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Repair of Extensive Thoracoabdominal Aortic Aneurysm with a Tetrafurcate Graft: Midterm Results of 63 Cases

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ABSTRACT

Objective: The objective is to present a method for maintaining the spinal cord blood supply and our midterm results for using a tetrafurcate graft in extensive thoracoabdominal aortic aneurysm (TAAA) repair.

Methods: From August 2003 to October 2007, we used a tetrafurcate graft to perform repairs to TAAAs of Crawford extent II in 63 consecutive patients. The mean age of this group of patients was 39.98 ± 10.62 years, and 46 (73%) of them were male. All of the procedures were performed under profound hypothermia with a short interval of circulatory arrest. T6 to T12 intercostal arteries were reconstructed as a "neo–intercostal artery" (N-IA) and were connected to an 8-mm sidearm of the graft to maintain the spinal cord blood supply. Visceral arteries were joined into a patch and were anastomosed to the end of the main graft. The left renal artery was anastomosed to an 8-mm sidearm or joined to the patch. The other 10-mm sidearms were anastomosed to iliac arteries.

Results: With 100% follow-up, the early-mortality rate was 7.94%. The incidence of cerebral complications was 9.52%. Temporary paraplegia was observed in 2 patients, and paraparesis occurred in 1 patient. Pulmonary complication was the most common morbidity in this group (25.40%). Two patients with Marfan syndrome had N-IA artery pseudoaneurysms during follow-up. The mean survival time of this group was 50.64 ± 2.13 months, with survival rates of 92.06% after 1 year, 88.38% after 2 years, and 86.11% after 3 years.

Conclusion: The N-IA may play an important role in spinal cord protection, and N-IA pseudoaneurysm should be avoided in Marfan syndrome patients. The use of a tetrafurcate graft is a reliable method for TAAA repair, with satisfactory midterm results.

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INTRODUCTION

Since Creech et al [1956] introduced the open surgical technique for thoracoabdominal aortic aneurysm (TAAA) repair, many approaches, such as the inclusion technique [Crawford 1974], the Carrel patch technique [Dardik 2001], and profound hypothermia [Kouchoukos 1995], have been applied in recent years to reduce its mortality and morbidity. Because of the extent of the operation and the substantial mortality and morbidity, however, total TAAA (tTAAA) resection and replacement remain a challenge for both cardiovascular surgeons and patients [Coselli 2000, 2002; Lombardi 2003]. Since 2003, we have adopted a method in our institution that uses a presewn tetrafurcate graft (Meadox, 4 Branch Graft; Boston Scientific, Natick, MA, USA) (Figure 1) to perform this complex procedure. In this report, we describe our experience and present midterm outcomes for 63 consecutive tTAAA operations involving resection and replacement with a tetrafurcate graft in Fu Wai Hospital.

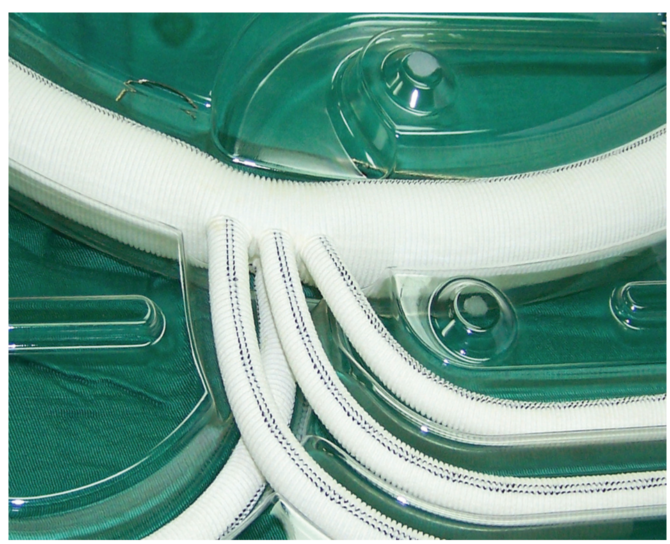

Figure 1. Tetrafurcate graft (Meadox/Boston Scientific).

