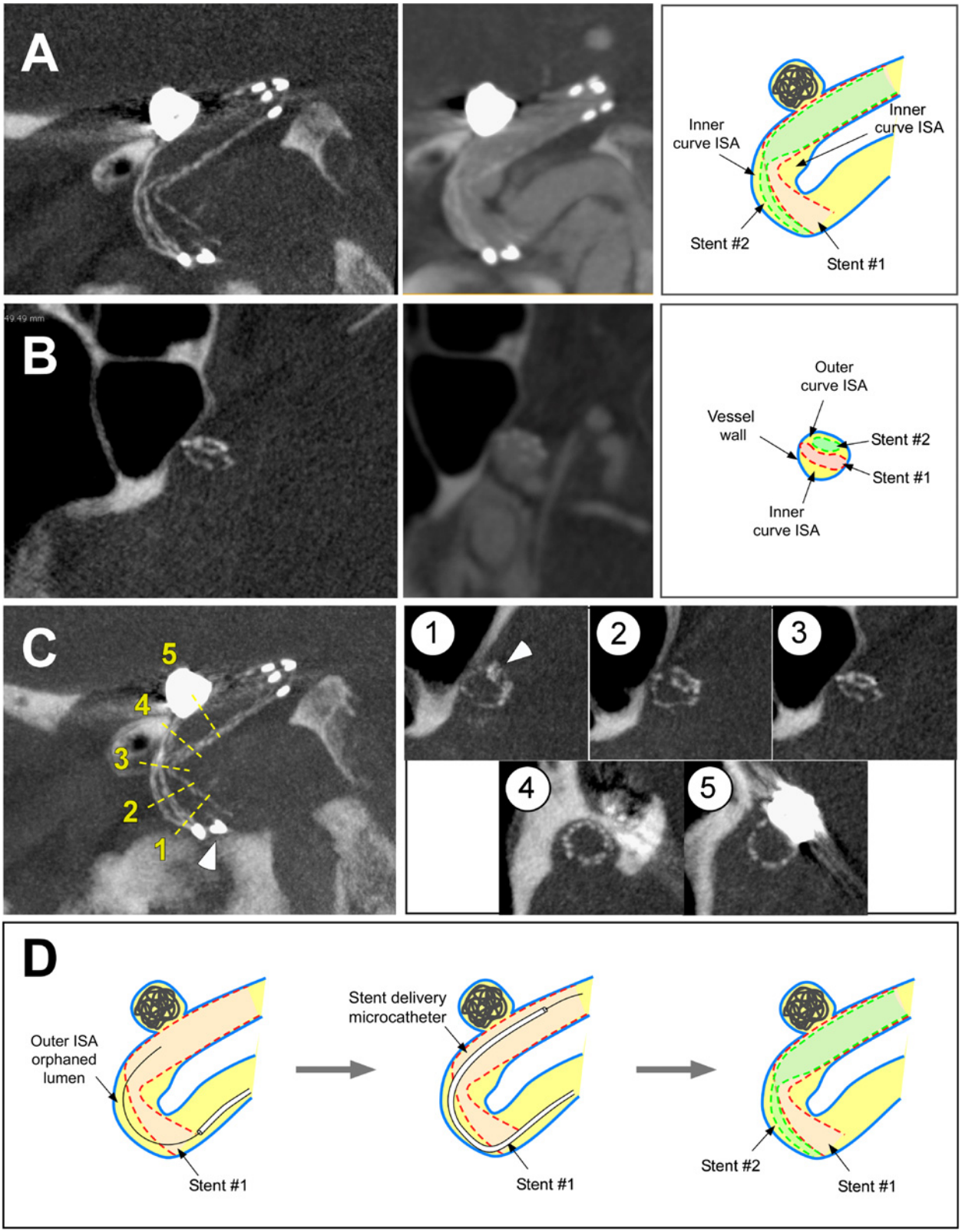


Figure 2 Thin multiplanar reconstruction (MPR) of C-arm cone beam CT (CBCT) at the 1 year follow-up in sagittal (A) and axial (B) orientations, without (left) and with (middle) dilute contrast injection, shows the twin-barrel appearance (in schematic form, right panel) of the two stents. The first stent shows incomplete apposition to the vessel wall and significant kinking and ovalization of the lumen at the mid-curve of the carotid siphon. Multiple orthogonal cross sectional thin MPR of CBCT (C) confirms the deployment of the second stent in the orphaned lumen resulting from outer curve incomplete stent apposition (ISA) and the incompletely deployed proximal markers (arrowhead, slice 1), compressed stent No 2 in slices 2 and 3 and eventual expansion into the distal internal carotid artery lumen with double strut coverage across the aneurysm neck in slices 4 and 5. Schematic reconstruction of the events (D) showing wire passage into and out of the ISA orphaned lumen, followed by advancement of the second stent delivery microcatheter (middle) and final relative stent positions (right).

