Published in final edited form as:

J Clin Neurosci. 2014 July ; 21(7): 1141–1147. doi:10.1016/j.jocn.2013.11.007.

Stent recanalization of carotid tonsillar loop dissection using the Enterprise vascular reconstruction device

Jason P. Rahal, Bulang Gao, Mina G. Safain, and Adel M. Malek*

Cerebrovascular and Endovascular Division, Department of Neurosurgery, Tufts Medical Center, 800 Washington Street #178, Proger 7, Boston, MA 02111, USA

Abstract

Although advances in endovascular techniques have permitted reconstruction of intimal dissections and related pseudoaneurysms of the extracranial cervical internal carotid artery, highly tortuous tonsillar loop anatomic variants still pose an obstacle to conventional extracranial self-expanding carotid stents. During a 12 year period, nine of 48 cases with cervical carotid dissections were associated with a tonsillar loop. Five patients required endovascular treatment, which was performed using a microcatheter-based technique with the low-profile Enterprise vascular reconstruction device (Codman Neurovascular, Raynham, MA, USA). Technical, radiographic, and clinical outcomes were analyzed for each patient. Dissection etiology was spontaneous in three patients, iatrogenic in one, and traumatic in one. Four near-occlusive tonsillar loop dissections were successfully recanalized during the acute phase. Dissection-related stenosis improved from $90 \pm 22\%$ to $31 \pm 13\%$, with tandem stents needed in three instances to seal the inflow zone. There were no procedure-related transient ischemic attacks (TIA), minor/major strokes, or deaths. Angiographic follow-up with a mean of 28.0 ± 21.6 months showed all stents were patent, with average stenosis of $25.2 \pm 12.2\%$. Focal ovalization and kinking of the closed-cell design was noted at the sharpest curve in one patient. Clinical outcome (follow-up of 28.1 ± 21.5 months) demonstrated overall improvement with no clinical worsening, new TIA, or stroke. Tonsillar loop-associated carotid dissections can be successfully and durably recanalized using the low-profile Enterprise stent with excellent long-term patency rate and low procedural risk. The possibility of stent kinking and low radial force should be considered when planning reconstruction with this device.

Keywords

Carotid dissection; Carotid kink; Dissecting pseudoaneurysm; Enterprise stent; Tonsillar loop

© 2013 Elsevier Ltd. All rights reserved.

*Corresponding author. Tel.: +1 617 636 8200; fax: +1 617 636 7587. amalek@tuftsmedicalcenter.org (A.M. Malek).

Publisher's Disclaimer: This is a PDF file of an unedited manuscript that has been accepted for publication. As a service to our customers we are providing this early version of the manuscript. The manuscript will undergo copyediting, typesetting, and review of the resulting proof before it is published in its final citable form. Please note that during the production process errors may be discovered which could affect the content, and all legal disclaimers that apply to the journal pertain.

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

1. Introduction

Internal carotid artery (ICA) dissection is a common cause of ischemic stroke, especially in young patients, which can lead to significant morbidity.^{1–3} Carotid dissections have a poorly understood natural history and are classified as spontaneous, traumatic, or iatrogenic, with several risk factors identified^{4, 5}. Endovascular recanalization can provide significant benefits in a subset of patients, including hemodynamically significant stenosis with poor collateral/isolated hemisphere, bilateral or multi-vessel dissection, development of enlarging dissecting pseudoaneurysm, or symptomatic failure of medical therapy.^{6, 7}

Improvements in endovascular reconstruction techniques have enabled the recanalization of dissections involving the straight or gently curved cervical ICA, using large profile self-expanding biliary or carotid atherosclerosis stents.^{6, 8–15} Nonetheless, severe cervical ICA tortuosity remains a unique challenge for this treatment modality. Specifically, tonsillar loop anatomic variants of the ICA, which have been shown to confer an increased risk of traumatic dissection, remain a therapeutic conundrum.^{16–18} The stiff extracranial self-expanding biliary or carotid stents are unable to navigate or be deployed across a tonsillar loop or >180° turn without iatrogenic injury.^{19, 20}

In contrast, low-profile self-expanding stents intended for intracranial coil support are designed for navigating tortuous anatomy through low-profile microcatheters and are excellent at atraumatic passage through the tight bends encountered in cervical ICA tonsillar loops. We present a series of patients demonstrating the endovascular management of cervical carotid dissection in the setting of tonsillar loop anatomy, employing the low-profile closed-cell design Enterprise nitinol self-expanding stent (Codman Neurovascular, Raynham, MA, USA).