Figure 2. Computed tomography reconstruction of an extensive thoracoabdominal aortic aneurysm (Crawford extent II), showing the extension of the aneurysmal aortic dissection to the iliac arteries.

Table 1. Clinical Characteristics of 63 Patients Who Underwent Thoracoabdominal Aortic Aneurysm (TAAA) Repair*

Characteristic	
Age, y	39.98 ± 10.62
Sex, n	
Male	46 (73%)
Female	17 (27%)
TAAA extent (Crawford II), n	63
Chronic Stanford A aortic dissection	16 (25.40%)
Chronic Stanford B aortic dissection	41 (65.08%)
Aortic aneurysm	6 (9.52%)
At diagnosis	
Aneurysm diameter, mm	71.36 ± 12.74
Left ventricular end-diastolic diameter, mm	48.11 ± 6.75
Left ventricular ejection fraction, %	60.58 ± 6.18
Hypertension, n	41 (65.08%)
Marfan syndrome, n†	22 (34.92%)
Aortic rupture, n	1 (1.59%)
All prior aortic operations, n	26 (41.27%)
Bentall procedure	11 (17.46%)
Ascending aorta replacement	5 (7.94%)
Total arch replacement with "stented elephant trunk"	7 (11.11%)
David procedure	1 (1.59%)
Endovascular aortic stent implantation	2 (3.17%)

*Data are presented as the mean ± SD where indicated.

†These patients received diagnoses of Marfan syndrome according to the Ghent diagnostic criteria [De Paepe 1996].

PATIENTS AND METHODS

Between August 2003 and October 2007, tTAAA resection and replacement operations were performed in our institution in 63 consecutive patients with Crawford II TAAA (Figure 2). Table 1 provides details of the patients' preoperative characteristics. The Institutional Review Board of Fu Wai Hospital granted approval for the retrospective review of these patients.

Operative Technique

All of the procedures were performed with the patient under profound hypothermia with a short period of circulatory arrest. The entire descending aorta was exposed via a left posterolateral intercostal incision combined with abdominal incision. The intercostal incision was through the left fifth intercostal space and an amputated costal arch. The abdominal incision was from the left linea pararectalis to the level of the pubic symphysis via a retroperitoneal approach. The diaphragm was incised circularly to expose the aorta. In this way, the entire descending aorta and the iliac arteries were exposed sufficiently. After the patient was administrated heparin (4 mg/kg), a 22F or 24F straight aortic cannula (according to the patient's weight) was placed in the left external iliac artery, and a 24F/29F or 30F/33F two-interval cannula was inserted through the left external iliac vein over a guidewire and positioned at the level of the right atrium. Left cardiac drainage was performed through a pulmonary vein or via the left ventricular apex. Cooling was carried out after the establishment of extracorporeal bypass, and flows of 2.0 to 2.8 L/m^2 per minute were achieved. During cooling, a 26- or 28-mm tetrafurcate graft was selected and trimmed according to the size of the relatively normal part of the patient's aorta. When the nasopharyngeal temperature had reached 18°C to 20°C (rectal temperature, 24°C-26°C), the patient was placed in a Trendelenburg position. A clamp to the descending aorta was placed at the level of the hilum of the left lung while the flow to the lower body was maintained at 1.0 to 1.4 L/m^2 per minute.

The patient's head was packed in ice during cooling; the upper-body circulation was then arrested. The aorta was transected adjacent to left subclavian artery, and the main graft of the trimmed tetrafurcate graft was sutured to the proximal aorta. During the proximal anastomosis, drainage of the left heart was stopped to avoid air embolism in the brachiocephalic arteries, which might cause cephalic embolization. After this step was completed, a 24F artery cannula was attached to a 10-mm sidearm of the tetrafurcate graft as the second perfusion line. The distal end of the graft was de-aired and clamped, and the left heart drainage was resumed. Then, total flow to and perfusion of the upper body were restored.

