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INTERVENTIONAL NEURORADIOLOGY

Management of pseudoaneurysms in the intracranial segment of the internal carotid artery with covered stents specially designed for use in the intracranial vasculature: technical notes

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Abstract Vascular diseases like aneurysms, pseudoaneurysms and direct high-flow carotid-cavernous fistulas on the intracranial segment of the internal carotid artery are usually managed through transarterial embolization with detachable coils or balloons. Utility of covered stents has been reported with good results in the treatment of selective cases. But the current generation of covered stents for coronary use is rather stiff and difficult to navigate in tortuous vessels particularly in the intracranial vasculature. Herein, we report on the use and technical respects of balloon-expanded covered stents specially designed for intracranial vasculature in the treatment of two pseudoaneurysms secondary to the successful obliteration of direct CCFs on the intracranial segment of the internal carotid artery. This is the first report of covered stents specially developed for use in intracranial vasculature.

Keywords Pseudoaneurysm · Carotid-cavernous fistula · Internal carotid artery · Covered stent · Intracranial vasculature

Introduction

The transarterial treatment of high-flow or direct carotid-cavernous fistulas (CCFs) is usually performed through embolizing the cavernous sinus with detachable balloons or coils with or without a stent-assisted technique [1, 2]. The use of covered stents has been reported with good results in the treatment of selected patients with intracranial aneurysms and arteriovenous fistulas including pseudoaneurysms [3–9]. However, the current generation of covered stents for coronary use are rather stiff and difficult to navigate in tortuous vessels particularly in the intracranial vasculature. We report here the use of balloon-expanded covered stents specially designed for the intracranial vasculature in the treatment of two pseudoaneurysms secondary to the successful obliteration of direct CCFs in the intracranial segment of the internal carotid artery (ICA). This is the first report of covered stents specially developed for use in the intracranial vasculature.

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Case report

Patient 1

A 50-year-old man was injured in a car accident. After the wound on the head had healed 1 month later, pulsatile protrusion, ecchymosis and swelling of both eyes could not be relieved. Bilateral proptosis, orbital swelling, chemosis and periorbital bruits were noted on physical examination with a greater degree of severity on the right side. Three-vessel cerebral angiography (bilateral ICA and left vertebral artery) demonstrated bilateral CCFs. Right ICA injection showed an almost complete absence of filling of the ICA above the fistula with venous drainage from the right cavernous sinus into the ipsilateral superior ophthalmic vein, the inferior petrosal sinus, the pterygoid plexus and the intercavernous sinus (Fig. 1A). Left ICA injection revealed that the venous drainage of the CCF was primarily through the superior ophthalmic vein (Fig. 1B).