2. Methods

2.1. Patient selection criteria

From June 2007 through June 2012, five patients underwent endovascular stent reconstruction of cervical ICA dissections involving tonsillar loop anatomy at our center. Patients were considered eligible for stent therapy only if they had failed optimal medical therapy, had hemodynamically significant flow-limiting stenosis, developed an intraprocedural iatrogenic flow-limiting dissection or progressively enlarging pseudoaneurysm, or were unable to undergo anticoagulation. Procedure details and clinical outcome at last follow-up are provided.

2.2. Procedure

In elective cases, patients were administered clopidogrel 75 mg/day (Bristol-Myers Squibb/Sanofi Pharmaceuticals, New York, NY, USA) and aspirin 325 mg/day (acetylsalicylic acid) a minimum of 3 days before intervention; in acute interventions, a bolus of 325 mg of aspirin and 600 mg of clopidogrel administered by gastric tube, and an intraprocedural bolus of weight-based intravenous eptifibatide (Merck & Co., Whitehouse Station, NJ, USA) was administered followed by intravenous drip (1 mcg/kg/minute) for 24 hours with a continued oral regimen of aspirin and clopidogrel daily. Complete digital subtraction angiography

(DSA) was performed of the entire cerebral circulation for evaluation of collateral flow pattern and caliber of the anterior/posterior communicating arteries. After femoral arterial access, a baseline activated clotting time was obtained, and a weight-based bolus of intravenous heparin (70 U/kg) was administered to achieve an activated clotting time of greater than 240 seconds; this was halted after administration of eptifibatide.

The dissection flap was analyzed to recognize true from false lumen. Next, a Synchro or Synchro-2 Soft microwire (Stryker Neurovascular, Fremont, CA, USA), selected for its low stiffness to avoid distorting the tonsillar loop anatomy, was used in conjunction with a Prowler Plus or Prowler Plus Select (Codman Neurovascular) to gently access and stay within the true lumen as the tonsillar loop was navigated. Once distal to the tonsillar loop, a run was performed to insure distal position within the true lumen. Contrast was administered to ensure diffusion within the entire lumen of the distal carotid artery rather than a focal false luminal pocket. The appropriate length Enterprise stent was then deployed to recanalize the dissected lumen. In cases where the inflow zone of the dissection was proximal to the tonsillar loop, an exchange length microwire was used to deliver either a Protégé extracranial carotid stent (ev3 Endovascular, Plymouth, MN, USA) or an Xpert biliary stent (Guidant, Indianapolis, IN, USA) of larger diameter to accommodate the greater caliber of the proximal ICA and tack down the proximal intimal flap. Stenosis was measured on two dimensional DSA using the North American Symptomatic Carotid Endarterectomy Trial (NASCET) method²¹ with the Osirix digital imaging software (Osirix Foundation, Geneva, Switzerland).

3. Results

During the 12 year period from October 2001 through June 2012, 48 patients were found to have cervical ICA dissection. Nine of these involved tonsillar loop anatomy, of whom five underwent endovascular therapy. All patients were women, aged 39–77 years with a mean age $\pm$ standard deviation (SD) of 52 ± 11.6 years. Patient demographics, presentation, etiology, and indications for treatment are displayed in Table 1. Three patients had spontaneous dissection, two were associated with trauma, and one patient had an iatrogenic dissection. Four patients (Patients 6 to 9) did not meet the criteria for endovascular recanalization and were treated medically. Procedural data are presented in Table 2. There were no procedural complications and all cases were technically successful. In three patients, one or two Enterprise stents were used alone. Two patients required additional placement of a proximal conventional biliary or carotid stent to tack down the inflow zone in the more proximal parent vessel. Patient 2 had a dissecting pseudoaneurysm that was treated with coil embolization using the jailing technique (see Section 4. Illustrative patients).