While hypothermia was maintained, the aorta clamp was re-placed to just above the ostia of the visceral arteries. The thoracal aneurysm was incised longitudinally. After removal of thrombus and excess aneurysmal aortic wall, the orifices of the first 5 intercostal arteries were sutured in the lumen of the aorta. The rest of the intercostal orifices were formed into

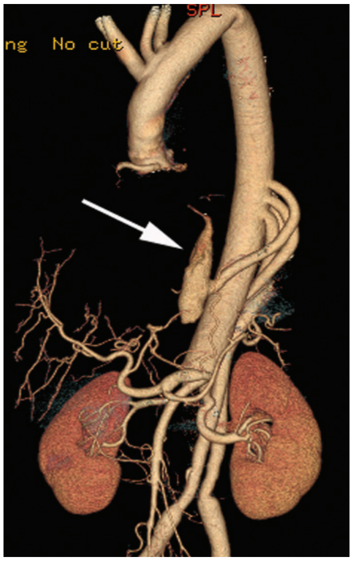

Figure 3. Computed tomography reconstruction of a patient's aorta, which was repaired with a tetrafurcate graft. Neo–intercostal artery is indicated (arrow).

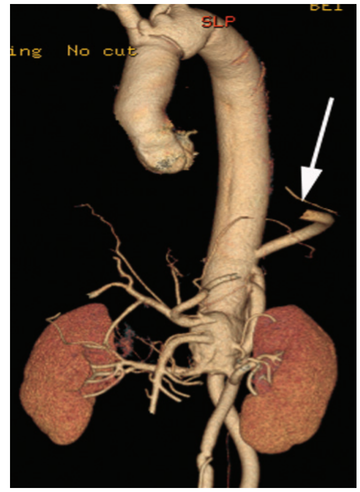

Figure 4. Computed tomography reconstruction showing occluded neo–intercostal artery (arrow).

a tube—a "neo–intercostal artery" (N-IA)—approximately 2 cm in diameter and anastomosed to an 8-mm branch of the graft in a side-to-end fashion (Figure 3). After air evacuation, perfusion to the spinal cord was restored.

The body flow was then reduced to one half of full flow, and the distal aorta clamp was repositioned on the iliac arterial cannula. Circulatory arrest to the lower body was started. The abdominal aorta aneurysm was also incised longitudinally, and one of 2 steps was taken. If the renal arteries were very close to each other, the celiac, superior mesenteric, and renal arteries were joined to a single button and anastomosed to the distal end of the graft. If the renal arteries were distant from each other, the left renal artery was anastomosed to an 8-mm sidearm of the graft. The other 3 arteries were joined to a patch and were anastomosed to the end of the main graft. After reconstruction of the visceral arteries, the blood supply was restored to the viscera after air evacuation. The blood flow was recovered to two thirds of full flow, and rewarming was initiated. When the rectal temperature rose to >34°C, the ice packed around the patient's head was removed.

Table 2. Operative Details of 63 Patients Who Underwent Thoracoabdominal Aortic Aneurysm Repair*

Variable	
Cardiopulmonary bypass time, min	199.40 ± 67.23
Rewarming time, min	62.73 ± 20.61
Cerebral ischemic time, min	16.53 ± 4.96
Spinal cord ischemic time, min	18.36 ± 4.67
Visceral ischemic time, min	28.38 ± 10.64
Packed red blood cells, units	18.51 ± 6.98
Fresh frozen plasma, L	1.72 ± 0.80
Platelets, units	2.71 ± 1.05

*Data are presented as the mean ± SD.

The left common iliac artery was anastomosed to a 10-mm branch in an end-to-end fashion. When this step was finished, perfusion to the left external iliac artery was restored, and flow of the second perfusion line to the 10-mm sidearm was discontinued. This side branch was anastomosed to right common iliac artery. If aortic disease involves the common iliac arteries, these 2 branches can be anastomosed to external iliac arteries. The inferior mesenteric artery was anastomosed to the graft in an end-to-side fashion or to the 8-mm sidearm, if available. As the final anastomosis was completed, cardiopulmonary bypass was discontinued when the rectal temperature reached 36°C to 37°C.

After surgery, methylprednisolone (500 mg) and mannitol (125 mL) were routinely administered to every patient as an additional protection.

Statistical Methods

Descriptive data were expressed as the mean ± SD. Midterm survival curves were assessed with Kaplan-Meier methodology, and conducted with SPSS 11-0.

