CLINICAL RESEARCH

From the Society for Vascular Surgery

Endovascular treatment of thoracoabdominal aortic aneurysms

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Objective: **This study assessed the role of multibranched stent grafts for thoracoabdominal aortic aneurysm (TAAA) repair.**

Methods: **Self-expanding covered stents were used to connect the caudally directed cuffs of an aortic stent graft with the visceral branches of a TAAA in 22 patients (16 men, 6 women) with a mean age of 76 ± 7 years. All patients were unfit for open repair, and nine had undergone prior aortic surgery. Customized aortic stent grafts were inserted through surgically exposed femoral (n = 16) or iliac (n = 6) arteries. Covered stents were inserted through surgically exposed brachial arteries. Spinal catheters were used for cerebrospinal fluid pressure drainage in 22 patients and for and spinal anesthesia in 11.**

Results: **All 22 stent grafts and all 81 branches were deployed successfully. Aortic coverage as a percentage of subclavian-to-bifurcation distance was 69% ± 20%. Mean contrast volume was 203 mL, mean blood loss was 714 mL, and mean hospital stay was 10.9 days. Two patients (9.1%) died perioperatively: one from guidewire injury to a renal arterial branch and the other from a medication error. Serious or potentially serious complications occurred in 9 of 22 patients (41%). There was no paraplegia, renal failure, stroke, or myocardial infarction among the 20 surviving patients. Two patients (9.1%) underwent successful reintervention: one for localized intimal disruption and the other for aortic dissection, type I endoleak, and stenosis of the superior mesenteric artery. One patient has a type II endoleak. Follow-up is >1 month in 19 patients, >6 months in 12, and >12 months in 8. One branch (renal artery) occluded for a 98.75% branch patency rate at 1 month. The other 80 branches remain patent. There are no signs of stent graft migration, component separation, or fracture.**

Conclusions: **Multibranched stent graft implantation eliminates aneurysm flow, preserves visceral perfusion, and avoids many of the physiologic stresses associated with other forms of repair. The results support an expanded role for this technique in the treatment of TAAA. (J Vasc Surg 2008;47:6-16.)**

Large aneurysms of the thoracoabdominal aorta (TAAA) are at high risk for rupture and death.[1] Conventional surgical repair involves wide aortic exposure and interruption of flow to abdominal organs that have little tolerance for ischemia. The resulting mortality and morbidity rates vary with the extent of the disease, the health of the patient, and the expertise of the center providing care.[2-7] Statewide audits provide the best indication of overall results. In California, for example, the 30-day mortality is 19%, and the 1-year mortality is 31%.[2]

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Endovascular technique substitutes transarterial access for surgical exposure and stent-mediated attachment for sutured anastomosis, thereby minimizing arterial exposure and avoiding visceral ischemia. One approach involves a combination of conventional visceral artery bypass and conventional stent graft implantation.[8-11] An even less invasive alternative maintains perfusion of the celiac, superior mesenteric, and renal arteries through multiple branches of the stent graft.[12-18]

We report a phase I, single-center, prospective, clinical study of endovascular aneurysm repair using a modular multibranched stent graft. In this approach, a large-caliber primary stent graft arborizes to the visceral arteries through multiple caudally directed covered stents, and additional large-caliber components extend the trunk of the stent graft proximally or distally, depending on the location of the aneurysm.

METHOD

Study population. The selection criteria are listed in Table I. Arterial anatomy was assessed using three-

Table I. Selection criteria

Inclusion

1. Thoracoabdominal aortic aneurysm >6 cm in diameter or >5 cm in diameter and enlarging at a rate of >10 mm/y
2. Anticipated mortality greater than 20% with conventional surgical treatment
3. Life expectancy of >2 years
4. Ability to give informed consent and willingness to comply with follow-up schedule
5. Suitable arterial anatomy for endovascular repair

Exclusion

1. Free rupture of the aneurysm
2. Pregnancy
3. A history of anaphylactic reaction to contrast material
4. Allergy to nitinol, stainless steel, or polyester
5. Serious systemic or groin infection
6. Uncorrectable coagulopathy
7. Aortic dissection
8. Presence of a dominant artery to the spinal cord arising from the area of stent graft implantation

dimensional analysis (AquariusNET, TeraRecon Inc, San Mateo, Calif) of fine-cut (≤3-mm slice thickness) contrast-enhanced computed tomography (CTA) scans of the chest, abdomen, and pelvis. The study was conducted under an Investigational Device Exemption (IDE #G000265) from the United States Food and Drug Administration (FDA), as well as under the approval of the Institutional Committee on Human Research (CHR).

Device design. The primary component of this thoracoabdominal aortic stent graft system was the cuff-bearing aortic stent graft, manufactured by Cook-Australia, Inc (Brisbane, Australia), with two (n = 1, 4.5%), three (n = 5, 22.7%) or four (n = 16, 72.7%) caudally directed cuffs positioned to correspond to the axial and circumferential location of the arterial branch on the native aortic aneurysm. This component had a wide proximal segment, a wide distal segment, and a narrow central, cuff-bearing segment (Fig 1). Its construction, sterilization, shipping, and regulatory processing took 6 to 8 weeks.

The entire length of the woven polyester primary aortic stent graft was supported by a series of stainless steel Z stents (Fig 1, *A*). In the latter part of the series, the caudally oriented barbs of the proximal stent projected through the graft material. Earlier devices had uncovered proximal stents. The caudally directed cuffs were 18 mm in length and 6 to 8 mm in diameter. The celiac cuff was usually one stent length above the superior mesenteric cuff, which was usually one stent length above the left renal cuff. The position of the right renal cuff was more variable. Radiopaque markers on the trunk of the stent graft indicated overall orientation. Other markers indicated the position of the proximal and distal ends of each cuff.

More extensive aneurysms required additional components. Those involving the proximal aorta (Fig 2) require unbranched proximal extensions, and those involving the distal aorta require bifurcated distal extensions. Stent grafts extensions were sized to ensure an overlap between components of at least three stent bodies.

