Paraplegia prevention branches: A new adjunct for preventing or treating spinal cord injury after endovascular repair of thoracoabdominal aneurysms

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In this report, we describe a technique that could potentially be used for both prevention and treatment of spinal cord ischemia (SCI) in endovascular repair of thoracoabdominal aneurysms. This technique involves using a specially designed endograft with side branches (paraplegia prevention branches [PPBs]), which are left patent to perfuse the aneurysmal sac and any associated lumbar or intercostal arteries in the early postoperative period. The use of PPBs with this technique is feasible and allows for a temporary controlled endoleak that may be useful for preventing or reversing spinal cord injury. This technique may be considered as an adjunct to the more standard perioperative physiological manipulations such as permissive hypertension and spinal fluid drainage. (J Vasc Surg 2011;54: 252-7.)

Spinal cord ischemia (SCI) and consequent paraplegia/paraparesis is reported to occur in 0% to 17% of cases undergoing endovascular repair of thoracoabdominal aneurysms (TAAAs).[1-5] An important benefit of the endovascular approach is avoidance of aortic cross-clamping with subsequent cord reperfusion injury and systemic inflammatory response.[6] Adjunctive physiological measures have been implemented to prevent or reverse SCI after TAAA repair, including cerebrospinal fluid (CSF) drainage and systemic blood pressure optimization. Despite the combination of the endovascular technique and these prophylactic measures, SCI remains a significant risk and can result in devastating consequences for both the patient and his or her family.

The need for consideration of novel physiological and/or anatomic measures to manage SCI risk after endovascular repair of TAAA has become evident. Recently, Reilly and Chuter[7] reported a direct anatomic treatment approach using an induced type Ib endoleak to increase spinal cord perfusion and reverse paraplegia occurring after endovascular exclusion of a type II TAAA. In this report, we describe a more predictable anatomic approach that may theoretically decrease the risk of SCI. This technique involves side branches, or paraplegia prevention branches (PPBs), to perfuse the aneurysmal sac in the early postoperative period. This novel concept originated by Professor Krassi Ivancev (personal communication), may be used as both prevention and treatment of SCI in endovascular TAAA repair with branched aortic stent grafts.

TECHNIQUE

A 71-year-old man underwent endovascular repair of an asymptomatic type II TAAA with a branched stent graft. The maximum diameter of the aneurysm was 7.5 cm and considerable burden of clot was present throughout the length of the aneurysm (Fig 1). The patient was considered to be at increased risk for open aortic repair because of significant comorbidities, including coronary artery disease. Preoperative imaging demonstrated a normal left subclavian artery and internal iliac arteries. There was a prominent intercostal artery of 3.4-mm diameter at the T5 level, whereas at the infrarenal portion of the aorta, one pair of lumbar arteries was perfused through the aneurysm sac (Fig 2).

Four stent graft components (Cook Medical, Bloomington, Ind) were required (thoracic, paravisceral, bifurcated infrarenal, and iliac extension) to cover the whole length of the descending thoracic and abdominal aorta, beginning just distally to the origin of the left subclavian artery and ending proximal to the iliac bifurcations (Fig 3). The technique has been described previously.[4,8] The customized paravisceral component was designed with four downward-facing side branches for the celiac, superior mesenteric, and two renal arteries. The distal edge of this component was planned to land in the proximal third of the

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Competition of interest: none.

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The editors and reviewers of this article have no relevant financial relationships to disclose per the JVS policy that requires reviewers to decline review of any manuscript for which they may have a competition of interest.