RESULTS

Mortality

Table 2 presents details of the operations, such as operation time, clamping time, circulatory arrest time, and so forth.

There were no intraoperative deaths, and the 30-day mortality rate was 7.94% (5/63). One early death was a 46-year-old man with a Crawford II lesion concomitant with coronary artery disease. This patient died after surgery of low cardiac output syndrome with acute myocardial infarction. Although coronary artery bypass grafting was carried out urgently, his cardiac bypass could not be withdrawn. The second death was

Table 3. Postoperative Characteristics of 63 Patients Who Underwent Thoracoabdominal Aortic Aneurysm Repair

Variable	
Intensive care unit stay, d*	6.47 ± 7.37 (1-53)
In-hospital death, % (n)	7.94 (5/63)
Intraoperative death	0
Postoperative death	7.94 (5/63)
Complications, % (n)	
Reexploration for bleeding	7.94 (5/63)
Cerebral complications	9.52 (6/63)
Transient spinal cord ischemia	4.76 (3/63)
Paraparesis	1.59 (1/63)
Paraplegia	3.17 (2/63)
Acute renal dysfunction	6.35 (4/63)
Pulmonary complications	
Prolonged intubation (>48 h)	25.40 (16/63)
Tracheotomy	31.25 (5/16)
Late deaths, % (n)	5.17 (3/58)
Total deaths, % (n)	12.7 (8/63)

*Data are presented as the mean ± SD (range).

of a 55-year-old woman who underwent an urgent operation. After surgery, the celiac artery became obstructed because of celiac artery dissection. She died 10 days postoperatively from multiple organ dysfunction and sepsis. Another 2 early deaths occurred in 2 patients who had renal dysfunction before surgery. After surgery, these patients were not cured even though dialysis had been carried out, and they died of multiple organ dysfunction. The fifth death occurred in a male patient with diffuse neurologic dysfunction after an emergency operation. Mechanical ventilation could not be withdrawn, and he died of infective shock and multiple organ dysfunction.

Morbidity

The mean length of the intensive care unit stay was 6.47 ± 7.37 days (range, 1-53 days). Reoperation for bleeding was performed in 5 patients (7.94%). The volumes of red blood cells, fresh frozen plasma, and platelets transfused postoperatively are summarized in Table 2. Cerebral complications occurred in 6 patients, including cerebral hemorrhage in 1 patient with Marfan syndrome who had previously undergone a Bentall procedure, and 1 patient died with diffuse neurologic dysfunction. The rest of the patients experienced temporary neurologic dysfunction and were cured with no nervous system sequelae before discharge from our hospital. Transient paraparesis and paraplegia were observed in 3 patients (Table 3). These patients recovered before discharge from our hospital.

Prolonged intubation (>48 hours) was required in 16 (25.4%) of the patients (Table 3), and tracheotomy was needed in 5 of these patients. Renal failure occurred in 4 patients. After dialysis, 2 were cured, and 2 were dead.

Follow-up

The patients underwent routine computed tomography or duplex echocardiography scanning during their follow-up evaluations. The mean duration of follow-up was 36.57 ± 12.31 months (range, 8-57 months), with a follow-up rate of 100%. There were 3 late deaths. A 32-year-old man died of cerebral hemorrhage 20 months after discharge. He had undergone a Bentall procedure before TAAA repair and experienced cerebral hemorrhage in the intensive care unit. The other 2 patients died from a rupture of the ascending aorta and from a residual penetrating ulcer of the aortic wall at 23 months and 30 months, respectively, after discharge. During the follow-up, the N-IA was found occluded in 11 (18.96%) of 58 patients (Figure 4). A 24-year-old woman and a 51-year-old man with Marfan syndrome were found to have developed a N-IA pseudoaneurysm 2 years after surgery. No late paralysis or paraparesis was found in any of the survivors, however, even in the patients with N-IA occluded and those with N-IA pseudoaneurysm.

Midterm Prognosis

Midterm survival was calculated according to the length of time patients were alive following surgery. The overall survival rate for all patients undergoing this procedure in our study was 92.06% after 1 year, 88.38% after 2 years, and 86.11% after 3 years (Figure 5).

