Endovascular Stent–Graft Treatment for Blunt Aortic Injury

Masaaki Kato, MD; Shougo Yatsu, MD; Hiroshige Sato, MD; Shunei Kyo, MD

Background  Thoracic aortic injury resulting from blunt trauma is usually fatal and almost always associated with multiple, complex, nonaortic injuries that can adversely affect standard surgical repair of the aorta. Endovascular stent–graft treatment offers these patients a less invasive operative treatment option.

Methods and Results  Between January 2002 and October 2003, 6 patients with blunt aortic injury (BAI) were treated with a stent–graft. In all cases endovascular management was selected because of associated polytrauma or comorbidities. All stent–grafts were homemade and deployed through the femoral artery with 18–20 Fr delivery sheaths. There were no cases of perioperative death, renal failure, or neurologic complication. In one patient the postoperative computed tomography scan showed proximal endoleak requiring additional balloon dilatation and stenting. No other endoleaks were observed by CT in the acute phase. None of the follow-up CT scans revealed evidence of endoleak, migration, or alteration of the stent–graft.

Conclusions  Endovascular repair for BAI is technically feasible and is an alternative to open surgery for high-risk patients. (Circ J 2004; 68: 553–557)

Key Words:  Aortic injury; Blunt trauma; Endovascular treatment; Stent–graft

Blunt aortic injury (BAI) is a life-threatening complication of chest trauma. Approximately 85% of patients die at the scene of the accident and patients who arrive at hospital alive frequently have associated lesions such as cerebrospinal trauma, abdominal trauma, or multiple bone fractures. The standard surgical technique for BAI requires left posterolateral thoracotomy, single-lung ventilation, proximal aortic cross-clamping, and use of cardiopulmonary bypass (CPB) or left atriofemoral shunt for preventing ischemic, neurologic, and visceral complications during the cross-clamping. Despite the recent advances in surgical and circulatory assistance techniques, postoperative mortality ranges from 15% to 30%.[1–4] The presence of severe associated injuries precludes the possibility of performing the standard surgical repair. Endovascular stent–graft treatment offers these patients a less invasive operative treatment option.

Patient Selection
From January 2002 to October 2003, 6 patients were admitted with a BAI. Two patients had been in automobile accidents, 1 in a motorcycle accident, and 3 had fallen accidentally. Three of the patients were male and the age range was 18–57 years (mean, 34.5 years).

In 5 patients the BAI was diagnosed by computed tomography (CT) in the emergency room after clinical suspicion was raised by symptoms and/or chest radiograph findings. One patient was treated as a BAI 7 days after the accident because of delayed diagnosis of a periaortic hematoma. The indication for the stent–graft procedure was the presence of serious comorbidities, such as severe pulmonary contusions, closed head injury, spinal cord injury, and pelvic fracture, that made open surgical repair extremely risky (Table 1). Preoperative workup included spiral CT scan of the chest, transesophageal echography (TEE), and subtraction angiography of the thoracic aorta. During the same period as this series, we performed 4 open repairs for BAI (age range, 17–67) because those patients were considered a low risk for open surgery, having either few associated injuries (3 patients) or a long interval (8 years) after the original trauma (1 patient).

Stent–Graft
The dimensions of the stent–graft were determined from the CT and angiography images (Fig 1a–c). The precise diameters proximal and distal to the injured aorta were measured using the CT built-in scale of straight line distance for CT (Hispeed Advantage SG: GE Medical Systems, Milwaukee, WI, USA). We confirmed these diameters using intraoperative angiography with a measuring guidewire. The graft was oversized by 10% compared with the normal, adjacent aorta and in this series, the average stent–graft diameter was 23 mm (range, 18–26 mm), and average length was 92 mm (range, 58–110 mm).

The homemade stent–graft comprised 2 Gianturco stents (William Cook Europe, Bjaeverskov, Denmark) and a thin-wall, woven polyester graft (Nakao Filter Co, Osaka, Japan). Each device had a 15–20 mm long stent-free area between the proximal and distal stents that could adapt to the curvature of the distal arch to the descending aorta (Fig 2).

Stent–Graft Placement
Informed consent was obtained from all patients or from
the next of kin. All 6 procedures were performed in the angiography suite because of the high-quality imaging required. Five patients underwent general anesthesia because they had already been intubated preoperatively for their respiratory dysfunction and one patient underwent local anesthesia, which is the usual method for endovascular stent–grafting at this hospital. Systemic heparin was administered at approximately 100 U/kg.