0741-5214/$36.00

doi:10.1016/j.jvs.2010.11.131

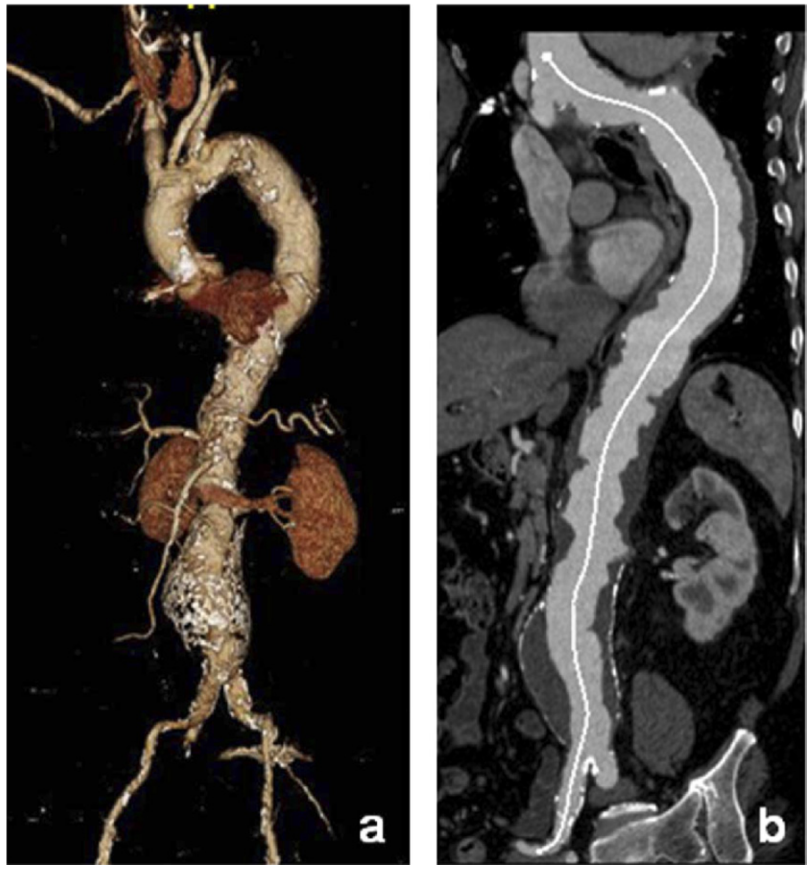

Fig 1. a, Type II thoracoabdominal aneurysm. **b,** The maximum diameter of the infrarenal aorta was 7.5 cm. There was increased burden of clot throughout the descending thoracic and abdominal aorta.

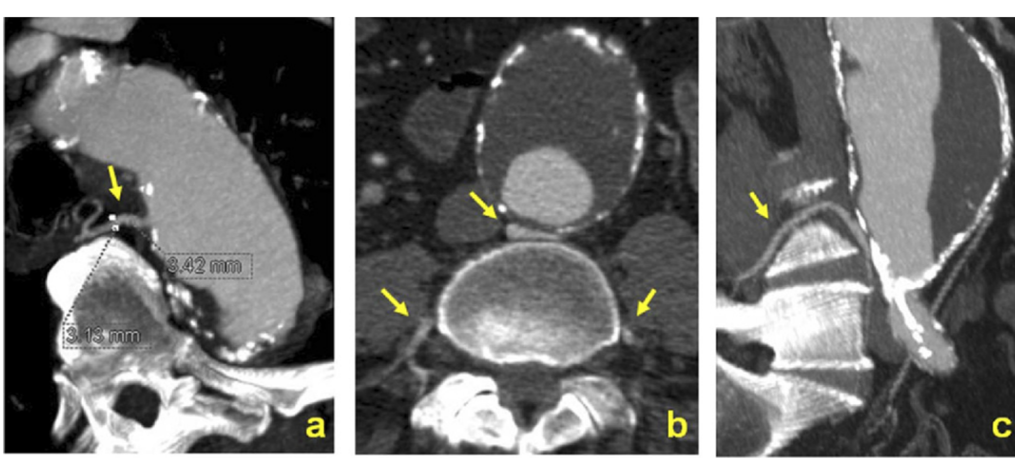

Fig 2. a, A prominent intercostal artery of 3.4-mm diameter at the T5 level. **b and c,** A pair of large lumbar arteries perfused from the aneurysmal sac (*yellow arrows*).

infrarenal aorta. The infrarenal custom-made bifurcated graft was planned with two upward-facing side branches (6 × 21 mm; PPBs), that were deployed in the mid-portion of the infrarenal aneurysm (Fig 4).

All aortic stent grafts were successfully inserted and deployed through the surgically exposed right femoral artery. The procedure lasted 5.5 hours, estimated blood loss was 550 mL, and the infused contrast volume was 210 mL.

Fig 3. Postoperative computed tomographic angiography (CTA) showing the extent of aortic coverage.