DISCUSSION

After Creech et al first introduced open surgical repair for TAAA [Creech 1956], open surgery became the treatment of choice for repair of TAAAs of Crawford extent II and Crawford extent III. The operative mortality and morbidity rates remained high, however. Consequently, many techniques, such as profound hypothermia and circulatory arrest [Kouchoukos 1995], left cardiac bypass [Schepens 1995], cerebrospinal fluid drainage [Cina 2004], were developed to improve the outcome of tTAAA resection and replacement. Nevertheless, the results have not been encouraging. The early mortality rate for tTAAA repair has ranged from 10% to 42% [Frank 1994; Bavaria 1995; Gilling-Smith 1995; Kouchoukos 1995; Schepens 1995; Mauney 1996], and until now, none of the protective adjuncts have permitted a physiological procedure without disturbing the hemodynamics of the aorta during surgical repair of tTAAA [Verdant 1992]. Therefore, it is very important to shorten the aortic clamping time and to rapidly reestablish the blood flow to the spinal cord and visceral organs.

In this group of patients, all of the procedures were accomplished with profound hypothermia and a short interval of circulatory arrest. Profound hypothermia, along with a short period of circulatory arrest, can provide a clear and bloodless operative field. It allows a safe interval for reconstruction of the blood supply to the spinal cord, kidneys, and other abdominal organs while providing satisfactory protection to the central nervous system and visceral organs in this lengthy procedure [Kouchoukos 1995]. Profound hypothermia with circulatory arrest has its own shortcomings, however, and the

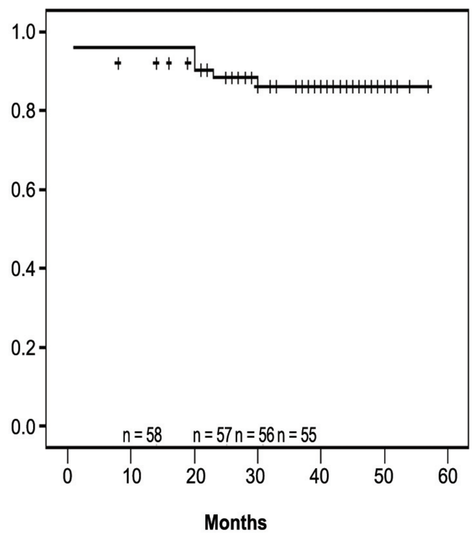

Figure 5. Kaplan-Meier survival estimate. Three-year survival of 63 patients who underwent thoracoabdominal aortic aneurysm repair in our institution.

safe duration of hypothermia is limited [Hagl 2003]. In this patient group, only 1 patient experienced stroke after surgery, and two thirds of the patients experienced only transient neurologic complications, which were cured before their discharge from the hospital. We found that the use of a tetrafurcate graft can avoid a lengthy circulatory arrest in tTAAA replacement without the need of other adjunct procedures. The multiple presewn branches of the graft permit the establishment of a second perfusion line through one of the 10-mm branches. After the anastomoses of the arteries are finished, the blood supply to the affected organs can be resumed immediately. In this patient group, the mean time of ischemia to the brain, spinal cord, and visceral organs is shorter than 30 minutes (Table 2). In addition, because the central nervous system and the visceral organs will not tolerate a long period of circulatory arrest, the temperature can be maintained relatively high. Use of a higher temperature shortened the cooling and rewarming times and reduced the injuries attributable to long-term cardiopulmonary bypass [Laffey 2002].