Clinical and radiographic follow-up data are summarized in Table 3. The four nearcomplete occlusions were recanalized and the dissecting pseudoaneurysm was occluded. The average $\pm$ SD dissection-related stenosis was $90 \pm 22\%$ prior to treatment and improved immediately post-treatment to $31 \pm 13\%$ ($p < 0.01$). Patients were followed radiographically with MRI and magnetic resonance angiography (MRA), computed tomography angiography and DSA, with an average $\pm$ SD angiographic follow-up of 28.0 ± 21.6 months. At the last follow-up, dissection-related stenosis improved or remained stable in all patients, with an average

stenosis of $25.2 \pm 12.2\%$ (Fig. 1). Upon discharge, the clinical status of all patients had either improved or remained stable with a latest clinical follow-up mean of 28.1 ± 21.5 months (range, 10 days to 58 months).

4. Illustrative patients

4.1. Patient 2

A 47-year-old left-handed woman presented to a community hospital with acute onset of right-sided weakness and global aphasia, with a National Institutes of Health Stroke Scale (NIHSS) score of 23. She was administered intravenous tissue plasminogen activator (tPA), with an improvement of NIHSS score to 13. Further workup revealed a left ICA dissection. The following day her symptoms worsened. A CT scan demonstrated a dense left middle cerebral artery (MCA) sign, and the patient was transferred to our institution for endovascular intervention. Angiography revealed a left cervical ICA dissection without distal flow (Fig. 2A). After several attempts, the true lumen was accessed via a microcatheter, revealing a 360 degree tonsillar loop involved in the dissection (Fig. 2B). Intra-arterial tPA was administered in the distal lumen and an exchange wire was used to change the Excelsior SL-10 (Boston Scientific, Boston, MA, USA) to a Prowler Plus Select microcatheter. The distal ICA was catheterized, revealing the M1 occlusion (Fig. 2C). Thrombolytic therapy was administered to recanalize the MCA. Two Enterprise stents were deployed across the distal dissection flap in tandem within the tonsillar loop. Finally, a 5 mm $\times$ 40 mm Guidant Xpert stent was deployed concentrically within the proximal Enterprise stent across the proximal dissection flap, re-establishing flow through the left ICA (Fig. 2D). Cone beam computed tomography reconstruction demonstrated some kinking of the stent interstices at the apex of the curvature (Fig. 2E). Despite this kinking, the intimal flap was tacked down and the vessel caliber restored. Follow-up imaging 1 year later demonstrated patency of the stent construct and preserved distal flow (Fig. 2F).

4.2. Patient 3

A 60-year-old woman presented to an outside hospital with two episodes of headache and neck pain. CT scan demonstrated subarachnoid hemorrhage (SAH). A ruptured 4 $\times$ 10 mm wide-necked anterior communicating artery aneurysm and a right cervical ICA tonsillar loop were noted on DSA (Fig. 3A, left panel). The anterior communicating artery aneurysm was coiled endovascularly with complete occlusion (Fig. 3A, right panel). The left cervical ICA demonstrated a tonsillar loop associated with a dissecting pseudoaneurysm (Fig. 3B, top left). This was managed with systemic heparin. The patient underwent hyperdynamic treatment as well as intra-arterial verapamil for SAH-associated vasospasm. Two days after aneurysm embolization, DSA demonstrated an interval increase in the size of the left cervical ICA tonsillar loop-associated pseudoaneurysm (Fig. 3B, top right), increasing further 10 days (Fig. 3B, bottom left) and 25 days later (Fig. 3B, bottom right) with associated parent vessel stenosis threatening cerebral perfusion. A 4.5 $\times$ 37 mm Enterprise stent was deployed across the lesion after navigating a microcatheter into the aneurysm in a jailing technique (Fig. 3C). The pseudoaneurysm was coiled, with minimal residual flow in the inferior aspect of the aneurysm (Fig. 3D). Angiography 2 months and then 2 years later revealed no residual filling of the dissected pseudoaneurysm at the left ICA tonsillar loop

(Fig. 3E) with persistent patency of the native vessel and a modified Rankin Scale score of 0.