Proximal thoracic extensions were delivered using the standard Zenith TX-2 (Cook Medical Inc., Bloomington, Ind) delivery system. Bifurcated aortoiliac stent grafts were delivered using the standard Zenith delivery system. The cuff-bearing primary aortic stent graft was delivered through a modified version of the Zenith fenestrated stent graft delivery system. Sheath sizes were 20 to 24F (inner diameter).

The branches of the stent graft consisted of Fluency covered stents (C. R. Bard, Inc, Tempe, Ariz), measuring 60 mm in length and 7 to 9 mm in diameter, combined with vascular Wallstents (Boston Scientific Corp, Natick, Mass), measuring 38 to 39 mm in (nominal) length and 8 to 10 mm in (nominal) diameter.

Device implantation. General anesthesia was used for 12 procedures (54.5%), and a combination of spinal and local anesthesia was used for 10 (45.5%). Spinal catheters were inserted for cerebrospinal fluid (CSF) pressure monitoring and drainage. Intravenous heparin was given before arterial puncture, and additional doses were titrated to maintain an activated clotting time (ACT) ≥300 seconds.

Although we have sought to standardize our basic approach, the technique of endovascular TAAA repair remains a work-in-progress. The description that follows reflects current practice. The procedure had two parts: transfemoral insertion of the cuffed primary aortic stent graft and any proximal aortic or distal aortoiliac stent graft extensions, followed by transbrachial insertion of the covered stents into the visceral branches.

Step 1. Implantation of cuffed primary aortic stent graft. The primary aortic stent graft was inserted through the surgically exposed femoral artery in 16 patients (72.7%) or through a conduit in six (27.3%) to the common iliac artery (Fig 3, *A*). Conduits were most often required to treat women (50%). Our current practice is to create the conduit (Fig 3, *B*) and inert the stent graft at two separate operations. In this approach, the proximal anastomosis is end-to-end and the distal anastomosis end-to-side, thereby avoiding competitive flow and providing a route for retrograde flow up the external iliac artery to the internal iliac artery.

Aortic and aortoiliac stent grafts were inserted over a stiff guidewire, starting with the most proximal components. Standard techniques were used to insert and deploy the proximal aortic, distal aortic, and distal aortoiliac stent graft components. Deployment of the cuffed primary aortic stent graft was more complex because its cuffs had to be

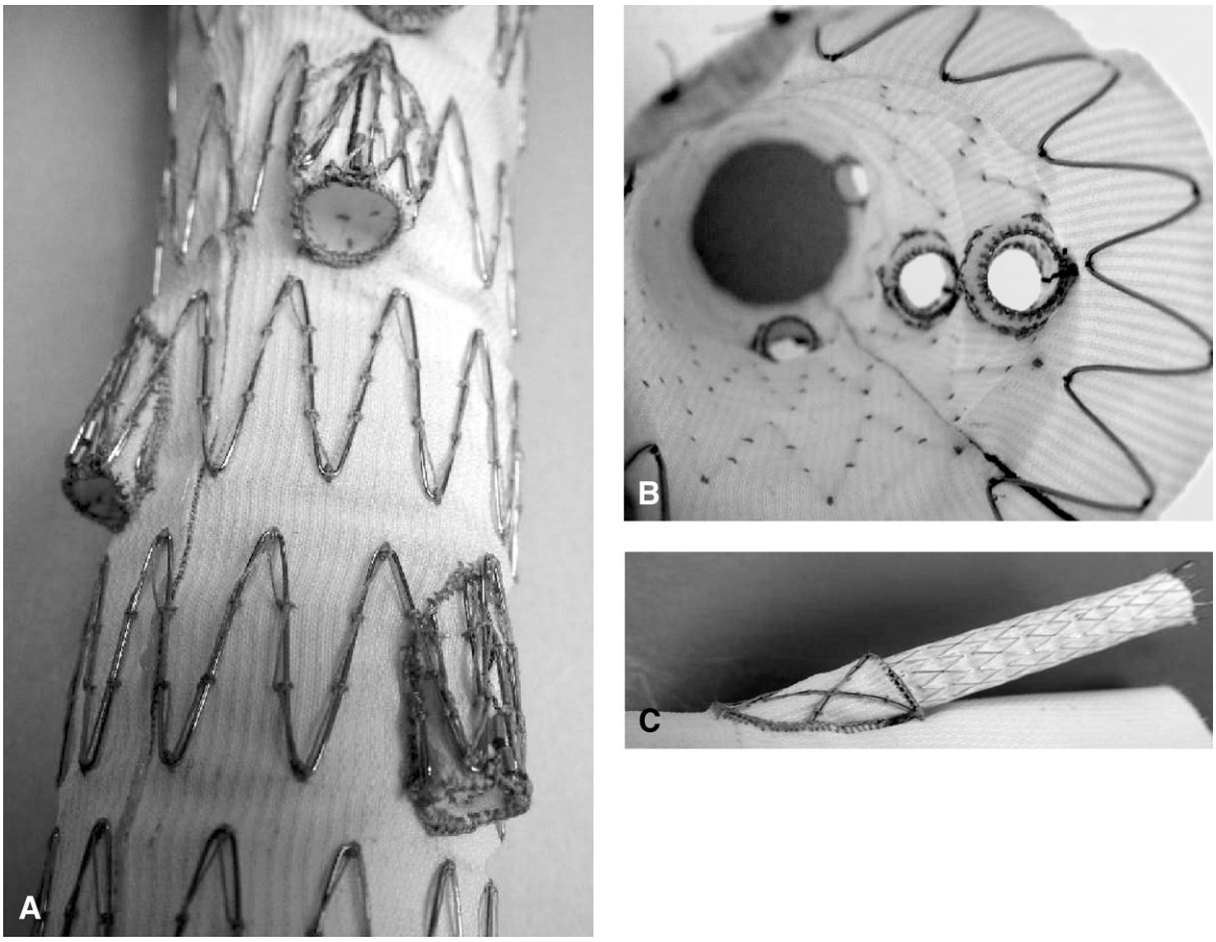


Fig 1. A, An anterior view of the cuff-bearing segment of the primary aortic stent graft. **B,** An internal view of the same stent graft. **C,** A Fluency (C. R. Bard, Inc, Tempe, Ariz) covered stent within a cuff of the primary aortic stent graft.

oriented to the axial and circumferential position of the visceral aortic branches. To minimize the use of contrast, we substituted selective visceral branch catheterization for flush aortic injections (Fig 4, *A*).

