Staged Repair of Extensive Aortic Aneurysms
Morbidity and Mortality in the Elephant Trunk Technique

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Background—Extensive aortic aneurysms (ascending aorta, aortic arch, and descending or thoracoabdominal aorta) require innovative surgical techniques. Some surgeons advocate a single procedure with long periods of profound hypothermia, whereas others use a staged approach. We adopted a two-staged procedure (elephant trunk technique) in 1991 for elective repair of extensive aortic aneurysms.

Methods and Results—Between February 1991 and May 2000, we performed a total of 1146 aortic aneurysm operations. Of these, 182 (15.9%) operations were first- or second-stage elephant trunk procedures, performed in a total of 117 patients. Stage 1 was completed in all 117 patients. Stage 2 was completed in 65 (55.6%) of 117 patients. Thirty-day mortality rate for the first stage was 5.1% (6 of 117). Mortality rate during the interval between operations was 3.6% (4 of 111), of which 75% (3 of 4) were the result of aneurysm rupture. Thirty-day mortality rate for the second stage was 6.2% (4 of 65). A total of 43 patients did not return for second-stage repair. Among these patients, within an average period of 3.4 years (range, 1.5 months to 4.9 years), 13 of 43 (30.2%) died, 4 of 13 (30.8%) as the result of rupture. Two of 117 (1.7%) first-stage patients had postoperative stroke. No spinal cord dysfunction occurred in second-stage patients.

Conclusions—Extensive aortic aneurysms can be repaired with acceptable morbidity and mortality rates through the use of the elephant trunk technique. Death was most commonly the result of rupture, both in interval patients awaiting scheduled second-stage repair and in patients who did not return. After the first stage, prompt treatment of the remaining segment is crucial to the success of staged repair. (Circulation. 2001;104:2938-2942.)

Key Words: aorta ■ surgery ■ aneurysm

The management of extensive aortic aneurysms poses a challenge to all persons involved, demanding multiorgan protection and maximum technical support. Graft replacement of the ascending aorta, arch, and descending thoracic aorta performed in a single operation can exaggerate potential hazards. The patient is submitted to a lengthy procedure, requiring multiple incisions, an increased number of protective surgical adjuncts, longer clamp times, and greater blood loss. Before the introduction of the elephant trunk technique in 1983,1 staged repair was also fraught with complications, particularly in the second stage when aortic dissection to gain proximal control caused excessive bleeding. Frequently, the pulmonary artery or the aorta would be entered, causing catastrophic bleeding.2 The elephant trunk technique permitted the surgeon to avoid cross-clamping of the highly vulnerable proximal descending aorta in the second stage and obviated the bleeding problem. We have routinely used the elephant trunk technique since 19911 (Figure 1). In the first stage, cardiopulmonary bypass, profound hypothermia, circulatory arrest, and retrograde cerebral perfusion provide protection to the brain and guard against stroke. In the second stage, distal aortic perfusion and perioperative cerebrospinal fluid (CSF) drainage provide protection to the spinal cord and defense against paraplegia or paraparesis. In the second stage, we also use passive core cooling as well as active visceral cooling, with excellent results in renal protection.

Methods
Between February 1991 and May 2000, we performed 1146 operations for aortic aneurysms. One hundred seventeen of the patients operated during this period had extensive aortic aneurysms with involvement of the ascending aorta, aortic arch, and descending or thoracoabdominal aorta. At this time, there have been 182 operations with 65 of 117 (55.6%) patients completing both stages. Mean age was 62.9 years (range, 16 to 87). Sixty-one (52.1%) patients were men and 56 (47.9%) were women. Associated diseases were typical of patients with fewer extensive aneurysms and included similar percentages of cerebrovascular disease, heart disease, coronary artery disease, renal insufficiency, hypertension, and chronic obstructive pulmonary disease (Table 1). Marfan syndrome occurred in 5 of 117 (4.3%) patients. Aortic dissection was present in 49 of 117 (41.0%) patients; 6 of 48 (12.5%) were acute and 42 of 48 (87.5%) were chronic.
In 117 first-stage operations, 53 of 117 (45.3%) patients were operated for valve, ascending aorta, and aortic arch replacement; 64 of 117 (54.7%) were operated for ascending aorta and aortic arch. Cardiopulmonary bypass and profound hypothermic circulatory arrest were used in all 117 patients. In 102 of 117 (87.2%) patients, we used retrograde cerebral perfusion for brain protection. Operative variables are shown in Table 2. Total cardiac ischemic time ranged from 14 to 178 minutes (mean, 76.5 minutes). Circulatory arrest averaged 44 minutes (range, 16 to 85 minutes); pump time averaged 139 minutes (range, 58 to 252 minutes). Retrograde perfusion averaged 43 minutes (range, 16 to 85 minutes).

