“Squid-Capture” Modified In Situ Stent–Graft Fenestration Technique for Aortic Arch Aneurysm Repair

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Abstract An 83-year-old female was found to have an fusiform aneurysm in the aortic arch. She was deemed to be a high surgical risk; therefore, endovascular stent–graft placement followed by revascularization of the brachiocephalic trunk using in situ stent–graft fenestration was considered. However, the safe application of fenestration was deemed difficult due to the tortuosity of the brachiocephalic artery. The patient was successfully treated with the aid of the “squid-capture” technique, which consists of deployment of the stent–graft in a snare wire loop that was

advanced from the brachiocephalic artery and fenestration of the stent–graft with the support of the loop. A follow-up exam revealed complete sealing of the aneurysm without any complications. The squid-capture technique allows for the safe and secure puncture of the graft.

Keywords Arterial intervention · Aorta · Endovascular aneurysm repair/endovascular aortic repair · Thoracic aortic aneurysm · In situ fenestration · Total aortic arch reconstruction

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Introduction

The major limiting factor of thoracic endovascular aortic repair (TEVAR) for the treatment of thoracic aortic aneurysms (TAA) involving the aortic arch is an inappropriate landing zone, such as a short, irregular, or angled neck, that does not ensure an adequate seal. Although supra-aortic arteries may be covered to gain a proximal landing zone, this step often necessitates additional extra-anatomical bypass surgery to maintain blood flow to the carotid or subclavian arteries [1, 2]. Covering the brachiocephalic artery necessitates prior total debranching of the supra-aortic trunks through a sternotomy [2], which renders these hybrid procedures highly invasive.

Retrograde in situ fenestration is an endovascular option for revascularization of the supra-aortic branches after covering the supra-aortic arteries. In this technique, the stent–graft is first deployed in the aorta prior to being punctured and then fenestrated in situ by a retrograde approach from the target vessel. This technique also can be adapted to revascularize the brachiocephalic artery after a zone 0 landing, which allows endovascular aortic arch reconstruction without performing a sternotomy or aortic

side clamping [3–5]. We were fortunate to puncture the graft successfully at a proper position via the brachiocephalic artery in our first reported case [3]; however, there was a limitation of the in situ fenestration technique due to the anatomy. The delivery sheath or catheter has to be placed as close to the stent-graft as possible and ideally be directed perpendicular to the stent-graft when puncturing the fabric or graft material. However, navigating the sheath or catheter and then maintaining the ideal position during puncture is especially challenging in patients with a hostile anatomy. A tortuous nature and acute angle of the target artery and an offset take-off where the supra-aortic trunk tilts either anteriorly or posteriorly to the axis of arch are major limiting factors. Poor controllability of the needle and inappropriate puncture due to these anatomical challenges not only leads to compromise of the quality of fenestration but also may lead to damage to the access artery, the aorta or the surrounding organs.

To overcome this issue, we devised a modified in situ fenestration technique that we call the “squid-capture” technique, which consists of a deployed stent-graft that is punctured in situ through a sheath that was positioned with the aid of a snare wire loop. The purpose of this article was to report a case that was safely and successfully treated with the in situ fenestration of a stent-graft from a hostile brachiocephalic artery by applying the squid-capture technique.

Case Report

Institutional review board approval by our institution was not necessary for the preparation of this report. An 83-year-old female with chronic obstructive pulmonary disease on home oxygen therapy was found to have an asymptomatic fusiform aneurysm in the aortic arch and was referred to our institution. Contrast-enhanced computed tomography (CT) acquired at our institution revealed a fusiform

aneurysm in the aortic arch measuring 83-mm in its largest diameter (Fig. 1). The aneurysm involved the take off of the brachiocephalic artery. The aorta just proximal to the brachiocephalic artery was normal in appearance and 38 mm in diameter. The diameter of brachiocephalic artery was 12 mm. The patient was considered high-risk for open surgical repair or bypass surgery through a median sternotomy due to compromised pulmonary function. However, the length of the fixation area distal to the brachiocephalic artery was insufficient for TEVAR because full coverage of the brachiocephalic arteries was indispensable to sufficient stent-graft fixation. Therefore, we performed endovascular aortic arch reconstruction by “Zone 0” stent-graft implantation with in situ stent-graft fenestration via the brachiocephalic artery to gain antegrade flow.