In general, we positioned the cuffs 10 to 30 mm above the corresponding visceral artery orifices. The exact position was not critical as long as no cuff was distal to the corresponding visceral artery orifice. After the sheath was removed, the constraining wire retained the stent graft in a partially deployed state, allowing for small adjustments in the longitudinal position or orientation of the stent graft. Once a satisfactory position had been achieved, all three control wires were pulled, the delivery system removed, the implantation sites balloon-molded, and the stent graft access sites repaired, restoring normal lower extremity perfusion.

Step 2. Implantation of covered stents into visceral branches. We generally used the longest available catheters, guidewires, and delivery systems (Table II) and tried to instrument the aortic arch as little as possible. We inserted 10F and 12F coaxial kink-resistant Flexor sheaths (Cook Medical Inc.), one inside the other, over a stiff guidewire through the surgically exposed right (n = 5, 22.7%) or left (n = 17, 77.3%) brachial artery, around the distal aortic arch, and into the descending thoracic aorta. The 12F sheath was sutured to the skin of the arm once it was inserted to its fullest extent. In cases of steep subclavian angulation, we inserted the sheaths over a tensioned 0.035-in brachial-femoral guidewire. This was then exchanged for a 0.014-in coronary guidewire (Grand Slam, Asahi Intec Co, Ltd), which was small enough to share the lumen of the 10F sheath with a Fluency delivery system (Fig 4, *B*).

Each visceral branch was constructed by using the same series of steps. The most distal branches (renals) were usually deployed first, and the most proximal (celiac), last. An angled catheter was directed through the target cuff, out of the aortic stent graft, across the aneurysm sac, and into the corresponding target artery (Fig 4, *B*). Small volumes of dilute contrast were injected through the selective catheter to locate the visceral artery orifice, confirm catheter position, and define the branching pattern of the

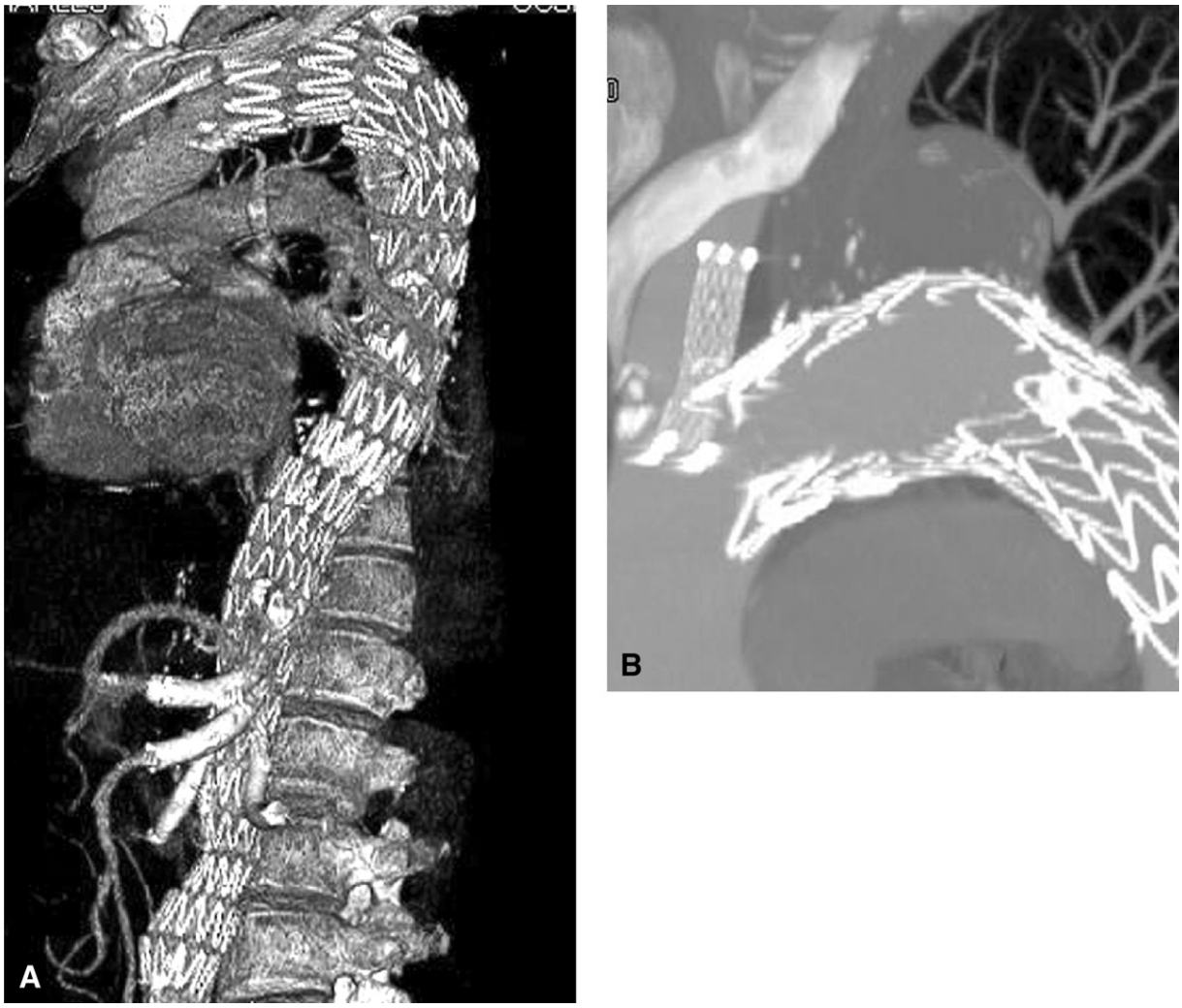


Fig 2. A, A computed tomography angiography (CTA) after multibranched repair of a type II thoracoabdominal aortic aneurysm shows the usual branches to the celiac, superior mesenteric, and renal arteries. **B,** CTA after left carotid-subclavian bypass and endovascular repair of a distal arch aneurysm, which was performed in conjunction with multibranched repair of the thoracoabdominal aorta. There is a covered stent within the left carotid artery to preserve flow while lengthening the proximal implantation site.

visceral artery. The Fluency delivery system (Fig 4, *C*) was inserted over a Rosen guidewire (Cook Medical Inc.). The distal 10 to 20 mm of the 60-mm-long Fluency covered stent was deployed inside the target artery, and the proximal 20 to 25 mm inside the cuff and the lumen of the aortic stent graft, leaving approximately 20 mm bridging the aneurysm. Each covered stent was lined with an oversized Wallstent to prevent kinking and augment fixation.