4.3. Patient 4

A 44-year-old right-handed woman presented to a community hospital with left-sided hand, arm and leg clumsiness, dysarthria lasting about 20 minutes, and right-sided neck and ear pain 10 days after a motor vehicle accident. MRI and MRA showed right frontal acute and subacute infarcts and bilateral cervical ICA dissections. She was placed on heparin and pre-medicated with aspirin and clopidogrel for 3 days. Because of the bilateral pathology, angiographic evaluation was recommended. Injection of the right ICA demonstrated dissection of the cervical segment extending from the carotid bulb through a tonsillar loop with no distal flow (Fig. 4A). Left ICA injection demonstrated a non-flow-limiting dissection with a pseudoaneurysm (Fig. 4B). Given the patient had an occlusive dissection on the right and a stenotic lesion on the left, the risk for progression of her infarcts was considered high and the decision was made to attempt endovascular reconstruction of the right-sided dissection. A Prowler Select Plus microcatheter guided with a Synchro-2 microwire was used to access the true lumen of the right ICA dissection and cross the distal tortuous tonsillar segment (Fig. 4C). Then a 37 mm × 4.5 mm Enterprise Stent was deployed across this segment followed in tandem with a proximally placed Protégé 8 mm to 6 mm tapered stent across the dissection inflow zone (Fig. 4D). This restored flow across the dissection, with a small area of residual stenosis at the proximal end of the tonsillar loop (Fig. 4E). The tonsillar loop in this case was very tightly wound making a corkscrew turn. The Enterprise stent ended at the proximal end of the turn and the opening force of the stent was not sufficient to keep the true lumen completely open. Her 3 month follow-up angiography demonstrated slight narrowing of the vessel lumen due to progressive collapse of the twisted stent tines (Fig. 4F). Further intervention was deemed high risk, as balloon angioplasty within the kinked stent carried the risk of catching the stent tines with the balloon. At her 24 month clinical follow-up, the patient had recovered completely.

5. Discussion

5.1. Tonsillar anatomy and carotid artery redundancy

The tonsillar loop represents an anatomic variant of the cervical carotid artery also known as carotid artery redundancy. Cervical ICA redundancy has been classified as loops, coils and kinks.^{16, 22, 23} Kinks are sharp bends in the vessel with an angle less than 90°. Coils are 360° turns in a vessel, and a loop produces a C or S-shaped deformity with two turns in the vessel with angles less than 90°.²³ Coils may be due to embryological causes while C- or S-shaped tortuosity and kinking have been ascribed to atherosclerosis or fibromuscular dysplasia^{23, 24}. The congenital etiology may be related to differential growth of the spine and descent of the great vessels into the chest, and is often bilateral when seen in children. Atherosclerotic degeneration of the ICA contributes to redundancy, which may be related to hemodynamic effects as well as the change in elasticity of the artery^{23, 24}. Estimates of the prevalence of tonsillar anatomy in the general population range from 4% to 66% in autopsy series and from 3% to 5% in angiographic series.^{16, 25}

Barbour et al. studied spontaneous ICA dissection finding that ICA redundancy is significantly associated with ICA dissection.¹⁶ La Barbera et al. demonstrated a modification in the structure of the tunica media of vessels with kinking and coiling in which both elastic and muscular tissues were substituted by loose connective tissue in a metaplastic process.²⁴ They hypothesized that the formation of dissection and aneurysm could occur due to a weakened arterial wall caused by this change and may explain the association of redundancy with spontaneous ICA dissection. In our series, three of the five cases were spontaneous. Interestingly, Patient 4 presented with bilateral dissections associated with tonsillar loops along with a ruptured intracranial aneurysm, suggesting a more diffuse arterial pathology.

Tonsillar loop cervical ICA anatomy may serve as an obstacle to the navigation of endovascular devices such as microwires, microcatheters, and stent-delivery systems, and as such iatrogenic injury may cause dissection. Frequent and forceful manipulation of these devices through a tortuous vessel risks damage to the intima of the vessel and can cause dissection. In Patient 1, iatrogenic dissection was caused during navigation across tonsillar anatomy. In this patient, a previously coiled aneurysm with a recurrent remnant at the neck could not be treated endovascularly due to an inability to navigate across the tonsillar cervical ICA.

