In situ bending of thoracic stent grafts: Clinical application of a novel technique to improve conformance to the aortic arch

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Purpose: **A straight thoracic stent graft often complies poorly with the curvature of the aortic arch. We have previously reported an in vitro model of a modified stent graft that can be bent in situ after deployment to improve conformance to the aortic arch. We now report the first clinical experience with this technique in three consecutive patients.**
Methods: **Between September 2007 and August 2008, three patients were treated for different pathologies of the aortic arch with a modified thoracic stent graft that was fitted with a sliding self-locking knot and a detachable Bowden cable. Transfemoral traction on the Bowden cable enables controlled shortening of the proximal part of the stent graft at the inner curve after deployment. The stent graft is thereby directed to allow for better apposition to the aortic wall.**
Results: **The modified thoracic stent grafts were correctly orientated and deployed in all patients. Transfemoral traction on the Bowden cable successfully bent all stent grafts and improved vessel wall apposition without a residual gap on the inner curve. The Bowden cable was successfully released and withdrawn in all patients.**
Conclusion: **In situ bending of thoracic stent grafts with a sliding self-locking knot is feasible and improves proximal apposition of the device at the inner curve of the aortic arch. More data and longer follow-up are required to confirm the applicability of this technique. (J Vasc Surg 2009;49:1613-6.)**

Endovascular repair of the thoracic aorta has emerged during the last decade.[1-3] Despite expanding indications for stent grafting to more proximal lesions in the aortic arch,[4-6] technical and anatomic difficulties persist, caused by the inflexible structure of most tubular stent grafts and their inability to conform to the curved aortic arch. Several articles have reported inadequate stent graft apposition along the inner curve of the arch resulting in type I endoleaks and stent graft collapse.[7-10]

The anatomic and procedural factors that may be associated with stent graft collapse include small aortic diameter, gross stent graft oversizing, emergency treatment for aortic transsection, and the presence of a so-called gothic arch.[8,11-13] The systolic jet that hits the outer aspect of a protruding stent graft may also cause excessive pulsatile motion of the proximal stent. Metal fatigue may develop rapidly, with subsequent stent fracture and stent graft collapse.[11,12]

Precurved stent gafts have been proposed to prevent this potentially devastating complication.[12-14] We recently presented a technique that may improve stent graft alignment in the aortic arch by bending the proximal part of the thoracic stent graft in situ after deployment by means of a Bowden cable.[15] We now report the first clinical experience with this technique in three consecutive patients.

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METHODS

Stent graft customization. Conventional thoracic stent grafts (Cook Zenith TX2, Cook Europe, Bjaeverskov, Denmark) of various diameters were used.[2] Modification of the stent graft has been described previously in detail.[15] In the first patient, the stent graft was mounted on a straight delivery system with a nitinol core; but subsequently, a precurved stainless steel core was used. The precurved core facilitates insertion and correct rotation of the device within the aortic arch. A Bowden cable was added to transmit traction from the groin to the stent graft with a sliding knot. The suture is placed to shorten the stent graft at the inner curve; thereby, the stent graft is bent. A release mechanism allows detachment of the Bowden cable so that only the graft-shortening suture on the outer aspect of the stent graft is left behind after deployment (Fig 1). Proximal graft-fixating barbs were only used on the outer half of the circumference of the proximal stent to prevent intimal damage during the bending motion.