Paraplegia is a catastrophic complication of surgical repair of TAAA and leads to an unfavorable prognosis for these patients. Despite the many maneuvers that can be taken to minimize this complication, such as cerebrospinal fluid drainage, intraoperative neuromonitoring, and intrathecal papaverine, the risk of spinal cord injury during TAAA repair remains significant [Estrera 2001; Jacobs 2003]. Whether thoracic and abdominal segmental arteries should be reimplanted or sacrificed is still controversial [Etz 2006; Woo 2007]. Griepp's team argued that with monitoring of motor evoked potentials and somatosensory evoked potentials, sacrifice—without reimplantation—of as many as 15 intercostal and lumbar arteries during TAAA repair is safe [Etz 2006]; however, as Dr. Kazui pointed out [Kazui 2006], one of the patients in their cohort experienced paraplegia as he underwent sacrifice of intercostal arteries T3 to L3. Furthermore, according to a recent report from Coselli and colleagues, one patient who underwent emergency operation without reattachment of intercostal arteries experienced permanent paraplegia [Coselli 2008]. Therefore, keeping as many intercostal arteries as possible may reduce the risk of paraplegia, especially in patients with TAAA of Crawford extent II. In our group of patients, we provided a simple but effective method for keeping intercostal arteries. As we described above, the aortic posterior wall, which contains artery orifices from T6 to T12, was sutured to form a 2-cm tube (ie, the N-IA). Then, an 8-mm branch was anastomosed to the N-IA in an end-to-side fashion. The advantage of our maneuver to form this N-IA is obvious. No permanent paraplegia or paraparesis was observed in this group of patients. Only 3 patients had transient paraplegia or paraparesis, and they were cured before discharge from our department. Compared with the method mentioned by Woo et al [2008], our method of reestablishing the intercostal arteries is simpler, which means that the intercostal arteries can be reconstructed in a short time and the blood supply can be restored more quickly to the spinal cord during the operation. During the follow-up, the N-IA was found to be occluded (within 2 years) in 11 of the survivors, but none of these patients experienced paraplegia or paraparesis. This result may be due to the establishment of a collateral circulation for the spinal cord. In our opinion, use of this method avoids acute spinal cord ischemia, even if the intercostal arteries are occluded, because of the sufficiently short time to develop a collateral circulation for the spinal cord. One should be cautious in using N-IA reconstruction in Marfan syndrome patients, however. N-IA pseudoaneurysm was found in 2 Marfan syndrome patients in this group within 2 years after surgery. This complication is difficult for us to correct after tTAAA repair. In our later operation, less of the residual aortic wall was kept, and the N-IA diameter was <1.5 cm during N-IA formation in Marfan patients. No other N-IA pseudoaneurysms have been found in other Marfan patients who underwent tTAAA repair in our department.

Major pulmonary complications (prolonged mechanical ventilation support and tracheotomy) were the most common morbidity in this group. We also noticed that pulmonary complications were relatively high in many other series of descending aortic surgeries that used profound hypothermia with circulatory arrest [Safi 1998; Kouchoukos 2001]. Many risk factors are related to the high prevalence of pulmonary complications in tTAAA repair; such factors include age, sex, preoperative pulmonary function, comorbidity, operative technique, bypass skill, postoperative complications, and blood transfusion [Etz 2007]. In our group, prolonged intubation and tracheotomy had a strong relationship with postoperative complications (12 of 16 patients) and a large amount of blood transfusions. Heavy blood loss (>3 L) from the respiratory tract occurred during the operation in some patients. This blood loss was related to intraoperative pulmonary manipulations, especially in the patients who had previously undergone pneumothorax operation. Such manipulations will surely increase blood transfusions, which will aggravate pulmonary function after tTAAA operation. Therefore, pulmonary complications are a major shortcoming of profound hypothermia with circulatory arrest in tTAAA repair. Thorough drainage of the pulmonary diffusate and reduced pulmonary handling are the major protective methods in such situations.

According to Kouchoukos and associates [Kouchoukos 2005], tetrafurcate grafting provides a number of options for attaching the multiple branches to renal and visceral arteries. In our group, we adopted a different approach to attach the branches of the graft to the aorta and visceral arteries. It provides an easy and effective way to restore the blood supply to the spinal cord and visceral organs and has achieved a satisfactory midterm result.

CONCLUSION

On the basis of our experience, we conclude the following: (1) The N-IA may play an important role in protecting the spinal cord during TAAA repair. In patients with Marfan syndrome, a careful and reliable suturing technique should be carried out, and less residual aortic wall should be kept in order to avoid N-IA pseudoaneurysm. (2) Thoracoabdominal aorta replacement with a tetrafurcate graft is a reliable method with a satisfactory midterm result.

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