A completion angiogram was performed before relinquishing wire access into the branch. Deployment of the celiac branch completed the repair. From then on, CSF pressure was carefully monitored, and the patient's lower extremity motor function was tested at frequent intervals, depending on the anesthetic technique. We no longer perform a completion flush aortogram because the yield is low and the contrast load high. All wires, sheaths, and catheters were removed. The brachial artery was repaired, restoring perfusion to the arm. Anticoagulation was reversed, and all wounds were closed.

Postoperative monitoring. All patients spent at least 2 days in the intensive care unit after the operation to monitor spinal cord function, CSF pressure, and arterial pressure. We routinely drained 10 mL of CSF hourly during the first 12 hours, depending on CSF pressure and lower extremity neurologic symptoms. If the patient was neurologically stable, the drain was clamped on the second postoperative day and removed on the third. We now withhold most antihypertensive medications, except cardioprotective β-blockers, for up to 48 hours postoperatively. The goal is to augment spinal cord perfusion.

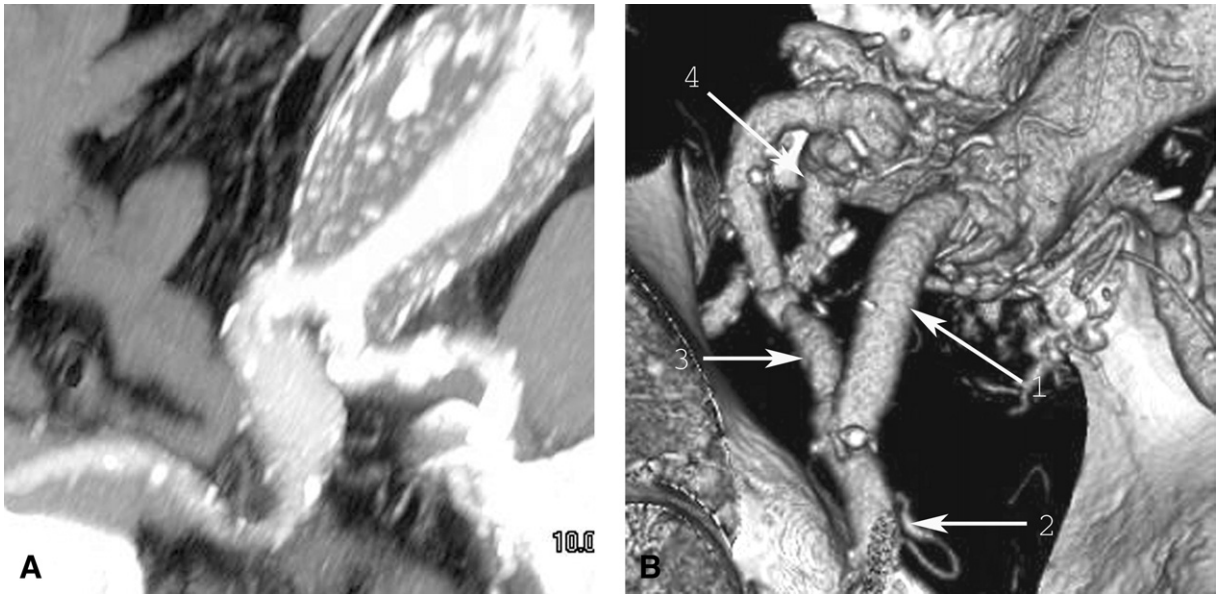


Fig 3. A, A preoperative computed tomography (CT) scan shows a right common iliac aneurysm, left common iliac stenosis, and bilateral iliac stenosis. **B,** A CT scan shows a *(1)* right common iliac to external iliac bypass, with *(2)* prograde flow to the common femoral artery and *(3)* retrograde flow through the external iliac artery to the *(4)* internal iliac artery. Two weeks later, this bypass graft was used as a route for stent graft insertion.

Follow-up. Patients underwent 64-slice CTA before discharge. Follow-up clinical assessment, laboratory testing, and CTA were performed at 1, 6, and 12 months, and yearly thereafter. Outcome data were reviewed and reported to the FDA and CHR after every fifth treated patient.

RESULTS

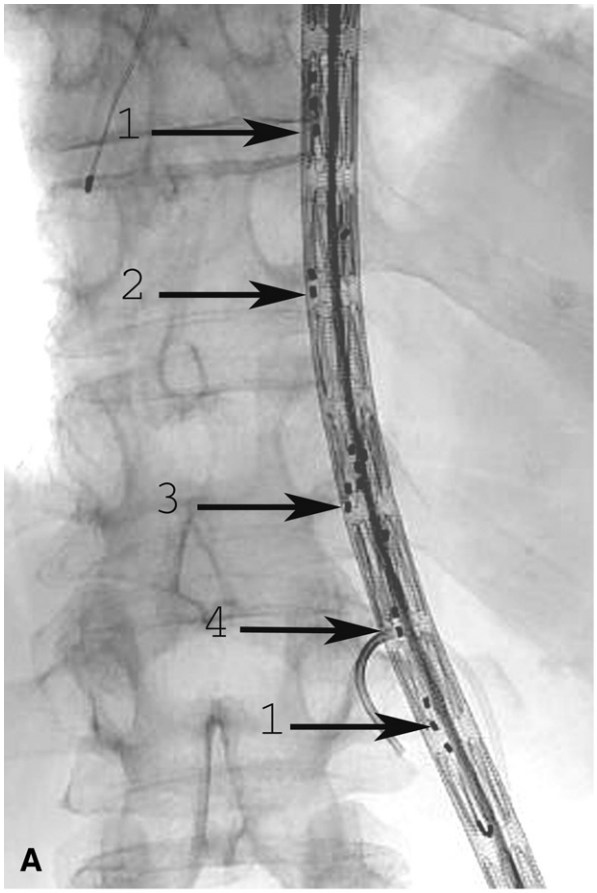
Between January 2006 and May 2007, 22 patients (16 men, 6 women) with a mean age of 76.2 ± 7.4 years underwent endovascular TAAA repair using multibranched stent grafts with caudally oriented cuffs. The mean aneurysm diameter was 67.4 ± 9.3 mm. Nine patients (41%) had undergone prior aortic surgery. All were considered unfit for open operation.