5.2. Endovascular management of tonsillar loop dissection

To our knowledge there has been only one prior report of endovascular recanalization of a tonsillar loop dissection.²⁶ Pride et al. utilized the Neuroform self-expanding intracranial stent (Boston Scientific) in a telescoping fashion with a balloon-expandable stent to treat a dissecting pseudoaneurysm associated with a tonsillar loop. This patient initially presented with a dissection with complete ICA occlusion, was treated medically, and developed spontaneous recanalization. Subsequent angiography demonstrated the tonsillar loop dissecting pseudoaneurysm, which was treated via stent-mediated coil embolization. To our knowledge there have been no reports of crossing a severely stenotic or occluded dissected tonsillar segment with a microwire or catheter to reconstruct the true lumen.

In our series, we applied the Enterprise stent to treat five extracranial ICA dissections involving tonsillar anatomy. The Enterprise stent is designed for intracranial aneurysm treatment and has a closed-cell structure that is designed to better restrain coils from herniating into the parent vessel. However, the closed-cell design may lead to incomplete stent apposition when deployed around very tight curves, and this may contribute to increased thromboembolic events.^{27, 28} The stent is designed to be retrievable when up to 70% of the device has been deployed, allowing it to be adjusted if placement is not optimal. This attribute allows for “tweaking” the delivery technique for better apposition to the wall in tight curves which may counteract the stent-wall apposition issue.²⁹ Finally, the Enterprise stent may be deployed using the 0.021 inch Prowler Plus microcatheter. The small size and flexibility of this catheter is advantageous for navigation across the dissection flap and subsequently across the loops of the tonsillar anatomy.

Kinking of the closed-cell Enterprise stent can be an issue in tight curves. The tight “corkscrew” configuration of the tonsillar loop in Patient 4 resulted in twisting of the stent

interstices, with incomplete apposition at both ends of the stent (Fig. 4F). The stent was deployed at the distal end of the tonsillar loop, and combined with this twisting the stent did not maintain the full patency of the vessel over time. Kinking of the stent also complicates subsequent catheter navigation and stent deployment. If stent interstices are not recognized during a second stent deployment, crossing stents can result in “double-barrel” entanglement.³⁰

6. Conclusion

Dissection of the cervical ICA associated with tortuous tonsillar loop anatomy can be safely and effectively recanalized using the low-profile self-expanding nitinol Enterprise stent, with long-term patency rate and low procedural risk. Although this technique enables stenting where conventional larger profile and stiffer biliary or carotid stents cannot navigate, kinking and limited radial force of the Enterprise stent remain limitations that should be carefully considered.

Acknowledgments

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

References

1. Schievink WI, Mokri B, Whisnant JP. Internal carotid artery dissection in a community. Rochester, Minnesota, 1987–1992. *Stroke; a journal of cerebral circulation*. 1993 Nov; 24(11):1678–1680.
2. Giroud M, Fayolle H, Andre N, et al. Incidence of internal carotid artery dissection in the community of Dijon. *Journal of neurology, neurosurgery, and psychiatry*. 1994 Nov; 57(11):1443.
3. Leys D, Bandu L, Henon H, et al. Clinical outcome in 287 consecutive young adults (15 to 45 years) with ischemic stroke. *Neurology*. 2002 Jul 9; 59(1):26–33. [PubMed: 12105303]
4. Rubinstein SM, Peerdeman SM, van Tulder MW, Riphagen I, Haldeman S. A systematic review of the risk factors for cervical artery dissection. *Stroke; a journal of cerebral circulation*. 2005 Jul; 36(7):1575–1580.
5. Yaghi S, Maalouf N, Keyrouz SG. Cervical artery dissection: risk factors, treatment, and outcome; a 5-year experience from a tertiary care center. *The International journal of neuroscience*. 2012 Jan; 122(1):40–44. [PubMed: 21905965]
6. Schirmer CM, Atalay B, Malek AM. Endovascular recanalization of symptomatic flow-limiting cervical carotid dissection in an isolated hemisphere. *Neurosurgical focus*. 2011 Jun; 30(6):E16. [PubMed: 21631217]
7. Liu AY, Paulsen RD, Marcellus ML, Steinberg GK, Marks MP. Long-term outcomes after carotid stent placement treatment of carotid artery dissection. *Neurosurgery*. 1999 Dec; 45(6):1368–1373. discussion 1373-1364. [PubMed: 10598705]
8. Kadhodayan Y, Jeck DT, Moran CJ, Derdeyn CP, Cross DT 3rd. Angioplasty and stenting in carotid dissection with or without associated pseudoaneurysm. *AJNR. American journal of neuroradiology*. 2005 Oct; 26(9):2328–2335. [PubMed: 16219841]
9. Ohta H, Natarajan SK, Hauck EF, et al. Endovascular stent therapy for extracranial and intracranial carotid artery dissection: single-center experience. *Journal of neurosurgery*. 2011 Jul; 115(1):91–100. [PubMed: 21417710]
10. Malek AM, Higashida RT, Phatouros CC, et al. Endovascular management of extracranial carotid artery dissection achieved using stent angioplasty. *AJNR. American journal of neuroradiology*. 2000 Aug; 21(7):1280–1292. [PubMed: 10954281]