Deployment technique. The procedures were performed in an endovascular operating room with a fixed

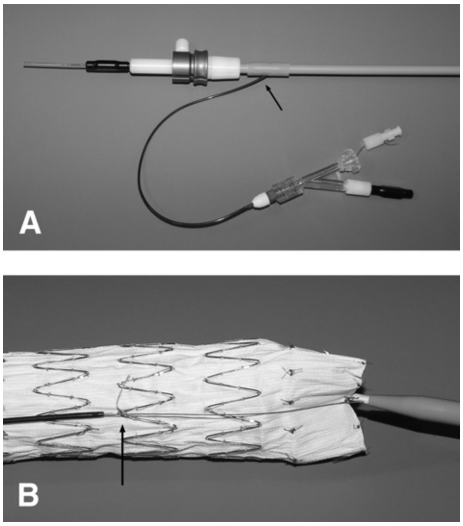

Fig 1. Customization of a conventional thoracic stent graft (Cook Inc). **A,** the Bowden cable enters the central rod *(arrow)* of the distal part of the introducer system. The Bowden cable contains a pulling line and a trigger wire for its detachment. **B,** The proximal part of the stent graft is attached to the central rod at the nose cone. The sliding knot is positioned just proximal to the Bowden cable housing on the inner curve *(arrow)*.

imaging system (Siemens Angiostar and Siemens Axiom Artis, Munich, Germany) under general anesthesia and systemic heparinization (100 U/kg). As an adjunctive measure, spinal fluid drainage to prevent spinal cord ischemia was used in patients 2 and 3, in whom the left subclavian artery (LSA) needed to be covered. The common femoral artery was accessed percutaneously and a Lunderquist super stiff guidewire (Cook Europe, Bjaeverskov, Denmark) was passed into the ascending aorta. A 5F angiographic catheter was placed from the contralateral common femoral artery. The stent graft was passed over the Lunderquist wire into the aortic arch and orientated with the suture line at the minor curve. Correct orientation was facilitated by the precurved central rod and could be confirmed under fluoroscopy by means of a notch that was excavated from the nose cone. Accurate placement was determined by repeat angiographies. The trigger wires for proximal and distal detachment of the stent graft were released.

The fully deployed stent graft was bent in situ by pulling the Bowden cable until the stent graft assumed full apposition to the inner curve of the aortic arch. Finally, the last trigger wire was released to disconnect the pulling line from the graft-shortening suture; thereby, no additional foreign material was left in the aortic lumen. A completion angiography confirmed the final position of the stent graft.

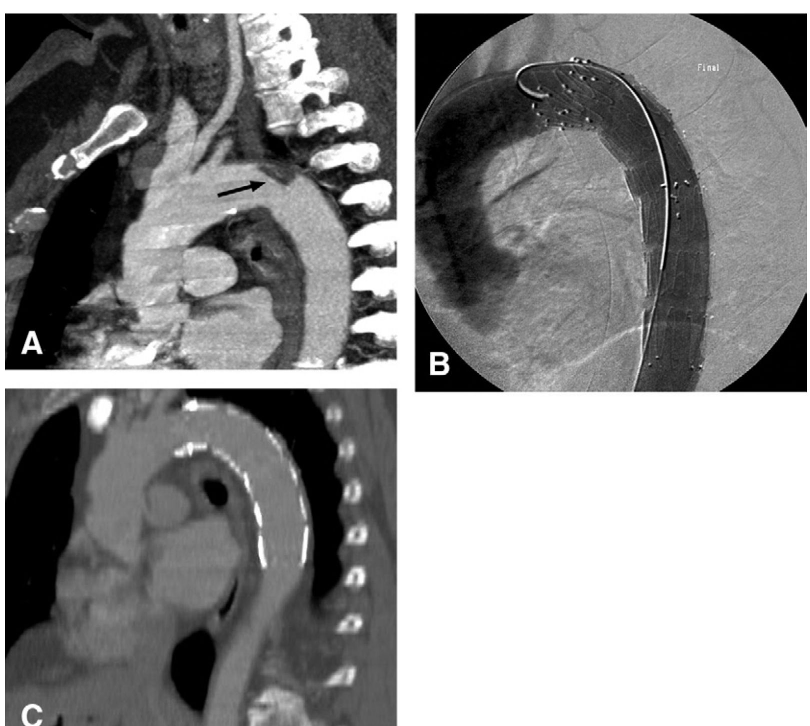

Fig 2. A, In this preoperative computed tomography angiography (CTA) in patient 1, the maximum intensity projection of the aortic arch shows a contrast-filling defect distally to the left subclavian artery *(arrow)*. **B,** Completion angiogram after placement of a thoracic stent graft and in situ bending shows full apposition to the inner curve. **C,** CTA after 1 year shows the apposition of the stent graft is unchanged.