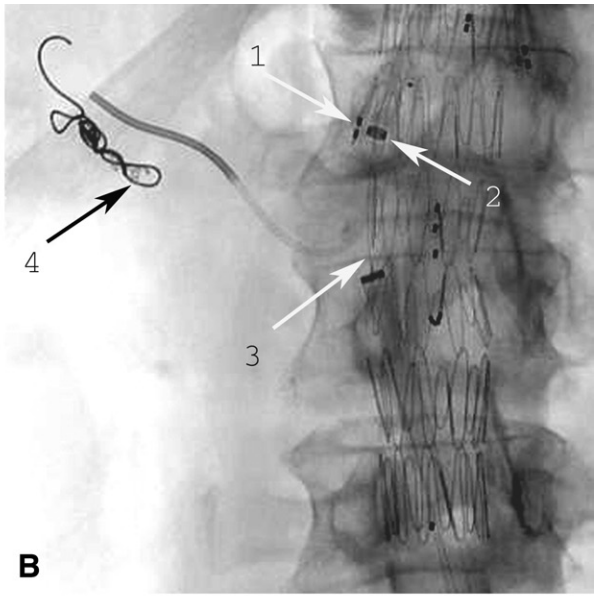
The procedural success rate was 100%. Cuffed primary aortic stent grafts were successfully deployed in all 22 patients, and covered stents were successfully deployed into 81 of 81 target visceral arteries. This represented two of three branches in one patient, three of three branches in five patients, and four of four branches in 16 patients. Six of the seven branches that were not treated were chronically occluded (1 celiac axis and 5 renal arteries), and one (a renal artery) was outside the field of repair. The extent of aortic coverage as a percentage of the distance from the subclavian artery to the aortic bifurcation was 69% ± 20%. The mean estimated blood loss was 714 mL, and the mean contrast volume was 203 mL. The mean length of hospital stay was 10.9 days.

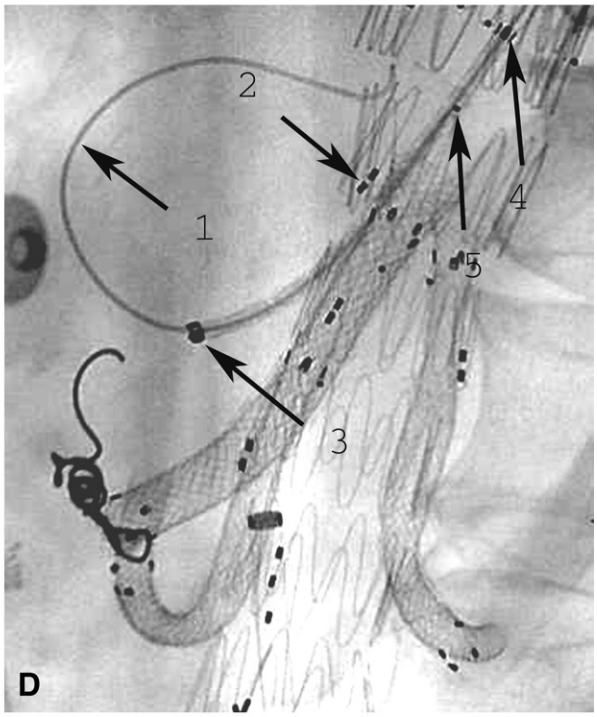
Two patients (9.1%) died perioperatively. One patient sustained a guidewire-induced arterial injury to a distal branch of her sole renal artery. Coil embolization of the affected branch appeared to stop the bleeding, and the operation was completed as planned; however, recurrent bleeding into the renal capsule caused renal failure, hypotension, and paraplegia. The patient declined dialysis and died. The other death resulted from the effects of a 50,000 μg phenylephrine injection upon arrival in the intensive care unit. The effects included stroke, myocardial infarction, low output heart failure, renal failure, and disseminated intravascular coagulation. Two other patients died from unrelated causes 6 and 13 months after TAAA repair. One died of pneumonia, complicating longstanding chronic obstructive pulmonary disease (COPD), the other died of sepsis from a decubitus ulcer. Fig 5 shows Kaplan-Meier plots of survival and freedom from aneurysm-related death.

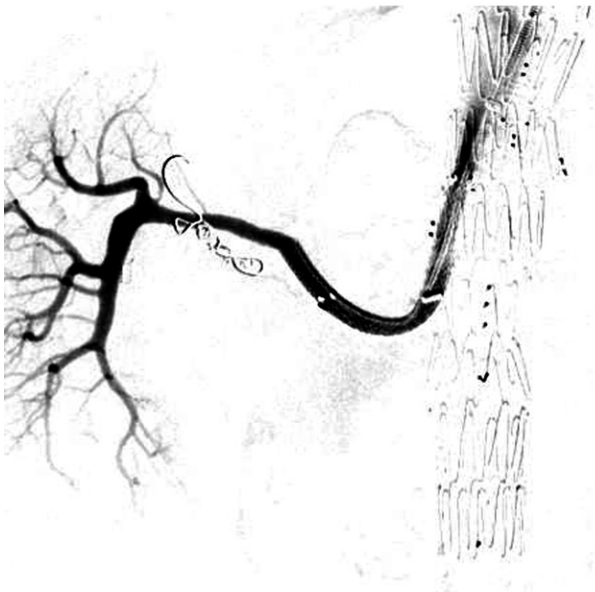
Renal failure, myocardial infarction, stroke, and paraplegia did not occur in any of the 20 patients who survived TAAA repair. Three patients (13.6%) experienced transient lower extremity weakness and numbness (paraparesis) during periods of hypotension, but none had any residual neurologic symptoms. Postoperative pneumonia developed in two patients (9.1%), both of whom had preexistent COPD. Table III lists all the serious complications in this study.