11. Cohen JE, Gomori JM, Itshayek E, et al. Single-center experience on endovascular reconstruction of traumatic internal carotid artery dissections. *The journal of trauma and acute care surgery*. 2012 Jan; 72(1):216–221. [PubMed: 22310130]
12. Cohen JE, Ben-Hur T, Rajz G, Umansky F, Gomori JM. Endovascular stent-assisted angioplasty in the management of traumatic internal carotid artery dissections. *Stroke; a journal of cerebral circulation*. 2005 Apr; 36(4):e45–e47.
13. Pham MH, Rahme RJ, Arnaout O, et al. Endovascular stenting of extracranial carotid and vertebral artery dissections: a systematic review of the literature. *Neurosurgery*. 2011 Apr; 68(4):856–866. discussion 866. [PubMed: 21242839]
14. Hong MK, Satler LF, Gallino R, Leon MB. Intravascular stenting as a definitive treatment of spontaneous carotid artery dissection. *The American journal of cardiology*. 1997 Feb 15;79(4):538. [PubMed: 9052373]
15. Horowitz MB, Miller G 3rd, Meyer Y, Carstens G 3rd, Purdy PD. Use of intravascular stents in the treatment of internal carotid and extracranial vertebral artery pseudoaneurysms. *AJNR. American journal of neuroradiology*. 1996 Apr; 17(4):693–696. [PubMed: 8730189]
16. Barbour PJ, Castaldo JE, Rae-Grant AD, et al. Internal carotid artery redundancy is significantly associated with dissection. *Stroke; a journal of cerebral circulation*. 1994 Jun; 25(6):1201–1206.
17. Albuquerque FC, Han PP, Spetzler RF, Zabramski JM, McDougall CG. Carotid dissection: technical factors affecting endovascular therapy. *The Canadian journal of neurological sciences. Le journal canadien des sciences neurologiques*. 2002 Feb; 29(1):54–60. [PubMed: 11858536]
18. Schulte S, Donas KP, Pitoulias GA, Horsch S. Endovascular treatment of iatrogenic and traumatic carotid artery dissection. *Cardiovascular and interventional radiology*. 2008 Sep-Oct;31(5):870–874. [PubMed: 18293032]
19. Chiam PT, Samuelson RM, Mocco J, et al. Navigability trumps all: stenting of acute middle cerebral artery occlusions with a new self-expandable stent. *AJNR. American journal of neuroradiology*. 2008 Nov; 29(10):1956–1958. [PubMed: 18768730]
20. Muller-Hulsbeck S, Schafer PJ, Charalambous N, Schaffner SR, Heller M, Jahnke T. Comparison of carotid stents: an in-vitro experiment focusing on stent design. *Journal of endovascular therapy : an official journal of the International Society of Endovascular Specialists*. 2009 Apr; 16(2):168–177. [PubMed: 19456191]
21. Beneficial effect of carotid endarterectomy in symptomatic patients with high-grade carotid stenosis. North American Symptomatic Carotid Endarterectomy Trial Collaborators. *The New England journal of medicine*. 1991 Aug 15; 325(7):445–453. [PubMed: 1852179]
22. Hines GL, Bilaniuk J, Cruz V. Management of carotid coils during routine carotid endarterectomy. *The Journal of cardiovascular surgery*. 2001 Jun; 42(3):365–368. [PubMed: 11398034]
23. Paulsen F, Tillmann B, Christofides C, Richter W, Koebke J. Curving and looping of the internal carotid artery in relation to the pharynx: frequency, embryology and clinical implications. *Journal of anatomy*. 2000 Oct; 197(Pt 3):373–381. [PubMed: 11117624]
24. La Barbera G, La Marca G, Martino A, et al. Kinking, coiling, and tortuosity of extracranial internal carotid artery: is it the effect of a metaplasia? *Surgical and radiologic anatomy : SRA*. 2006 Dec; 28(6):573–580. [PubMed: 17119858]
25. Collins PS, Orecchia P, Gomez E. A technique for correction of carotid kinks and coils following endarterectomy. *Annals of vascular surgery*. 1991 Mar; 5(2):116–120. [PubMed: 1826606]
26. Pride GL Jr, Replogle RE, Rappard G, Graybeal CL, White J, Purdy P. Stent-coil treatment of a distal internal carotid artery dissecting pseudoaneurysm on a redundant loop by use of a flexible, dedicated nitinol intracranial stent. *AJNR. American journal of neuroradiology*. 2004 Feb; 25(2):333–337. [PubMed: 14970042]
27. Heller RS, Miele WR, Do-Dai DD, Malek AM. Crescent sign on magnetic resonance angiography revealing incomplete stent apposition: correlation with diffusion-weighted changes in stent-mediated coil embolization of aneurysms. *Journal of neurosurgery*. 2011 Sep; 115(3):624–632. [PubMed: 21619405]
28. Heller RS, Malek AM. Parent vessel size and curvature strongly influence risk of incomplete stent apposition in enterprise intracranial aneurysm stent coiling. *AJNR. American journal of neuroradiology*. 2011 Oct; 32(9):1714–1720. [PubMed: 21816918]