In 65 operations for second-stage repair, 19 of 65 (29.2%) patients had descending aortic graft replacement, 18 (27.7%) had type II thoracoabdominal aortic replacement, and 28 of 65 (43.1%) had type I thoracoabdominal aortic replacement. (Classification for thoracoabdominal aortic aneurysms is illustrated in Figure 2.) In 49 of 65 (75.4%) second-stage operations, we used the adjuncts distal aortic perfusion and perioperative CSF drainage. Operative variables for stage 2 are shown in Table 3. Aortic clamp times ranged from 7 to 117 minutes (mean, 40 minutes). Pump times were 7 to 196 minutes (mean, 62 minutes).

Technique

The first stage of the elephant trunk technique, performed in a fashion similar to standard surgery of the ascending aorta and transverse arch, has been well described previously. The exception is the inverted distal graft. The folded edge of the inverted replacement graft is sutured to the descending thoracic aorta just distal to the left subclavian artery. When the distal anastomosis is completed, the inner portion of the tube graft is retrieved and the outer portion, or "elephant trunk," is left in the descending aorta. Retrograde cerebral perfusion, used in all cases since 1992, provides oxygenated blood through the superior vena cava and the internal jugular veins to the brain.

The second stage of the elephant trunk technique, as illustrated in Figure 3, is much like standard descending thoracic or thoracoabdominal aortic aneurysm repair. After induction of anesthesia, a 14-gauge needle inserted into the intervertebral space between L3 and L4 drains the CSF. Left heart bypass is from the left atrial appendage or pulmonary vein to the common femoral artery. With a clamp at the mid-descending thoracic aorta, the proximal third of the descending thoracic aorta is opened. Elimination of the proximal clamp reduces trauma to the aortic wall. The elephant trunk portion of the graft, inserted in the descending thoracic aorta during stage 1, is grasped and clamped. A new graft is sutured to the "elephant trunk."

Results

Morbidity

During surgery, 20 of 117 (17.1%) first-stage patients had significant coagulopathy involving low platelet count, massive bleeding, and abnormal coagulation profile. In the period before 1991, when retrograde perfusion became part of the standard operating procedure, there were 2 postoperative strokes. There have been no strokes since then. Early pulmonary complications, defined by tracheostomy, intubation for ≥4 days, or reintubation, occurred in 35 of 117 (29.9%) patients. Thirty-eight of 117 (32.5%) patients had early

<table>
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<th>Variable</th>
<th>Patients</th>
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<tr>
<td>Total</td>
<td>117</td>
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<td>Female</td>
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</tr>
<tr>
<td>Male</td>
<td>61</td>
<td>52.1</td>
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<tr>
<td>Acute dissection</td>
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<td>Chronic dissection</td>
<td>42</td>
<td>35.9</td>
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<td>Coronary artery disease</td>
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<tr>
<td>COPD</td>
<td>24</td>
<td>20.5</td>
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<td>Renal insufficiency</td>
<td>10</td>
<td>8.6</td>
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<tr>
<td>Marfan syndrome</td>
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<td>4.3</td>
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<tr>
<td>Cerebrovascular disease</td>
<td>6</td>
<td>5.1</td>
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<tr>
<td>Hypertension</td>
<td>86</td>
<td>73.5</td>
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</table>

COPD indicates chronic obstructive pulmonary disease.
cardiac complications, 12 (10.3%) had renal insufficiency or failure, and 21 (17.9%) had encephalopathy. Cardiac complications included atrial fibrillation, arrhythmia, and arrest. Encephalopathy included any patients with an abnormal process of the central nervous system caused by numerous causative factors such as metabolic dysfunction, renal insufficiency, sepsis, or ventilator-dependent state. Most often the condition was reversible.

Intraoperative coagulopathy occurred in 4 of 65 (6.2%) second-stage patients. After surgery, there was no instance of neurological deficit, either in patients who received or who did not receive CSF drainage and distal aortic perfusion. Early complications after surgery were 17 of 65 (26.2%) pulmonary, 7 of 65 (10.8%) renal insufficiency or failure, 14 of 65 (21.5%) cardiac complications, and 6 of 65 (9.2%) encephalopathy.

Mortality Rates
Mortality rates are for the 30 days after stage 1, 31 days to 6 weeks after stage 1 (interval), and 30 days after stage 2. Mortality rates were also recorded for the group of patients who did not return for second-stage repair (Table 4 and Figure 4). All 117 first-stage patients survived surgery. In the 30 days after stage 1 graft replacement, there were 6 of 117 (5.1%) deaths. In the interval between stage 1 and stage 2, mortality rate was 3.6% (4 of 111), 75% (3 of 4) as the result of rupture. Second-stage mortality rate was 6.2% (4 of 65 patients). One of 4 patients died of cardiac arrest the day of surgery. In the next 30 days, 2 of 4 deaths were the result of stroke and 1 of 4 the result of cardiac arrest. Forty-three patients discharged from the hospital did not return for second-stage repair. Follow-up surveys revealed 13 deaths among 43 (30.2%) nonreturning patients, 4 (30.8%) of which were due to aneurysm rupture. A comparison of mortality rates in patients who completed stages 1 and 2 versus nonreturning patients completing only stage 1 is shown in Figure 5. Figure 6 uses the Kaplan-Meier method to show the survival of all 117 patients, regardless of return for follow-up.