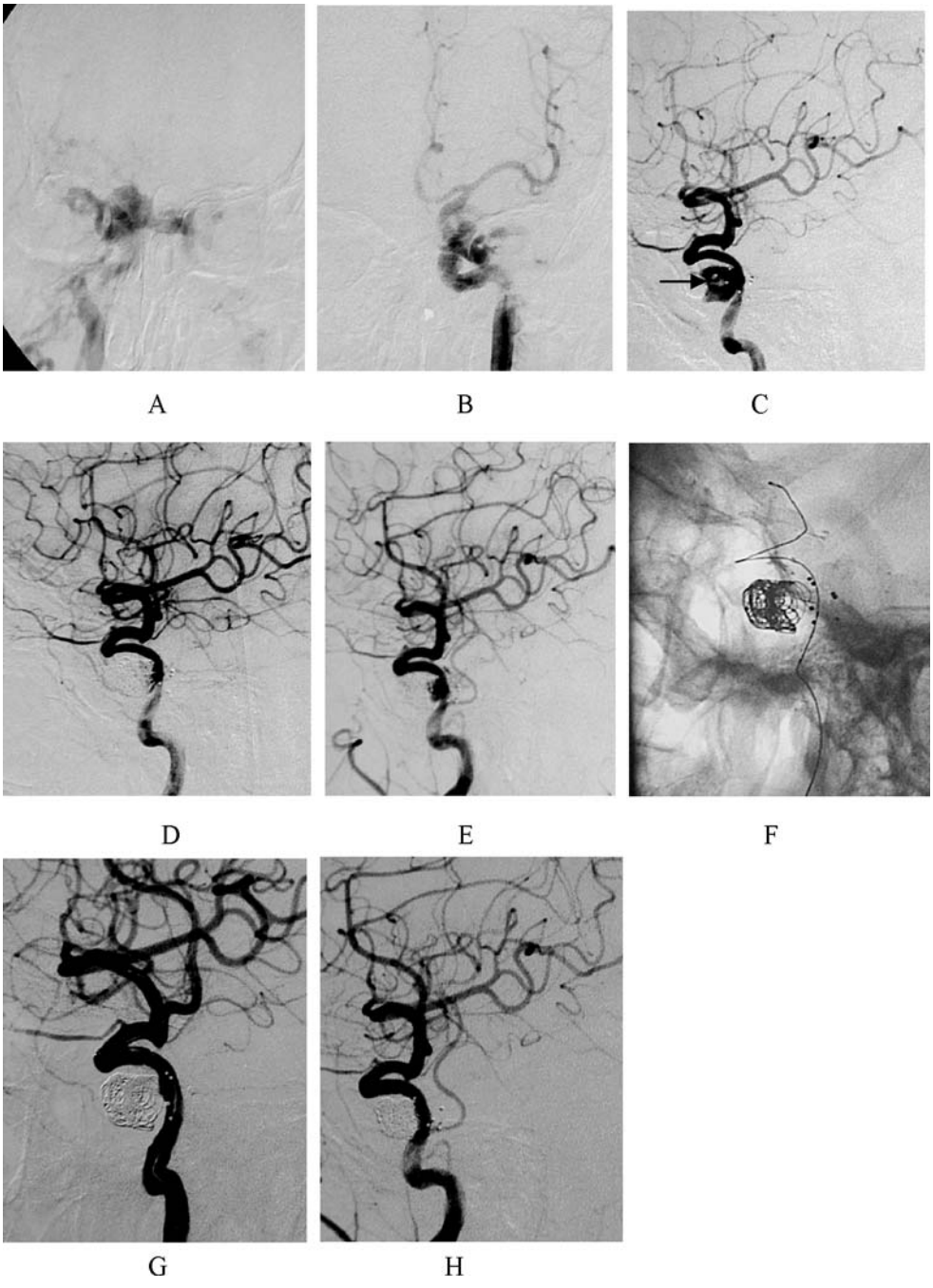

Fig. 1 Patient 1. **A** Injection of the right ICA (anteroposterior projection) showed a large direct high-flow CCF with almost no blood flow above the fistula. **B** Injection of the left ICA demonstrated a smaller direct CCF. **C** Cerebral angiography 1.5 months after both CCF had been occluded with balloons demonstrates the formation of a pseudoaneurysm (*arrow*) on the intracavernous portion of the right ICA with most balloons deflated. Both the left and right CCFs remained completely obliterated at this time. **D** Endovascular management with stent-assisted coiling resulted in the total obliteration of the pseudoaneurysm. **E** Follow-up cerebral angiography 5 months later demonstrates recurrence of the pseudoaneurysm due to coil compression. **F** A microguidewire was navigated into the right middle cerebral artery for implantation of a covered stent. **G** Post-stenting angiography shows complete obliteration of the pseudoaneurysm. **H** Follow-up cerebral angiography 3 months after the covered stenting procedure demonstrates total obliteration of the pseudoaneurysm

Transarterial embolization was immediately performed following the diagnostic angiography in the same session and the bilateral CCFs were successfully occluded with detachable balloons (Balt, Montmorency, France). After embolization, bruit on the right side disappeared and the proptosis, swelling, ecchymosis and chemosis also gradually improved over the next few days. However, 1.5 months after the procedure, besides a worsening headache and dizziness, the patient also complained of newly emergent blurred vision of the right eye and diplopia. Cerebral angiography demonstrated the formation of a pseudoaneurysm on the intracavernous portion of the right ICA (Fig. 1C). At this time, most detachable balloons within the cavernous sinuses had already deflated except two which had become much smaller and both CCFs had disappeared. The pseudoaneurysm was successfully embolized with stent-assisted coiling (Fig. 1D) but recurred 5 months later due to coil compression (Fig. 1E).