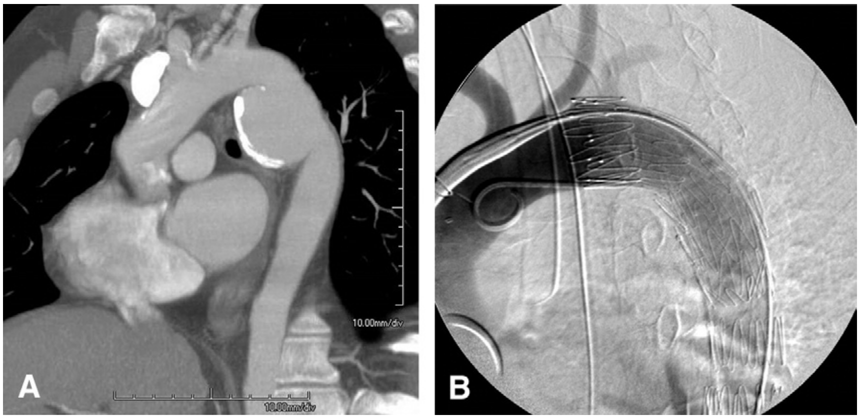

Fig 3. A, In this preoperative computed tomography angiography in patient 2, multiplanar reformation shows a calcified pseudoaneurysm of the descending aorta with a short neck and a steep angle of the aortic arch. **B,** Completion angiogram after placement and in-situ bending of a thoracic stent graft shows full apposition to the inner curve of the gothic aortic arch.