The perioperative period was also notable for striking hematologic abnormalities. Between the time of operation and the second postoperative day, the white cell count rose to 211% of baseline, the platelet count fell to 47% of baseline, and the INR rose to 120% of baseline. These effects correlated with the length of the prosthesis.









C

Fig 4. A, Intraoperative fluoroscopy shows *(1)* orientation markers, *(4)* a catheter within the superior mesenteric artery, and markers at the distal ends of cuffs for branches to the *(2)* celiac and *(3)* superior mesenteric arteries. **B,** Intraoperative fluoroscopy shows markers at the distal end of the *(1)* right renal cuff, the *(2)* tip of a 10F transbrachial sheath, *(3)* a tiny (0.014-in) brachial-femoral guidewire, and *(4)* coils in the smaller (3 mm) of the two renal arteries. **C,** Intraoperative angiography shows a branch of the stent graft to the larger (5 mm) of the two right renal arteries. **D,** Intraoperative fluoroscopy shows a *(1)* guidewire with its tip in the splenic artery, *(2)* markers at the outer end of the celiac cuff, *(3)* distal and *(4)* proximal ends of the undeployed Fluency (C. R. Bard, Inc, Tempe, Ariz) covered stent, and *(5)* a marker at the inner end of the celiac cuff.

Table II. Standard ancillary equipment

Instrument	*Manufacturer*	*Length, cm*	*Sheath size*	*Device dimensions*
Fluency covered stent	CR Bard	117	9F (OD)	7 × 60 mm (renal)
Fluency covered stent	CR Bard	117	9F (OD)	9 × 60 mm (celiac, SMA)
Wallstent	Boston Scientific	125	7F (OD)	8 × 38 mm (renal)
Wallstent	Boston Scientific	125	7F (OD)	10 × 39 mm (celiac, SMA)
Vertebral catheter	Cook Medical	125	5F (OD)	NA
MPA catheter	Cook Medical	100	5F (OD)	NA
C1 catheter	Cook Medical	65	5F (OD)	NA
Lunderquist guidewire	Cook Medical	260	NA	0.035 in
Glidewire guidewire	Terumo Medical	260	NA	0.035 in
Grand Slam guidewire	Asahi Intecc	300	NA	0.014 in
EN Snare System	MDT	NA	NA	27-45 mm
Flexor sheath	Cook Medical	80	10F (ID)	12F (OD)
Flexor sheath	Cook Medical	40	12F (ID)	14F (OD)

ID, Interior diameter; *NA,* not applicable; *OD,* outer diameter; *SMA,* superior mesenteric artery.

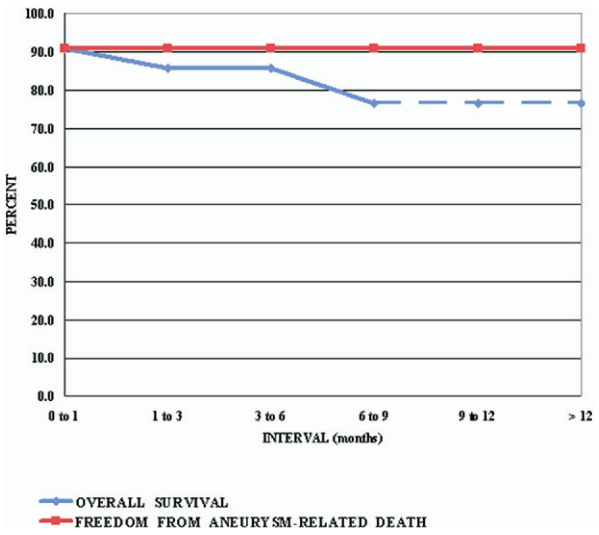


Fig 5. Kaplan Meier plots of overall survival *(diamonds)* and freedom from aneurysm-related death *(squares)*. The *dotted line* indicates a standard error >10%.

Two patients (9.1%) required reintervention to treat the complications of endovascular TAAA repair. One patient's initial CT showed an area of intimal disruption just above the top the stent graft. An additional stent graft was implanted to extend the proximal end of the repair and exclude this lesion from the circulation. Another patient underwent perioperative (<30 days) supplemental stent graft implantations to treat an iatrogenic type B aortic dissection. This patient also underwent covered stent implantation to treat a type 1 endoleak (early), and superior mesenteric angioplasty to treat late (>30 days) 70% stenosis. These interventions were successful.

Unusual gastrointestinal complications developed in two patients (9.1%), which greatly delayed their discharge from the hospital. One had ileus, requiring 4 weeks of parenteral nutrition. No cause was identified, and bowel function recovered spontaneously. Another patient sustained an iatrogenic cascade, starting 5 weeks after TAAA repair with upper gastrointestinal endoscopy for esophageal achalasia and ending with distal gastrectomy for duodenal bleeding. His eventual recovery was delayed by postoperative pneumonia.

Hydrocephalus developed in one patient a week after stent graft implantation, requiring placement of a temporary ventricular drain. The presumed cause was intrathecal bleeding at the spinal catheter insertion site.

Only two patients (9.1%) have had an endoleak at any point in their follow-up. The sole type 1 endoleak was eliminated, as already described. Another patient has a type 2 endoleak, and its management will be dictated by aneurysm behavior. Both endoleaks were visible on the first postoperative CT.