If we had re-embolized the pseudoaneurysm with coils, it might have recurred once more due to coil compaction because pseudoaneurysms have no real arterial wall to confine the packed coils. So, an ultimate decision was made

to occlude it with a balloon-expanded stent covered with polytetrafluoroethylene (PTFE) specially designed for use in the tortuous intracranial vasculature. The hospital Investigational Review Board was involved in evaluating and approving the request to place the newly designed covered stent, and after obtaining informed consent from the patient, anticoagulation of the patient was begun. Anticoagulation prescribed 3 days before stenting comprised 75 mg clopidogrel and 325 mg aspirin daily. The procedure was performed under local anesthesia and with systemic heparinization. With a guiding catheter located in the right ICA, a 0.014-inch microguidewire (Transcend, Boston Scientific, Fremont, Calif.) was navigated into the middle cerebral artery, and a balloon-expanded PTFE-covered stent (4.0×13 mm, MicroPort, Shanghai, China) specially developed for intracranial use was advanced over the microguidewire to the orifice of the pseudoaneurysm. After accurate localization of the covered stent, the balloon was inflated with 6 atm to the stent nominal diameter of 4.0 mm and the covered stent was detached right over the pseudoaneurysm neck. Post-stenting angiography showed complete obliteration of the pseudoaneurysm (Fig. 1F,G). Anticoagulation was carried out after the procedure with 2,000 U heparin for the first 24 h and another 2,000 U low-molecular-weight heparin daily for the next 2 days. Clopidogrel and aspirin were administered orally as before the procedure for the next 3 months. Cerebral angiography 3 months after the covered stenting procedure demonstrated total obliteration of the pseudoaneurysm with patency of the parent artery (Fig. 1H).

Patient 2

A 34-year-old man had had pulsatile protrusion, ecchymosis and swelling of the right eye for more than 6 months after trauma to the head. Bruit could be heard in the right orbital area. Cerebral angiography revealed a right direct high-flow CCF with venous drainage from the right cavernous sinus into the ipsilateral superior ophthalmic vein, the inferior petrosal sinus, the pterygoid plexus and the intercavernous sinus (Fig. 2A). Filling of the right ICA above the fistula was almost completely absent. Endovascular occlusion with detachable balloons was performed immediately after the diagnostic angiography and the right CCF was almost totally obliterated with two balloons delivered within the right cavernous sinus (Fig. 2B). Proptosis, orbital swelling, chemosis and periorbital bruits all improved over the next few days and the patient was discharged from hospital. At follow-up 2 months later,