Discussion
Before writing this report, we conducted many analyses, looking for significant preoperative risk factors for end points such as coagulopathy, stroke, dialysis requirement, and tracheostomy. Although there were a fair number of events—coagulopathies and tracheostomies in particular—no variables surfaced as statistically significant predictors. Most importantly, none of these variables came close to being sensitive or specific enough to use as criteria for determining patient selection. With respect to mortality, data were grouped to answer the following questions: What was immediate (30-day) outcome of stage 1 surgery? What was interval or long-term mortality of stage 1 surgery? What was the early mortality of stage 2? And what were the consequences of a patient’s failure to return for stage 2 repair? Again, no preoperative patient characteristics were associated with short-term (30-day) mortality for any period. For long-term mortality (beyond 30 days), the only significant predictors at the time of first-stage repair were increasing age at operation ($P<0.0011$) and failure to receive a second-stage operation ($P<0.025$).

Short-term mortality is notoriously difficult to predict from preoperative characteristics, and the lack of statistically significant predictors in a population of this size with a low event rate is not surprising. Perioperative complications such as coagulopathy and renal and respiratory failure are also difficult to predict from preoperative patient characteristics. Coagulopathy is related more to time on the pump than anything else, and this cannot be known ahead of time. Renal and respiratory failure are entwined after surgery as part of the cascade of postoperative complications (the occurrence of one predicts the onset of the other) and were not related to preoperative patient characteristics.

Early mortality rates after stage 1 (5%) and stage 2 (6.2%) were acceptable. Although the mortality rate during the interval between stages (3.6%) might also be considered satisfactory, the disturbing fact remains that 3 of the 4 deaths

<table>
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<th>Patients</th>
<th>Deaths</th>
<th>Percent</th>
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<tr>
<td>Stage 1</td>
<td>117</td>
<td>6</td>
<td>5.1</td>
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<tr>
<td>Interval</td>
<td>111</td>
<td>4</td>
<td>3.6</td>
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<tr>
<td>Stage 2</td>
<td>65</td>
<td>4</td>
<td>6.2</td>
</tr>
<tr>
<td>Nonreturning</td>
<td>42</td>
<td>13</td>
<td>30.9</td>
</tr>
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Stage 1 mortality indicates 30 days postop stage 1; interval mortality, 31 days postop stage 1 until planned second stage at 6 weeks; stage 2 mortality, 30 days postop stage 2; nonreturning, patients who failed to return for stage 2 whose deaths occurred 1.5 months to 4.9 years after stage 1.
during this 2-week period were due to rupture of the unoperated aortic segment. Although given an appointment at the time of discharge for their second procedure, 43 patients did not return for second-stage repair. Some patients did not respond to follow-up letters; some simply refused second-stage repair. We know of 13 of 43 (30.2%) deaths in nonreturning patients. In follow-up surveys completed by surviving relatives, the cause of death was unstated for six patients. Four (30.7%) of the deaths among nonreturning patients were due to aneurysm rupture. We now make every effort to perform second-stage surgery at 4 rather than 6 weeks after stage 1 repair if the patient’s condition permits. Staged repair with the use of the elephant trunk technique is effective treatment for extensive aortic aneurysms. However, surgery of just one portion of an extensive aortic aneurysm does very little to reduce the likelihood of aneurysm rupture and death.

The current alternative to the elephant trunk technique is repair in a single operation, which requires profound hypothermic circulatory arrest both as brain protection in the replacement of the ascending aorta and arch, and for spinal cord protection during graft replacement of the descending thoracic aorta.6–10 Although the protective properties of hypothermia are well documented in surgery of the ascending aorta and transverse aortic arch, the drawbacks of lowering systemic temperature are also well known.11 Although the ascending aorta, aortic arch, and proximal descending aorta can be reached through a single thoracotomy incision,12 the number of incisions and consequent risk is increased if surgery requires aortic or mitral valve replacement and/or coronary artery bypass.13

In 1992, brain protection in the first stage of the elephant trunk technique was enhanced by the introduction of retrograde cerebral perfusion.4 Since then, we have had no incidents of stroke after stage 1 repair. Second-stage graft replacement, in which we used distal aortic perfusion and cerebrospinal fluid drainage and in which 71% of patients had either type I or type II thoracoabdominal aortic aneurysms, had no instances of neurological deficit. The results in the current series and the favorable outcome demonstrated in previous studies of distal aortic perfusion and cerebrospinal fluid drainage ensure the continued use of these adjuncts in elephant trunk procedures.14 There have been some variations...
in Dr Borst’s original design of the elephant trunk technique, but the objective—to reduce surgical risks in extensive aortic aneurysm repair—remains the same.

References
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