Under general anesthesia, both common carotid arteries and the left subclavian and femoral arteries were exposed through bilateral cervical, left subclavicular and left femoral incisions. After systemic heparinization, an 8-mm ringed polyester graft (Gelsoft, VASCOTEK, Scotland) was anastomosed from the left axillary artery to the left femoral artery through tunneling from the chest to the abdominal wall. A left carotid-subclavian bypass and an intercarotid bypass were performed using 6- and 8-mm ringed polyester grafts, respectively. The left carotid artery was ligated just proximal to the anastomosis. The right subclavian artery was then exposed, and an 8-mm graft was anastomosed side-to-end as a conduit to achieve retrograde access to the brachiocephalic trunk. The external iliac arteries were not large enough to allow access; therefore, a common iliac conduit was created to provide access for the main graft. To reduce the risk of embolization, the right common carotid artery was clamped proximal to the anastomosis before the endoluminal procedure.

Before deployment of the aortic stent-graft, an 8-F, 25-cm sheath (Medikit, Tokyo, Japan) was placed into the

Fig. 1 Postcontrast CT of an 83-year-old female. **A** 3D volume-rendered reconstruction. **B** Axial image shows a fusiform aneurysm in the aortic arch at the level of the brachiocephalic artery (arrow)

brachiocephalic artery in a retrograde fashion through the right subclavian conduit. To create a retrievable snare wire loop, a microguidewire (Chikai 0.014/200 cm, Asahi Intec, Japan) was folded in two on the back table to form a loop before it was introduced into the 8-F sheath and deployed in the ascending aorta. A guidewire with a diagnostic 4-F catheter from the aortic conduit was advanced thorough the snare wire loop into the ascending aorta, and the wire was exchanged with a Landerquist wire (Cook, Bloomington, IN). The first Gore TAG stent-graft (34 mm in diameter and 150 mm in length; W. L. Gore Associates, Inc., Flagstaff, AZ) was introduced via a 24-F introducer sheath in the conduit, positioned just distally to the take-off of the left carotid artery and then deployed. A second Gore TAG stent-graft (40 mm in diameter and 200 mm in length) was advanced into the ascending aorta through the snare loop over the Landerquist wire and deployed within the snare loop with a 5 cm proximal landing in the healthy ascending aorta. The stent-grafts were dilated and aligned to the wall of the aortic arch with a balloon. By gently pulling both ends of the guide wire to contract the loop, the 8-F sheath in the brachiocephalic artery was advanced and the tip of the sheath was held in the stent-graft, which was then confirmed under left and right anterior oblique projection on digital subtraction angiography. While maintaining the tension of the snare loop, a 20-gauge, 40-cm needle (PTC needle, Hakko Co., Ltd., Tokyo, Japan) loaded in the dilator of the 6-F sheath (Flexor ANSEL Guiding Sheath, Cook) was inserted in the 8-F sheath in a parallel fashion to the snare wire and carefully advanced into the TAG graft through the fabric, followed by a 0.018-inch guidewire (Cope Mandrill Wire Guides, Cook) that was advanced through the inner lumen of the needle into the ascending aorta (Fig. 2A–E). The needle hole was dilated with a 4-mm angioplasty balloon. After the 0.018-inch wire was exchanged with a 0.035-inch Amplatz ultra stiff guide wire (Cook). After the retrieval of the 8-F sheath in the brachiocephalic artery, the snare loop was dislodged by pulling out the stiff end and feeding the flexible end of the 0.014-inch wire through the conduit at the right subclavian artery. A 12-F sheath (Gore DrySeal Sheath, W.L. Gore Associates, Inc.) was advanced into the ascending aorta through the fenestration in a retrograde fashion. A Gore excluder iliac extender stent-graft (14 mm in diameter and 7 cm in length) was positioned with the proximal edge advanced approximately 2 cm into the ascending aorta and then deployed. The fenestration was reinforced with a 30-mm length Palmaz Large stent loaded onto a 12-mm diameter balloon (Fig. 2F). A completion angiogram confirmed the sealing of the aneurysm and reperfused antegrade flow from the brachiocephalic artery to both common carotid arteries. The femoro-subclavian bypass was not ligated in case of a possible failure of the fenestration.