All stent–grafts were delivered through the femoral artery and digital subtraction angiography was performed with a pigtail catheter that was inserted from the brachial artery to the ascending aorta to show the anatomy and size of the aorta, and the morphology of the pseudoaneurysm (Fig 1c). Retrograde cannulation of the femoral artery was performed, and an 18–20Fr sheath (KTI sheath; Cook Inc, Bloomington, IN, USA) was introduced over a guidewire that had been inserted from the brachial artery to the femoral artery (pull-through wire) through the thoracic aorta.

The homemade stent–graft was advanced through the catheter until the tip was just proximal to the site of the injury. The mean arterial pressure was temporarily lowered to 60 mmHg by occluding both the superior and inferior vena cavae with balloons that had been inserted from the neck vein and femoral vein. The sheath was then retracted over the graft, resulting in deployment of the self-expanding stent–graft. Postdeployment digital subtraction angiographic aortography was performed to confirm good positioning and check for leakage around the graft (endoleak), which would suggest inadequate isolation of the pseudoaneurysm. If an inadequate seal was revealed by angiography, an additional bare stent (extra-large Palmaz stent; Cordis Co, Miami, FL, USA) was deployed with a large angioplasty balloon (Maxi LD; Cordis Europe N.V., Roden, the Netherlands). This extra-large Palmaz stent (inflated length, 37.8–30.6 mm) was inflated with 2–4 atmosphere using a 20 mm balloon for a graft diameter of 20 mm or less and a 25 mm balloon for a graft diameter of 22–28 mm. Digital subtraction angiography was repeated and if an adequate seal of the pseudoaneurysm was confirmed (Fig 1f), the femoral access site was repaired.

Follow-up
A plain chest radiograph was obtained as a record of the stent–graft skeleton and position. Follow-up CT angiography was routinely performed 4–8 days after the operation (Fig 1d,e) and further CT examinations were performed at 3, 6 and 12 months after the procedure and annually thereafter.

### Results
In all 6 patients the aortic tear was in the aortic isthmus or proximal descending aorta (Fig 1c). Five of the 6 patients were treated acutely and underwent stent–graft repair within 72 h of diagnosis (range, 4–70 h; mean, 35 h) (Table 1). The relatively short time to graft implantation for patients 1 and 4 was made possible by stocking a range of graft sizes that had been prepared as back-up stent–grafts for elective endovascular treatment of aortic aneurysm or dissection. In patient 5, delayed diagnosis of the BAI (7 days from the trauma to diagnosis) and stable hemodynamic

<table>
<thead>
<tr>
<th>Patient no.</th>
<th>Age (years)</th>
<th>Sex</th>
<th>Course of injury</th>
<th>Comorbidities and associated lesions</th>
<th>Interval from injury to diagnosis (h)</th>
<th>Interval from diagnosis to repair (h)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>25</td>
<td>F</td>
<td>Automobile accident</td>
<td>Hemopneumothrax, pulmonary contusion, multiple rib fracture, T11 T12 vertebral fracture, paraplegia</td>
<td>3</td>
<td>6</td>
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<tr>
<td>2</td>
<td>57</td>
<td>M</td>
<td>Automobile accident</td>
<td>Traumatic subarachnoid hemorrhage, multiple rib fracture, flail chest (intubated), left kidney rupture, lower limb fracture, upper limb fracture</td>
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<td>56</td>
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<tr>
<td>3</td>
<td>44</td>
<td>F</td>
<td>Fall</td>
<td>Multiple rib fracture, flail chest (intubated), pelvic fracture, lower limb fracture</td>
<td>8</td>
<td>70</td>
</tr>
<tr>
<td>4</td>
<td>26</td>
<td>M</td>
<td>Fall</td>
<td>Depression, hemopneumothrax, multiple rib fracture, flail chest (intubated)</td>
<td>16</td>
<td>4</td>
</tr>
<tr>
<td>5</td>
<td>18</td>
<td>M</td>
<td>Motorcycle accident</td>
<td>Hemopneumothrax, pulmonary contusion, multiple rib fracture, flail chest (intubated), pelvic fracture</td>
<td>168</td>
<td>168</td>
</tr>
<tr>
<td>6</td>
<td>37</td>
<td>F</td>
<td>Fall</td>
<td>Schizophrenia, bilateral hemothrax, pulmonary contusion, multiple rib fracture (intubated), C2 T5 T6 T10 T12 LI vertebral fracture, paraplegia, pelvic fracture</td>
<td>2</td>
<td>40</td>
</tr>
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</table>
state made the stent–graft treatment an elective operation and it was not performed until 14 days after the original trauma.