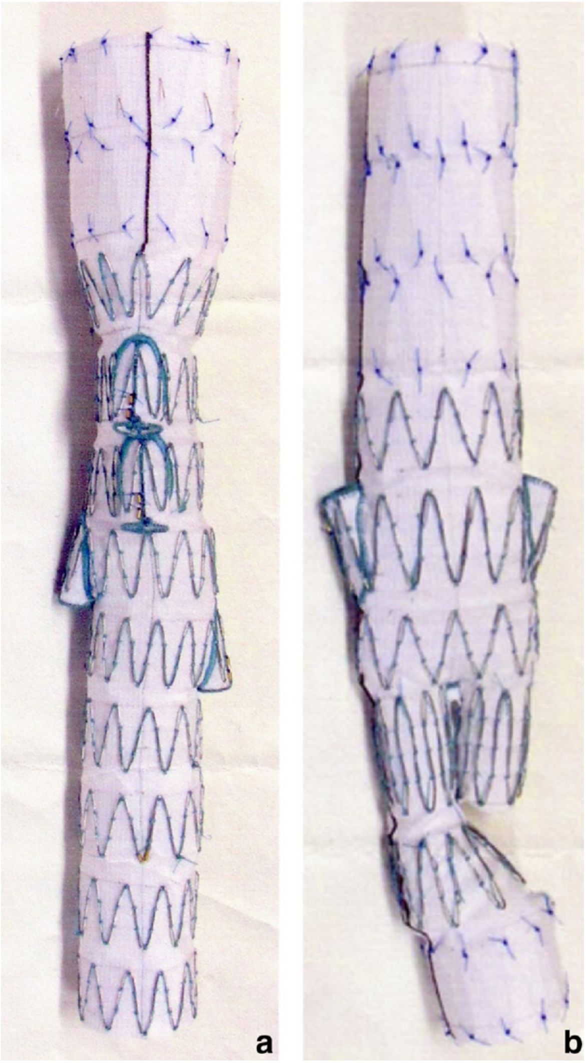

Fig 4. a, Paravisceral component with four downward-facing side branches for the celiac, superior mesenteric, and two renal arteries. **b,** Infrarenal custom-made bifurcated graft, designed with two upward-facing side branches paraplegia prevention branches (PPBs).

A spinal catheter was inserted for CSF pressure monitoring and drainage both during the procedure and postoperatively. The mean arterial blood pressure was maintained above 90 mm Hg and the CSF pressure was maintained at 10 cm H_2O, according to standard institutional protocols. The patient had intermittent postoperative confusion for the initial 3 days but otherwise had an uneventful recovery. A computed tomographic angiogram (CTA) obtained 3 days after the procedure, demonstrated flow into the infrarenal aneurysm and perfusion through the lumbar arteries (Fig 5).

Three weeks later, the patient was readmitted and repair was completed by percutaneous closure of the PPBs. A spinal catheter was placed for CSF drainage. Bilateral femoral access was obtained with two 55-cm Brite Tip 5F sheaths (Cordis, Miami, Fla), which were introduced up to the origin of the PPBs. PPBs were cannulated with the aid of a diagnostic curved multipurpose catheter and a 0.035-inch hydrophilic wire. Through the diagnostic catheters, two 8-mm Amplatzer Vascular Plugs IV (AGA Medical, Golden Valley, Minn) were delivered inside the PPBs but were not detached from the delivery wires (Fig 6). The 5F sheaths and the delivery wires were secured to the patient's groin with adhesive transparent membranes and a low infusion of heparinized saline solution was started through the sheath side branches (500 IU/hour). The patient was transferred to the intensive care unit (ICU) and standard precautions for preventing SCI were taken (CSF drainage and maintenance of high mean arterial blood pressure). The patient's neurological status was monitored in the ICU. No neurological deficit was observed for 6 hours and the patient was transferred back to the angiography suite where the delivery wires were disconnected from the vascular plugs. The 5F femoral sheaths were removed and hemostasis was achieved with manual compression.