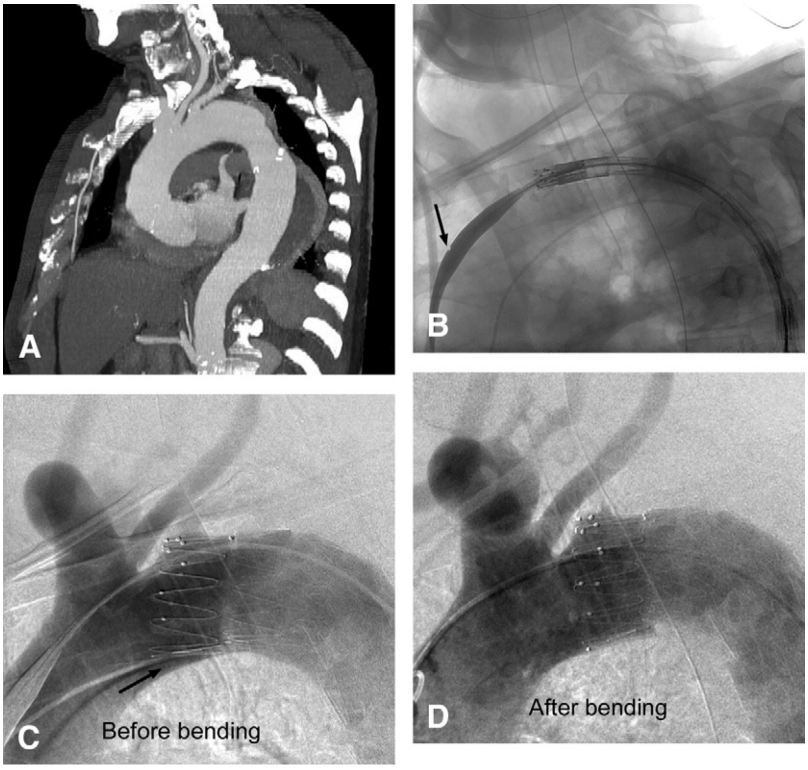

Fig 4. A, Maximum intensity projection of the preoperative computed tomography angiography in patient 3 demonstrates a 7-cm thoracic aortic aneurysm. **B,** A notch at the outer aspect of the introducer tip confirms correct orientation of the device in the aortic arch *(arrow)*. **C,** In the fully deployed sent graft before in situ bending, a gap is present between the proximal stent and the aortic wall at the inner curve *(arrow)*. **D,** Full apposition at the inner curve has been achieved after in situ bending. Note that the protrusion of the stent graft into the left subclavian artery occurred during early deployment and was not caused by the subsequent bending procedure.

Patients. Three patients with various aortic arch lesions and morphologies were enrolled. All were considered high-risk patients for conventional surgical repair and agreed to endovascular treatment.

Patient 1 was a 66-year-old woman who presented with repeated multiple arterial embolizations to both her lower limbs. A recurrent thrombotic mass developed in her descending aorta (Fig 2). The diameter of the aorta was 24 mm, and there was an unfavorable Gothic arch configuration. A 28-mm thoracic stent graft was customized as described above and deployed just distal to the LSA.

Patient 2 was a 41-year-old man who had undergone repeated heart and kidney transplantations. He presented with a pseudoaneurysm of the descending aorta 1 cm distally to the origin of the LSA (Fig 3). The diameter of the aorta was 26 mm, and a 30-mm thoracic stent graft was selected for placement across the LSA orifice.

Patient 3 was a 65-year-old man with hypertension who presented with a 7-cm thoracic aortic aneurysm. The proximal part of the aneurysm was located just distally to the LSA (Fig 4). The aortic diameter was 34 mm, and a 38-mm thoracic stent graft was selected.

RESULTS

Orientation, deployment, and in situ bending of the modified thoracic stent grafts were successful in all three patients. Proximal stent graft apposition was achieved without any residual gap on the inner curve (Figs 2-4). In patient 3, the proximal edge of the stent graft slid into the orifice of the LSA rendering a less favorable position of the sealing stent. The subsequent in situ bending, however, improved the stent position significantly (Fig 4).

One procedurally related complication occurred. In patient 1, a dissection developed of the right external iliac artery that subsequently continued to the common femoral artery and led to acute ischemia of the leg. The patient was treated with thromboendarterectomy of the common femoral artery and iliac stenting. The 1-year follow-up CT-angiography showed the modified stent graft had not changed position (Fig 2, *C*).

The clinical follow-up of all three patients was uneventful up to 14, 7, and 2 months.

DISCUSSION

The current study demonstrates the clinical feasibility and safety of in situ bending of thoracic stent grafts. A better proximal apposition of the device at the inner curve of the aortic arch was achieved that may prevent early and late stent graft complications.

A significant proportion of patients considered for endovascular treatment of thoracic aortic lesions have a short proximal landing zone.[16] Intentional coverage of the LSA can increase the length of the proximal landing zone and the number of patients suitable for endovascular repair. Current thoracic stent grafts are straight and semi-rigid due to their segmentation. The choice of a more proximal landing zone within the aortic arch may compromise the proximal seal due to incorrect orientation of the proximal stent. In situ bending enables reorientation of the proximal stent.

One limitation of in situ bending is the need for proper orientation of the stent graft. A notch on the dilatator tip proved to be a reliable marker for orientation (Fig 4, *B*). A precurved delivery system with a relatively stiff central core assumes automatically correct orientation within the aortic arch and is extremely helpful.

CONCLUSIONS

In situ bending of thoracic stent grafts with a sliding self-locking knot is feasible and improves proximal apposition of the device at the inner curve of the aortic arch. This may improve the proximal seal and reduce the risk of stent graft collapse. More data and longer follow-up are required to confirm the applicability of this technique.

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