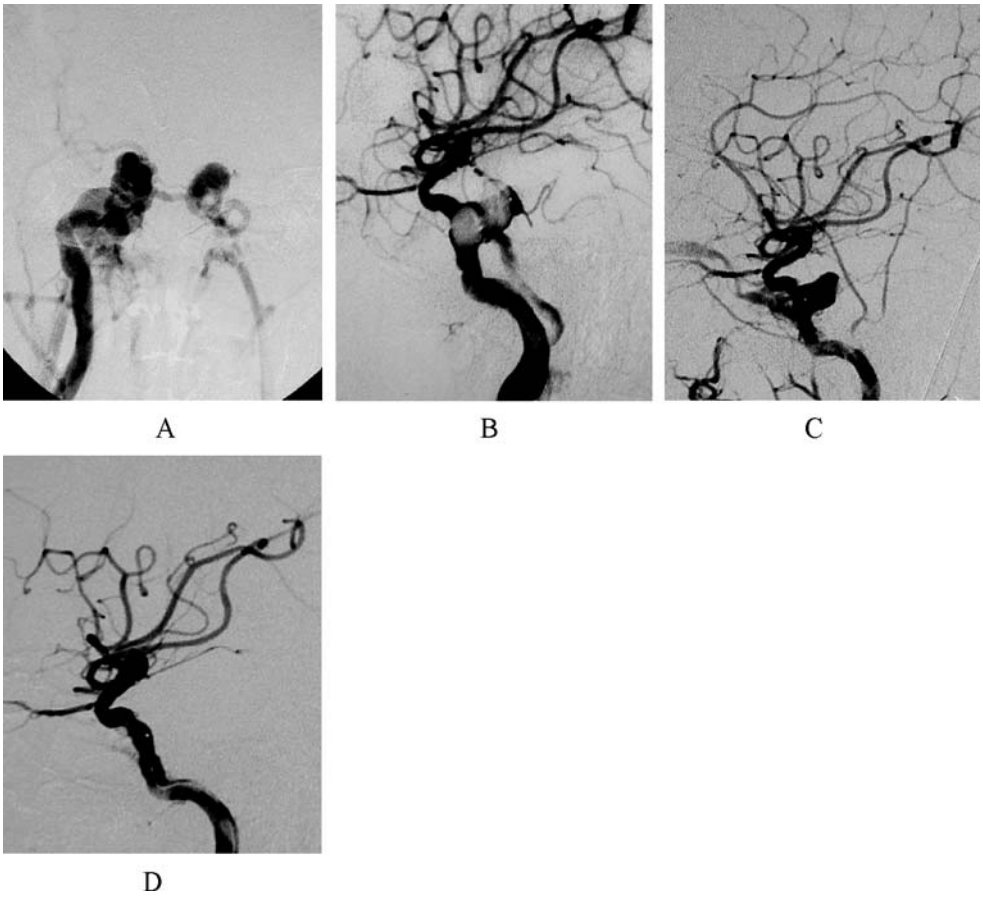

Fig. 2 Patient 2. **A** Right ICA angiogram shows a large direct high-flow CCF with almost no filling of the ICA above the fistula. **B** Detachment of two balloons within the right cavernous sinus resulted in nearly complete occlusion of the direct CCF. **C** At follow-up 2 months later, cerebral angiography demonstrates the formation of a pseudoaneurysm in the intercavernous portion of the right ICA. The two balloons had already deflated and the fistula had almost completely disappeared with only a small amount of venous drainage through the right superior ophthalmic vein. **D** Implantation of a PTFE-covered stent led to the total occlusion of both the pseudoaneurysm and the residual fistula

cerebral angiography demonstrated the formation of a pseudoaneurysm in the intercavernous portion of the right ICA (Fig. 2C). At this time, the two balloons in the right cavernous sinus had already deflated and the fistula had almost completely disappeared with only a small amount of venous drainage through the right superior ophthalmic vein. After obtaining informed consent from the patient and appropriate preparatory anticoagulation, the pseudoaneurysm was treated with a similar technique using a balloon-expanded covered stent specially designed for use in the intracranial vasculature (Fig. 2D). The pseudoaneurysm was successfully obliterated and the small amount of venous drainage also disappeared. Post-stenting anticoagulation was arranged as in the first patient. Telephone consultation with the patient 3 months later revealed nothing abnormal neurologically.

Discussion

The use of covered stents has emerged as a very effective therapeutic alternative to surgical reconstruction techniques not only in the treatment of aortic and peripheral vascular lesions but also in the treatment of head and neck arterial lesions including traumatic carotid-cavernous fistulas, aneurysms and pseudoaneurysms in the intracranial portion of the ICA, carotid blow-out syndrome in the neck, and iatrogenic injury of the cavernous ICA [3–10]. The intracranial segment of the ICA is the most common site of intracranial aneurysms, accounting for approximately 35% of intracranial aneurysms [11]. Covered stents may allow immediate exclusion of an aneurysm or a pseudoaneurysm, preservation of the parent artery, cessation of hemorrhage, obliteration of a fistula, and rapid stabilization of the patient's condition. However, the covered stents