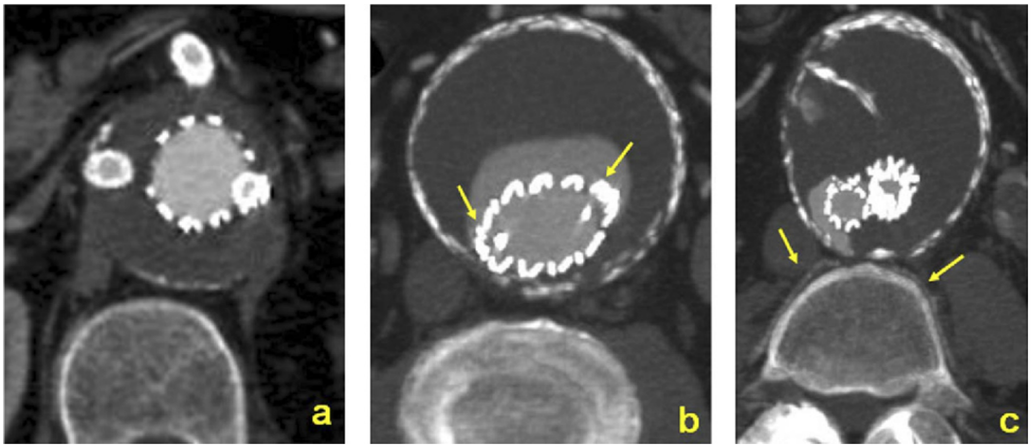

Fig 5. Computed tomographic angiography (CTA) 3 days after repair of the aneurysm. **a,** Paravisceral stent graft with stents placed in both renal arteries and the superior mesenteric artery (SMA) without endoleak. **b,** Flow into the aneurysm at the level of the paraplegia prevention branches (PPBs; *yellow arrows*). **c,** Perfusion of one pair of distal lumbar arteries from the aneurysmal sac (*yellow arrows*).

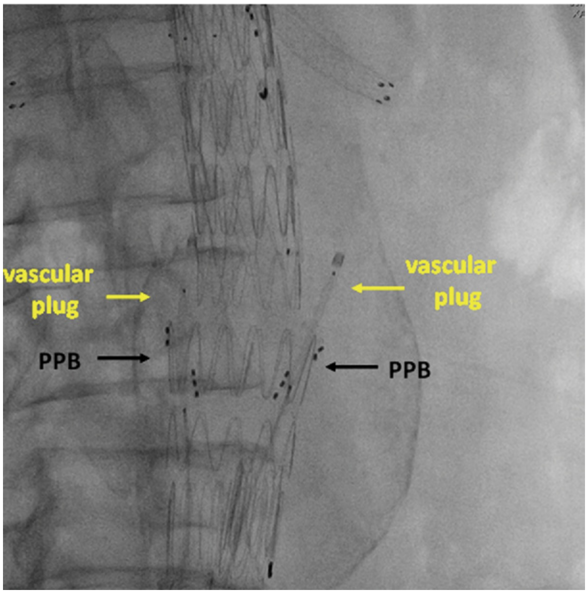

Fig 6. Occlusion of paraplegia prevention branches (*PPBs*) 3 weeks after the initial placement of stent grafts. The 8-mm vascular plugs delivered inside the PPBs (not yet deployed).

The patient remained in the ICU for 24 hours and CSF drainage continued for this period of time. A CTA on the second postoperative day showed successful exclusion of the PPBs, no flow into the aneurysm, and no continued antegrade flow into the lumbar arteries (Fig 7). The patient was discharged home on the third postoperative day.

DISCUSSION

The etiology of SCI after open or endovascular repair of TAAAs is multifactorial; however, alteration of the blood supply to the spinal cord seems necessary before any neurological complication occurs. Spinal cord blood supply greatly depends on a collateral circulation that has a large anatomic variability. Reduction of collateral flow, particularly through the intercostal and lumbar arteries, may cause ischemic damage to the spinal cord.[9,10] Moreover, factors that decrease the efficacy of the collateral network, such as systemic hypotension or CSF hypertension, may also induce paraplegia.[11] The concept of "spinal cord compartment syndrome" includes a sequence of events starting with intraoperative cord ischemia and followed by edema and increased CSF pressure that reduces cord perfusion postoperatively.[12] In the case of endovascular repair of TAAAs, instrumentation of the aneurysm sac may cause atheroembolization to the spinal cord circulation.[13] Subsequent postoperative ischemia due to impaired collateral circulation may enhance spinal cord edema and induce secondary spinal cord injury.