29. Heller RS, Malek AM. Delivery technique plays an important role in determining vessel wall apposition of the Enterprise self-expanding intracranial stent. *Journal of neurointerventional surgery*. 2011
30. Heller RS, Safain M, Malek AM. Double-barrel entanglement of intracranial Enterprise stents resulting from undetected incomplete stent apposition. *Journal of neurointerventional surgery*. 2012 Nov 1.4(6):e38. [PubMed: 22231279]

Fig. 1. Digital subtraction angiography pre and post-stent placement for (A) Patient 1, lateral left internal carotid artery (ICA) injection, (B) Patient 2, lateral left ICA injection, (C) Patient 3, anteroposterior (AP) left ICA injection, (D) Patient 4, AP right ICA injection and (E) Patient 5, lateral left ICA injection.

Fig. 2.

Patient 2. (A) Left lateral carotid digital subtraction angiography (DSA) demonstrating cervical internal carotid artery (ICA) dissection. (B) After crossing the dissection flap, DSA revealed a tonsillar loop and a left M1 occlusion. (C) Left anteroposterior (AP) ICA DSA showing a left M1 occlusion. (D) Left AP ICA DSA after stent deployment and thrombolysis of the middle cerebral artery. (E) Cone beam computed tomography reconstruction of the stent construct. (F) Left AP ICA DSA 1 year post-treatment showing the stent is patent with preserved distal flow.

Fig. 3.

Patient 3. (A) Digital subtraction angiography (DSA) demonstrating (left) pre and (right) post-coil embolization of a right anterior communicating artery aneurysm (arrow) and tonsillar loop anatomy of the right internal carotid artery (ICA). (B) Successive chronologic imaging (top left panel→top right panel→bottom left panel→bottom right panel) demonstrating enlargement of the left ICA dissecting pseudoaneurysm associated with the tonsillar loop. (C) DSA showing the stent deployed in a jailing technique with a microcatheter in the pseudoaneurysm dome and (D) successful embolization. (E) Follow-up lateral right ICA DSA at 26 months showing no residual filling with stent patency.

Fig. 4.