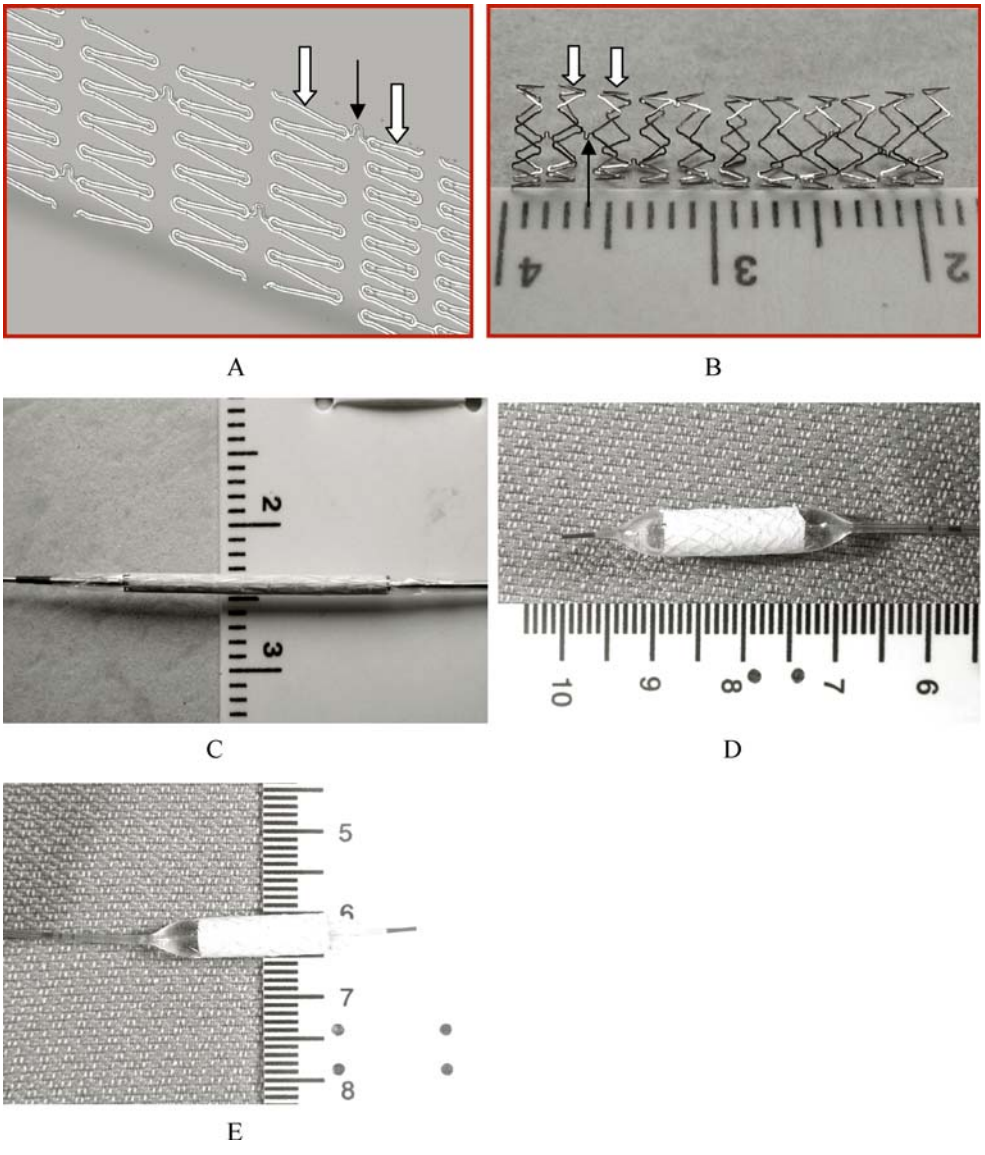

Fig. 3 PTFE-covered stent. **A** The bare stent used for PTFE-covered stents, specially designed for use in the tortuous intracranial vasculature by MicroPort Medical (Shanghai) Company, Shanghai, China, is dissected and spread to show its structure. *Hollow arrows* show two adjacent segments of the bare stent and the *black arrow* demonstrates the single point link between two adjacent segments. The many single linking points are staggered and not in one direct line. This particular construction makes the stent extremely flexible longitudinally compared with other stent products as shown in **E**. **B** *Hollow arrows* show two adjacent segments of the integral bare stent and the *black arrow* demonstrates the single point link between two adjacent segments. The length of the whole stent and the width of each segment are also shown. **C** The integral bare stent at its maximum expansion has been glued to a layer of PTFE membrane to produce the covered stent. A PTFE-covered stent had been compressed tightly against a balloon catheter. The covered stent and nondetachable balloon combined is less than 2 mm (1.7 mm) in diameter. **D**, **E** On inflation of the balloon, the PTFE-covered stent is 15 mm in length and 5 mm in diameter