Although touted as less invasive than traditional open repair, endovascular TAAA repair nonetheless results in a sizable physiological insult to patients who almost always have significant comorbidities. Postoperative instability is common with brief episodes of hypotension occasionally occurring. The addition of PPBs in branched stent grafts implanted in patients with TAAAs may be used to preserve blood flow to the aneurysm sac and antegrade flow in intercostal and lumbar arteries that contribute to the important collateral networks during this crucial early postoperative period. This might be of particular importance in patients at high risk of developing SCI, such as patients with increased length of excluded aorta (type II TAAA), previous aortic surgery/stented aorta, impaired vertebrobasilar blood flow, or advanced age. Preservation of spinal cord perfusion through collaterals in this high-risk group of patients allows for physiological optimization with stabilization of blood pressure, adjustment of hemoglobin, or improvement of impaired renal function. Moreover, it has been suggested that perfusion of

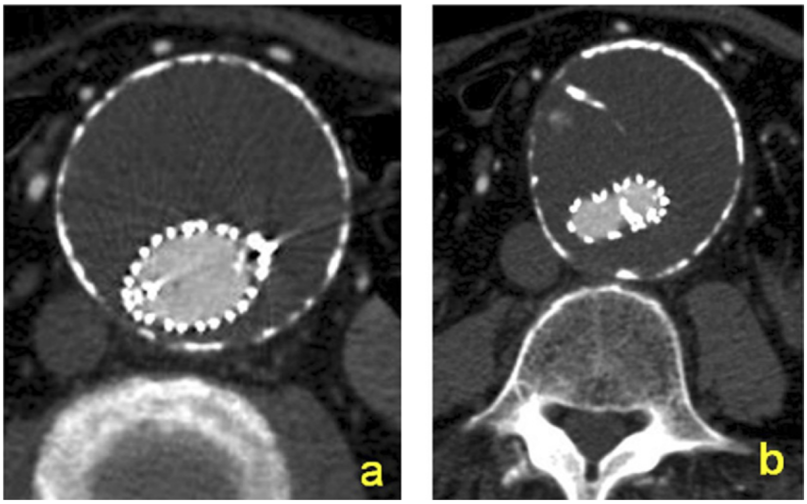

Fig 7. Computed tomographic angiography (CTA) 2 days after occlusion of paraplegia prevention branches (PPBs). **a,** No flow into the aneurysm at the level of the PPBs. **b,** No lumbar arteries are perfused from the aneurysmal sac.

the aneurysm sac through the PPBs may allow spinal cord collateral perfusion pathways to develop, working as a form of "ischemic preconditioning."[7]

In this case, our patient's anatomy precluded placement of PPBs at the T8 to L1 level of the aorta or the aortic segment containing the most prominent intercostal artery because of the limited diameter of aorta and presence of circumferential clot. When anatomy is suitable, it would theoretically be preferable to place the PPBs close to areas of the aorta containing this critical T8 to L1 segment of collateral arteries providing spinal cord perfusion.

The time interval before occluding the PPBs in our case was 3 weeks. This allowed cardiovascular instability to be settled and collateral networks to be potentially developed, as discussed above. This approach is similar to the "staged approach" for open or endovascular repair of aortic aneurysms involving different anatomic levels that has been favored by many authors.[14,15] Certainly, there exists a risk of aneurysm rupture before occlusion of PPBs and this perhaps represents the main weakness of this technique. This risk must be counterbalanced to the risk of SCI in this patient population.

PPBs can also be used after their occlusion to restore aneurysm sac perfusion and manage paraplegia/paraparesis as an adjunct to the physiological measures. In our case, we chose to leave the Amplatzer Vascular Plugs attached to their introduction wire so that if paraplegia occurred early during the first few hours, simply pulling the wires and resheathing the plug would result in immediate perfusion of the aneurysm sac giving the patient his or her best chance of paraplegia reversal. If paraplegia ensues hours to days after the plugs are released, other methods can be used to restore perfusion through the PPBs such as pushing the plugs into the aneurysm sac with interventional techniques creating "endotrash," or removing the plugs using devices such as intravascular snares or biopsy forceps and resheathing the plugs for removal.[16]

The use of PPBs with the technique that we have described is feasible and allows for a temporary controlled endoleak that can be used for preventing or reversing SCI, as an adjunct to the standard physiological manipulations with sustained hypertension and CSF drainage. In the hypothetical scenario that exclusion of the aneurysmal flow cannot be tolerated and the neurologic deficit recurs any time that the PPBs are occluded, despite maximum physiological support, the patient has the option to make a conscientious choice between living with an endoleak and the associated risk of rupture, or accepting the burden of neurological impairment. Further experience is needed with this technique to identify the optimal level for reperfusion, the adequate amount of reperfusion, and the most favorable interval of time before PPB occlusion.

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Submitted Nov 30, 2010; accepted Nov 30, 2010.