Cerebral oxygenation in the frontal region was continuously monitored using near-infrared spectroscopy, which did not show any significant changes throughout the procedure.

The patient was extubated 2 days after surgery. A contrast-enhanced CT exam acquired on postoperative day 2 revealed a type II endoleak from the left subclavian artery, which was subsequently occluded with coils through transcatheter embolization. Another CT scan acquired 11 days after the operation revealed stent-graft patency without an endoleak. The patient was discharged uneventfully on postoperative day 17 and is being followed up.

A follow-up CT after 6 months showed slight aneurysmal shrinkage (78 mm in diameter) without any type of stent-graft complication (Fig. 3). The patient continued to be free of any symptoms associated with the aneurysm at the 8-month follow-up.

Discussion

This report illustrates the modified procedure that we call the “squid-capture” technique. The term was coined in light of the similarity of the stent-graft within the snare loop to the attack position of a squid, as shown in Fig. 4A, for in situ fenestration after TEVAR for TAA involving the aortic arch. This modification allows a safe and secure in vivo puncture of the stent-graft in a retrograde fashion to reestablish blood flow in the brachiocephalic artery even with tortuous arteries. Furthermore, the TAA involving the aortic arch was successfully sealed without any type of endoleak or complication.

There are several reports regarding the in situ fenestration of stent-grafts for the treatment of TAAs, wherein the initial holes were created using a needle or a laser catheter in a retrograde fashion from the target vessel, dilated by balloons and then reinforced by covered or uncovered stents to maintain perfusion [3–6]. Throughout our clinical experiences with in situ fenestration, we often encounter difficulty in delivering the needle to the proper position due to poor control of the delivery sheath of the needle. When attempting retrograde fenestration, the tip of the delivery sheath or catheter should be placed as close to the stent-graft as possible while performing the puncture to obtain successful fenestration. However, navigating the sheath or catheter and keeping the sheath or catheter close to the stent-graft body in the orifice of the vessel until the delivery of the needle through tortuous arteries is quite challenging despite manipulating the preangulated sheath. With the squid-capture technique, the tip of the support sheath within the target vessel was advanced and then pressed against the body of the stent-graft by pulling both ends of the guide wire to tighten the snare loop and by

Fig. 2 **A** Schematic drawing of the squid-capture technique for in situ fenestration. After left femoral-subclavian, left carotid-subclavian and intercarotid bypasses were created, and the stent-graft was advanced and then deployed within the snare loop, which had been inserted via the right subclavian conduit. **B** Fluoroscopic image during the procedure shows the main aortic stent-graft deployed within the loop (arrow). **C** Right anterior oblique fluoroscopic image taken during the delivery of the needle shows that the tip of the sheath in the tortuous brachiocephalic artery was not positioned

close to the orifice. By gently pulling the snare wire, the sheath with the needle can easily be advanced to the stent-graft. **D** Left anterior oblique fluoroscopic image showed that the needle easily advanced to the ascending aorta through the graft, which is followed by the advancement of 0.018-inch wire through the needle. **E** The stent-graft (14.5 mm in diameter and 7 cm in length) was deployed at the fenestration in the brachiocephalic artery. **F** The branch was reinforced by a 30-mm Palmaz Large Stent (arrowhead)

pushing the delivery sheath (Fig. 4B, C). Applying this technique allows the stiff puncture needle to be delivered with a stable sheath.

The three-dimensional geometry between the graft body and needle during puncture affects the in situ fenestration and determines the properties of the fenestration itself.

Bench examination of the fenestration under various circumstances revealed that fenestrations of the graft with an acute angle between the fabric and the needle tend to create a non-circular hole or tear on the fringe of the fenestration [7, 8], which compromises the quality of fenestration and can potentially lead to type III endoleaks or tear

Fig. 3 Postcontrast CT obtained 6 months after the procedure. 3D volume-rendered reconstruction (A) and its original axial image (B) shows the successful isolation of the aneurysm. Note the patent femoro-subclavian bypass (arrow)