Of the 22 patients in this series, 19 have been followed up for >1 month, 12 for >6 months, and 8 for >12 months. There are no signs of stent graft migration, component separation, or fracture. One renal artery occluded within a month of implantation. The other 80 branches (98.8%) remain patent according to the most recent follow-up CT. During the 1- to 6-month follow-up interval, two patients presented with short-segment stenosis just downstream from the distal end of the covered stent. In one case (described above), an area of stenosis in the superior mesenteric artery was treated with balloon dilatation and

Table III. A patient-by-patient listing of complications

Patient	*Complication Perioperative*	*Late (>30 days)*	*Reintervention*	*Aneurysm status*	*Branch status*
1	Pneumonia	None	None	No endoleak	4/4 patent
2	None	None	None	No endoleak	4/4 patent
3	Renal failure Paraplegia Death	N/A	None	No data	No data
4	Renal occlusion	None	None	No endoleak	3/4 patent
5	None	None	None	No endoleak	4/4 patent
6	None	None	None	No endoleak	3/3 patent
7	None	None	None	No endoleak	4/4 patent
8	None	None	None	No endoleak	2/2 patent
9	None	None	None	No endoleak	4/4 patent
10	Aortic dissection Type I endoleak	SMA stenosis	Stent graft Covered stents Stent SMA	No endoleak	4/4 patent
11	Pneumonia	None	None	No endoleak	4/4 patent
12	None	None	None	No endoleak	4/4 patent
13	Transient paraparesis	None	None	No endoleak	4/4 patent
14	Transient paraparesis	None	None	No endoleak	3/3 patent
15	Transient paraparesis	None	None	No endoleak	4/4 patent
16	Ileus Catheter sepsis CHF HIT	None	None	No endoleak	4/4 patent
17	None	None	None	No endoleak	4/4 patent
18	None	None	None	No endoleak	4/4 patent
19	Stroke MI Pulmonary failure Extremity ischemia Death	N/A	None	No data	No data
20	Aortic dissection Achalasia GI bleeding Pneumonia MI	None None	Stent graft Laparotomy	No endoleak	4/4 patent
21	None	None	None	Type II endoleak	4/4 patent
22	Subarachnoid bleed Hydrocephalus Stroke	None	VP shunt	No endoleak	4/4 patent

CHF, Congestive heart failure; *GI,* gastrointestinal; *HIT,* heparin induced thrombocytopenia; *MI,* myocardial infarction; *N/A,* not applicable; *SMA,* superior mesenteric artery; *VP,* ventriculoperitoneal.
*By computed tomography scan at death or latest follow-up.

additional stent implantation. In the other case, moderate stenosis of the renal artery was left untreated.

DISCUSSION

There is good reason to seek a less invasive endovascular alternative to the open surgical repair of TAAA. Although individual high-volume centers report good outcomes, mortality and morbidity rates vary widely, depending on the health of the patient, the extent of the aneurysm, the skill of the surgeon, and the quality of the perioperative care.[4-7] Statewide audits[2,3] provide a sobering picture of the overall experience.

Endovascular techniques long ago assumed a prominent role in the management of aneurysms isolated to the descending thoracic and infrarenal abdominal segments of the aorta. The same would be true of the intervening thoracoabdominal segment were it not for the complexities involved in excluding the aneurysm from the circulation while maintaining flow to its branches.

One widely practiced approach combines open surgical bypass to the visceral arteries with endovascular exclusion of the aneurysm.[8-11] The hybrid surgical/endovascular procedure substitutes laparotomy for thoracoabdominal exposure, eliminates aortic mobilization and clamping, and reduces the duration of visceral ischemia, all of which should reduce morbidity and mortality. This method is widely applicable because both parts of the operation involve standard techniques and readily available stent grafts. The disappointing results in some series reflect the fact that visceral bypass still constitutes a large operation for this high-risk population.

The first branched stent grafts were of a unibody design, with the branches sutured to the primary stent graft.[18] The entire multibranched stent graft was inserted as a single

component, then manipulated into position using catheters. The inherent complexity of this approach has limited its application to a small number of single and double-branched repairs.

Modular stent grafts are assembled in situ from multiple components. All current multibranched modular stent grafts combine large-caliber self-expanding stent grafts with small-caliber covered stent branches.[12-17] They differ in the type of intercomponent connection. Our technique involves an overlapping connection between a self-expanding covered stent and a caudally directed cuff attached to the primary stent graft. Other designs have no overlap, just a ring of contact between a balloon-expanded covered stent and the margin of a hole (fenestration) in the stent graft. In the fenestrated approach, the branches emerge from the primary stent graft in a transaxial plane. This orientation provides little latitude for misalignment between the fenestration and the target artery and little resistance to displacement from caudally directed forces.

Many authors have combined fenestrations, fenestrated branches, and cuffed branches within a single device.[12-15] We have found such combinations cumbersome. Fenestrations depend on direct contact between the aorta and the stent graft,[19] whereas cuffed branches require a space between the aorta and the stent graft. As a result, fenestrated stent grafts tend to be wide and cuffed stent grafts tend to be narrow. The two are difficult to combine unless they are far enough apart to permit a significant change in stent graft diameter.

The potential advantages of an all endovascular approach are obvious: No body cavities are opened, no large arteries are clamped, and no organs are rendered ischemic. In theory, the endovascular procedure imposes less stress on the patient, which should translate into less mortality, morbidity, and debility. The rate of serious complications in this series was relatively low, considering that many of these high-risk patients had extensive aneurysms, yet their recovery was slower than one might expect given the limited nature of the surgical insult. All were affected by some combination of fever, leukocytosis, anorexia, malaise, thrombocytopenia, and coagulopathy. These are common findings after standard endovascular repair of abdominal and thoracic aortic aneurysms,[20,21] but the effects are usually mild. Perhaps the severity of the inflammatory response in this series reflects the extent of the repair or some specific characteristic of the technique. A pronounced inflammatory response is certainly not unique to the endovascular method of TAAA repair,[22] just more noticeable.

Unsuitable arterial anatomy was a relatively uncommon reason for exclusion from this series. The study group contained examples of stenosis, angulation, and aneurysm of the renal artery (Fig 6); stenosis and angulation of the celiac artery; aneurysm of the common iliac artery (Fig 3, *A*); aneurysm of the distal aortic arch (Fig 2, *B*); stenosis and tortuosity of the iliac arteries (Fig 3, *A*); and tortuosity of the aorta (Fig 7).