employed in the intracranial ICA portion reported in the literature were not specially designed for use in the intracranial vasculature. These kinds of covered stents were usually coronary stent grafts which are very stiff, lacking longitudinal flexibility, and very difficult to adapt to the curves of the neurovascular anatomy and are therefore associated with poor navigation in the cerebral arteries. Possible complications that may result from this rigidity are dissection and vasospasm of the cerebral arteries.

The use of stents for management of intracranial arterial disease has been limited by the interventionalist's inability to negotiate the relatively stiff covered stent/balloon assembly through the tortuous intracranial vessels such as the carotid and vertebral artery systems without damaging the vessel in the process. In order to solve this problem, the MicroPort Medical (Shanghai) Company, Shanghai, China, has developed a kind of flexible PTFE-covered stent, exclusively for use in the cerebral vasculature. This product is now in preliminary clinical trials and awaits Food and Drug Administration approval. The stent consists of high-grade steel that is lasered from a tube with a thickness of 0.06 mm and then electropolished. It is composed of several segments. At the maximum expansion, the stent fenestration is 0.5 to 1 mm while each segment is 2 mm wide. One segment is connected to the next at a single point and the connecting points are staggered and not in the same direct line, as shown in Fig. 3A. Markers of high density material are added at both ends of the stent. Then a PTFE membrane with a thickness of 0.010 mm is glued tightly using an organic agglomerant to the stent struts in the expanded shape of the stent. PTFE is a biocompatible polymer that can be manufactured in the form of distensible microporous membranes. It has been in use for a long time in surgical vascular prostheses. PTFE stent grafts have been available for implantation into human coronary arteries for several years [12]. PTFE membrane is the best available covering material for stent grafts in terms of patency rates [4, 10]. The length of the whole covered stent is 8 to 15 mm and its diameter at maximum expansion is 3.0 to 5.5 mm. The covered stent is closely compressed against a non-detachable balloon. The covered stent is then sterilized. The nondetachable balloon and covered stent combined has a diameter (3.8F or 1.27 mm) small enough to pass a 6F guiding catheter. After the nondetachable balloon and PTFE-covered stent combined is accurately placed in the desired location, the balloon is distended with 6 atm to the stent nominal diameter and the stent is expanded onto the wall of the ICA. Withdrawal of the nondetachable balloon after deflation concludes the process of PTFE-covered stenting and the pseudoaneurysm or any defect will be covered by the PTFE stent.

This PTFE-covered stent specially designed for the intracranial vasculature has several distinguishing features. First, unlike other stents (Fig. 3E) whose adjacent segments are connected by welding at several points, each segment of this stent is linked to the next at one single point (Fig. 3A, B), which makes this PTFE-covered stent extremely flexible longitudinally. Second, the many single linking points between two segments are staggered and not in one direct line which contributes to the flexibility (Fig. 3A, B). Third, the strut thickness is only 0.06 mm, much thinner than other kinds of stent which have a strut thickness of 0.09 mm [13], which also contributes to the flexibility. Fourth, the stent consists of only one stent and one piece of membrane stuck together (Fig. 3C), which distinguishes it from other stent grafts which are composed of a layer of PTFE membrane sandwiched between two metallic stents [5, 10, 12–15]. This feature also contributes a great deal to its flexibility. Fifth, the covered stent and nondetachable balloon combined has a very small diameter (3.8F) enabling the whole unit to pass through a 6F guiding catheter and to get through the tortuous segment of the intracranial ICA relatively easily (Fig. 3D). Other types of covered stents not specially designed for use in the intracranial vasculature are not so small in diameter and may need a guiding catheter as large as 9–10F [15]. Sixth, the stent and PTFE membrane are not sutured but pasted together. These particular characteristics make this PTFE-covered stent extremely flexible to enable it to pass through very tortuous vessels such as the intracranial portion of the ICA without much difficulty.

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Conflict of interest statement We declare that we have no conflict of interest.

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