Fig. 4 A Schematic drawing illustrating the squid's attack position, which led to the coining of the term "squid-capture". B, C Illustration of the cross-sectional view of the aorta in the squid capture technique before (B) and after tightening (C). Tightening of the loop

forced the delivery sheath into the proper position and angle during the puncture of the graft (arrow in C). Note blue circle = stent-graft in cross-section

propagation that results in the loss of stent-graft integrity. In addition, a simple puncture with hostile geometry potentially not only creates an inadequate hole on the main graft but may also injure the native aorta, access arteries or surrounding organs, which can lead to fatal complications. To obtain secure and high-quality fenestrations, the delivery sheath and needle should be ideally angled at 90° to the graft material [7, 9]. The squid-capture technique aids in attaining a perpendicular angle between the needle and the graft during the fenestration process and thus helps in the creation of high-quality fenestrations without any complications due to puncture error (Fig. 4).

Broad adaptability is another advantage of this technique because it allows for secure and high-quality fenestrations even in cases where there is a hostile anatomical relationship between the side branches and the aorta. This technique can also be applied with laser-based fenestration [9, 10], which also needs accurate positioning of the laser catheter to ensure precise puncturing of the endograft. This technique can even be adopted for the left subclavian and carotid arteries to fit various anatomical conditions. This

broad adaptability eventually widens the indications for in situ fenestrations and total endovascular reconstructions.

There are options in revascularizing supra-aortic branches in total aortic arch reconstruction using in situ fenestration. Single fenestration in either supra-aortic trunk combined with bypass surgery [3] and multiple fenestrations in the supra-aortic branches [4] have been reported. The brachiocephalic artery can provide a large enough diameter as a main trunk for the downstream carotid and subclavian arteries after reconstruction; therefore, we prefer to create a fenestration in the brachiocephalic artery along with bypass surgery among the supra-aortic arteries. Another advantage of revascularizing the brachiocephalic artery includes reduction of the efforts involved in and costs of the embolization after the procedure. Although embolization of the subclavian artery after these procedures is relatively simple and easy, the obliteration of the large and relatively short brachiocephalic artery after fenestration of the left common carotid artery or left subclavian artery can be challenging and costly. Another advantage is that the manipulation from the right subclavian artery to the brachiocephalic artery with

transient clamping of the proximal right common carotid artery may reduce the chance of stroke and injury to the carotid arteries. Hence, this squid-capture technique seems promising in enhancing the feasibility of single in situ fenestration of the brachiocephalic artery.

There are some concerns regarding the squid-capture technique. The manipulation of the snare loop in the aorta potentially causes embolic complications in the presence of mural thrombi or a plaque in the aortic arch; therefore, careful manipulation of the snare loop is essential to reduce the possibility of such complications. There also is an alternative wherein a distal aortic stent-graft is first deployed distally in the aortic arch and snare wire manipulation is conducted within the prior stent-graft. The second stent-graft can be advanced through the snare loop within the first stent-graft. While advancing the stent-graft through the snare loop in the aorta, the tip of the delivery system can be engaged with the snare wire due to a gap between the nose cone and the stent-graft. To dislodge the snare loop, the position or shape of the loop may be adjusted by loosening the snare wire or by pulling or pushing either end of the snare wire. While the snare loop is tightened during the puncture of the stent-graft, transient constraints of the stent-graft within the loop may also occur, which may alter the apposition of the stent around the targeted vessel. Too much tension should be avoided to prevent compromising the apposition of the stent-graft or migration. The seal should ideally be long enough proximally to reach the take-off of the revascularized artery, and it should be longer than 3 cm in order to maintain sufficient seal after the puncture of the main graft.

In conclusion, a TAA in the aortic arch was successfully treated with the in situ fenestration of a graft using a modified technique known as the “squid-capture” technique despite a hostile anatomy. Our limited experience indicates that the procedure was feasible enough for various differences in anatomy or use in other supra-aortic branches. This technique enhances the safety and security of in vivo graft punctures and expands the application of

in situ fenestration. Thus, it has the potential to extend the limits of thoracic endovascular therapy in the aortic arch.

Conflict of interest Norio Hongo has received fee for educational lectures at the request of Cook Medical. Shinji Miyamoto, Rieko Shuto, Tomoyuki Wada, Noritaka Kamei, Aiko Sato, Shunro Matsumoto, Hiro Kiyosue, and Hiromu Mori declared that they have no conflict of interest

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