Patient 4. (A) Right internal carotid artery (ICA) angiography showing dissection involving a cervical ICA with tonsillar loop anatomy (arrow). (B) Left ICA angiography demonstrating non-flow-limiting dissection. A tonsillar loop is distal and uninvolved in the dissection. (C) Left ICA angiography showing distal vessel filling after crossing tonsillar loop with a microcatheter. (D) Left ICA injection after placement of a Protégé stent (ev3 Endovascular, Plymouth, MN, USA) placed in tandem to close the proximal dissection flap. (E) Magnified left ICA digital subtraction angiography demonstrating narrow proximal segment of tonsillar loop after incomplete opening of Enterprise stent (Codman Neurovascular, Raynham, MA, USA). (F) Follow-up cone beam computed tomography demonstrating preserved flow despite incomplete stent apposition at both ends (arrows).

Table 1

Patient demographics, presentation and indication for treatment

Patient	Age, years/Sex	Presentation	Etiology of dissection	Indication for stent
1	50/F	Previously treated aneurysm follow-up	Iatrogenic (Neuron guide catheter ^a)	Flow-limiting occlusion
2	47/F	Right hemiparesis, global aphasia	Spontaneous (cough-associated)	Progressing hemodynamic infarct despite medical management
3	60/F	SAH/anterior communicating artery aneurysm	Spontaneous (cervical pain preceding SAH)	Progressively enlarging pseudoaneurysm and associated stenosis
4	44/F	Left hemiparesis, dysarthria, right Horner syndrome, right frontal cerebral infarct, bilateral cervical ICA dissection	Traumatic (motor vehicle accident)	Flow-limiting occlusion with bilateral cervical ICA dissections
5	54/F	Right hemiparesis, left hemisphere infarct	Spontaneous	Flow-limiting occlusion
6	42/M	Prior dissection, re-presenting with pulsatile cervical mass	Spontaneous	No stent: multiple shallow pseudoaneurysms with complex dissection
7	39/M	Neck pain, lightheadedness, multiple prior dissections	Spontaneous	No stent: chronic appearing.
8	77/F	Left hemiplegia from embolic right ICA infarct/atrial fibrillation	Iatrogenic	No stent: small intimal flap without hemodynamic compromise
9	57/M	Left hemisphere TIA symptoms	Spontaneous	No stent: sufficient collateral circulation.

F = female, ICA = internal carotid artery, M = male, SAH = subarachnoid hemorrhage, TIA = transient ischemic attack.

^aPenumbra, Alameda, CA, USA.

Table 2

Technical results of Stent recanalization of carotid tonsillar loop dissection

Patient	Location	Treatment	Pre→post-luminal stenosis	Complication
1	Cervical LICA	1 Enterprise ^a 4.5 × 37 mm	90% → 27%	None
2	Cervical LICA	2 Enterprise ^a 4.5 × 37 mm 1 Xpert ^b 5 × 40 mm	100% → 20%	None
3	Cervical LICA	1 Enterprise ^a 4.5 × 37 mm	50% → 50%	None
4	Cervical RICA	1 Enterprise ^a 4.5 × 37 mm 1 Protégé ^c 8–6 mm tapered	100% → 20%	None
5	Cervical LICA	2 Enterprise ^a 4.5 × 37 mm	99% → 38%	None

LICA = left internal carotid artery, RICA = right internal carotid artery.

^a Codman Neurovascular, Raynham, MA USA

^b Guidant, Indianapolis, IN, USA.

^c ev3 Endovascular, Plymouth, MN, USA.

Table 3

Technical and clinical outcomes

Patient	Anatomic follow-up	Clinical follow-up (months)	Clinical outcome
1	58 month DSA, patent stent	58	Asymptomatic
2	20 month DSA, patent stent	20	Improving right hemiplegia and aphasia; stable hemianopia
3	38 month MRA, patent stent	38	Asymptomatic
4	24 month CTA, patent stent	24	Complete resolution of neurologic deficit
5	2 day MRA, patent stent	0.33	Lost to follow-up, patient returned to native country by commercial flight

CTA = computed tomography angiography, DSA = digital subtraction angiography, MRA = magnetic resonance angiography.