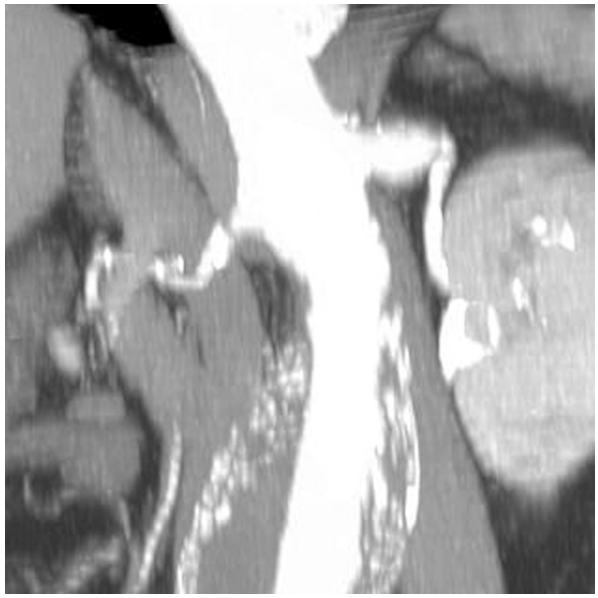


Fig 6. A preoperative computed tomography scan shows the aneurysm, stenosis, and angulation of the left renal artery and severe stenosis of the right renal artery.

Endovascular repair is feasible in most TAAAs. The issue is not who *can* be treated this way, but who *should* be treated this way. Perhaps the best candidate for endovascular repair is a patient with an extensive TAAA (type II or III), previous aortic surgery, and an otherwise normal life expectancy. Other patients stand to benefit less. High-risk patients are more likely to die of cardiac disease than of aneurysm rupture,[23] whereas low-risk patients with type IV TAAA often do quite well with open surgery.[4-6]

Before endovascular repair can assume a prominent role in the management of any subgroup of TAAA cases, the necessary skills and technology will have to become more widely available. Access to the device is currently limited by cost, regulatory constraints, and delays in manufacture. One of the commoner exclusion criteria among candidates for this study was the presence of symptoms that precluded a long delay. The interval between device design and operation was never less than 6 weeks. In some cases, it might be possible to eliminate this delay by choosing from a range of standard, premade components. The modular approach helps to limit the required inventory, because proximal and distal extensions can accommodate much of the variation in the size and location of the proximal and distal implantation sites, and the covered stents can accommodate much of the variation in the distribution of renal and splanchnic arteries.

During the past 7 years, we have performed endovascular TAAA repair using various multibranched stent grafts, combining external cuffs, internal cuffs, and fenestrations (no cuffs) with balloon-expanded and self-expanding stent grafts. Many design features of the current stent graft reflect the lessons of this experience. For example, we found long

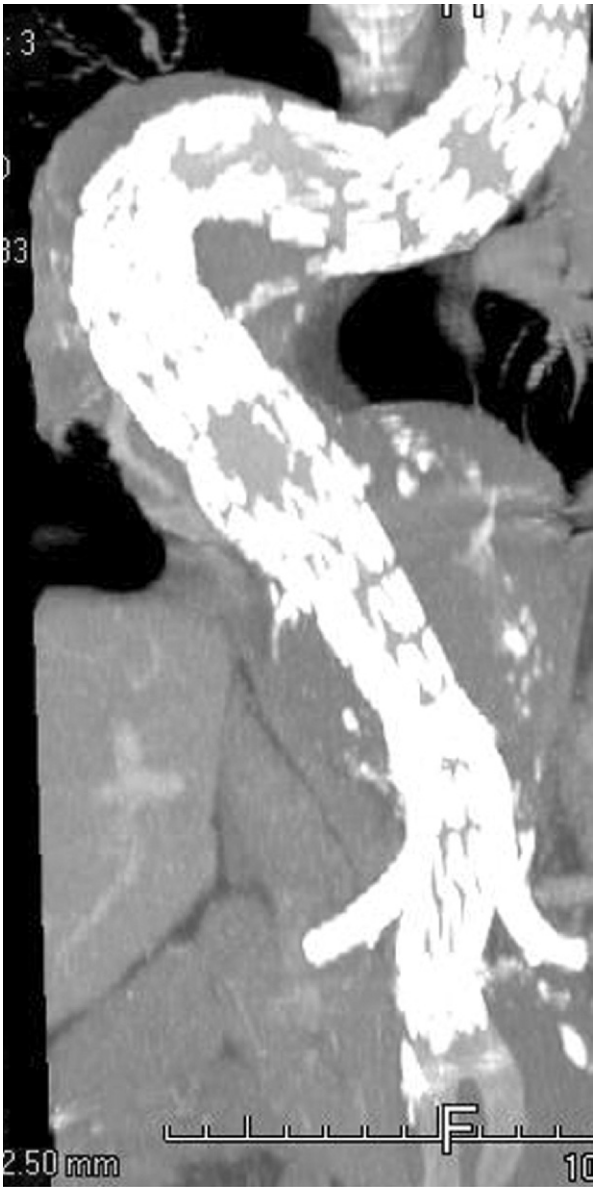


Fig 7. A postoperative computed tomography scan shows a tortuous stent graft within a tortuous aorta.

stent grafts difficult to orient, difficult to extrude, and difficult to deploy accurately; hence, the use of multiple overlapping aortic and aortoiliac components. A reduction in the bulk of the cuff-bearing component was an incidental benefit. The narrow waist of the current primary cuff-bearing component also had a volume-reducing effect. More important, the narrow waist provided space around the stent graft for flow to the visceral arteries during stent graft deployment. As the device evolved, so did the operation. Features such as coaxial kink-resistant sheaths, stiff J-tip wires, and brachial-femoral wires were first used to treat specific anatomic distortions and subsequently incorporated into the standard technique.

CONCLUSION

We would be the first to admit that there is a lot still to learn about this new method of TAAA repair. The results will almost certainly improve as the approach matures further, yet our experience suggests that multibranched stent graft implantation is already safe, effective, and applicable in a high proportion of cases. If this form of repair proves to be durable, the technique should assume a prominent role in the management of TAAA, especially for patients with extensive aneurysms who fare poorly after conventional open surgery.

AUTHOR CONTRIBUTIONS

Conception and design: TC, LR
Analysis and interpretation: TC, JR, JH, BH, LR
Data collection: TC, JR, JH, DS, BH, LR
Writing the article: TC, LR
Critical revision of the article: TC, JR, JH, DS, BH, LR
Final approval of the article: TC, JR, JH, DS, BH, LR
Statistical analysis: TC, JH, LR
Obtained funding: TC
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