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more tortuous anatomy[4] in a stent deployment technique sensitive manner.[10] The tendency of the Enterprise stent to be incompletely apposed to the vessel wall after deployment was not found to occur with the Neuroform stent although the latter exhibits fish scaling around vessel bends which can interfere with subsequent microcatheter navigation.[6]

Because real time visualization of intracranial stents has remained a difficult task even with modern digital subtracted angiography, stent architecture information remains sparse in actual in vivo arterial architecture. However, recent techniques employing CBCT have provided higher spatial resolution images and more information regarding restenosis following intracranial stenting. Numerous previous studies have demonstrated promising results for the effectiveness of CBCT in the diagnostic evaluation of the intracranial circulation[11–13] as well as in the visualization of stents deployed in the cerebral vasculature.[14 15]

There are three important findings elucidated by the current case. The first is that CBCT is an effective modality for the in vivo evaluation of stents with disruptions of intended stent architecture. Comparing the images obtained with and without dilute contrast injection in the current case enabled an accurate assessment of the architecture of the concentric Enterprise stents with respect to the vessel wall and highlighted clear evidence of ISA on both the inner and outer curves of the carotid siphon proximal to the aneurysm as well as clear evidence of the jailed stent.

The second finding relates to the demonstration that the kinking first noted by Ebrahimi *et al*[9] after in vitro bending of the deployed stent in elastic tubing also occurs in vivo around a curved vessel bend and that this crimping can precipitate technical sequelae that may impact on patient care. The inability of the Enterprise stent to remain fully expanded at its center resulted in ISA. This led to the generation of an orphaned, luminal crescentic region that contains a significant portion of the vessel's blood flow. Previous work has demonstrated that the mechanisms that contribute to kinking and ISA of the Enterprise stent and subsequent orphaned lumen formation are related to more tortuous vessel anatomy and placement of the Enterprise stent around curved vessels.[4] Deployment technique may be modified to employ a push–pull technique to mitigate the degree of ISA.[10]

The third finding of this case is that endovascular navigation into and through the pseudo-lumen via crossing in between unapposed stent struts can occur during follow-up procedures and cannot be adequately visualized using conventional digital subtracted angiography. There already exists an inherent difficulty associated with crossing previously deployed stents, and the presence of undetected ISA may compound the technical approach to patients similar to the current case. Previous reports have highlighted that the fish scaling of the Neuroform stent struts into the vessel lumen makes subsequent endovascular navigation more challenging as the stent struts can physically interfere with the path of the microwire.[6] The kinking of the Enterprise stent, as demonstrated in the current case, may represent a much more substantial physical barrier to guidewire advancement through the vasculature. Another concern is that the outward radial force generated by the undeployed portion of the Enterprise stent may detach the first stent from its attachment to the wall after endothelialization, an effect which could lift an intimal flap if the stent has been only partially endothelialized and not yet incorporated into the vessel wall.

One possibility of mitigating this problem is to form a tight radius J-curve on the tip of the microwire, thus decreasing the likelihood of entering between the struts leading to the orphaned luminal region of ISA. Another solution may be to perform CBCT after advancement of the wire or microcatheter to insure that its position is within the confines of the previously deployed stent in its entire path. CBCT in the current case was performed 1 year after the initial procedure and the double-barrel phenomenon was only deduced post hoc. Based on the experience of this case, it is recommended that a priori imaging be obtained using CBCT when envisaging concentric stent placement to ensure the stent deployment microcatheter is indeed within the intended lumen rather than within the orphaned crescentic region of poor apposition (figure 2D).

Because the presence of the ISA seen in this case increases the technical difficulty of endovascular navigation, preprocedural evaluation with CBCT is important for the identification of such ISA. A retrospective analysis of the 3 T MR angiography performed following the first stent coiling procedure may have enabled the identification of the crescentic signal outside of the stent induced metal artifact consistent with an area of ISA (figure 1C, D).[4] Although the patient has remained free of stroke on low dose acetylsalicylic acid (81 mg daily), the full implications of the reported finding are not yet known, and neurointerventionalists should be aware that incomplete apposition of the Enterprise stent has the potential for interfering with subsequent endovascular procedures within the intracranial circulation.

Competing interests AMM has received unrestricted research funding from Codman Neurovascular (manufacturer of the Enterprise stent) and Stryker Neurovascular (formerly Boston Scientific Corp, manufacturer of the Neuroform stent) for research that is unrelated to the submitted work.

Patient consent The patient signed hospital consent which provides for use of imaging for teaching and scientific purposes.

Ethics approval The study was approved by Tufts institutional review board.

Contributors RSH and MS collected the data, and drafted and reviewed the manuscript. AMM was responsible for conception and editing of the manuscript.

Provenance and peer review Not commissioned; externally peer reviewed.

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