The usual femoral artery access was used and in all cases one stent–graft gave adequate exclusion of the rupture. The diameter of the implanted device varied from 18 to 26 mm and in length from 58 to 110 mm (Table 2) and in 4 of the 6 patients, postdeployment digital subtraction angiography revealed minor leakage from the proximal side of the stent–graft. An additional extra-large Palmaz stent was implanted to attach the stent–graft to the proximal neck of the aorta. In all cases the final angiographic scan showed satisfactory deployment of the stent–graft with complete exclusion of the ruptured zone without endoleaks (Fig 1f).

There was one major perioperative complication in patient 1. The iliac bifurcation was ruptured by insertion of an overly large 18Fr sheath through her femoral artery and it was not discovered until the end of the procedure when after removal of the catheter sheath, the patient fell into hemorrhagic shock. She recovered after prompt balloon occlusion of the abdominal aorta and was returned to the operating theater for a graft interposed between the common and external iliac arteries.

There were no cases of renal failure, neurologic complication (stroke or paraplegia), embolization, or stent–graft migration, nor were there any perioperative deaths. The hospital stay ranged from 4 days to 3 months and all patients left the surgical intensive care unit for the trauma center on the first postoperative day for management of their associated lesions. The CT scan of the chest performed between 4 and 8 days postoperatively confirmed the satisfactory position of the stent–graft without proximal or distal endoleaks (Fig 1d,e) in 5 patients, but in patient 1 the CT scan at day 4 showed a proximal endoleak (type I) requiring placement of an additional balloon expandable bare stent (extra-large Palmaz stent). There were no complications of this second procedure.

All patients survived the follow-up period (range, 2–23...
months; mean, 6 months) without no evidence of stent–
graft failure, leak, or distal migration. In 5 cases the
pseudoaneurysm sac had regressed after 3 months or more.

Discussion

BAI is the second most common cause of death from
blunt trauma, after head injury.1 The standard treatment for
BAI is open surgical repair, usually requiring a major
thoracic approach, single-lung ventilation, shunting or
extracorporeal circulation, left heart bypass with partial or
total CPB, which can result in potential bleeding complica-
tions. The mortality rate from emergency treatment of BAI
ranges from 15% to 30%, and the incidence of paraplegia is
reported to be 13–14% in contemporary studies.1–4 In addi-
tion to these miserable surgical results, BAI is frequently
associated with pulmonary contusion and severe intra-
abdominal or cranial injuries making it very difficult to
decide to perform open surgical repair.

Endovascular treatment is a less invasive strategy and is
an attractive alternative to conventional surgery that poten-
tially can reduce the operative risk, hospital stay, and cost.
Both Semba et al13 and Kato et al14 have reported endovas-
tacular stent–graft treatment of acute traumatic rupture with
low mortality and no neurologic complications. The good
operative results in the present and other series15,16 attest to
the worth of considering this treatment as the first choice
for BAI with severe associated complications.

The main potential limitations to stent–graft treatment
for BAI are the site of the laceration, the vascular access,
and the availability of a stent–graft in an emergency. The
site of the laceration in BAI gravitates toward the small
curvature of the proximal descending aorta because the
rapid deceleration after chest trauma places excessive shear
stress on the aortic isthmus, which is fixed to the pulmo-
nary artery and mediastinum, and lacerates the aorta at this
particular site. The success of the endovascular procedure
greatly depends on the presence of a straight and long neck
proximal and distal to the aortic injury. In theory, our
device has good attachment between the stent–graft and
aortic wall, but if the patient has a short proximal landing
neck, 15–20 mm in length, the curvature of the distal arch
makes it difficult to get a tight seal between the stent–graft
and aortic wall. Our solution to this problem is in the
design of our homemade stent–graft, which has a stent-
free area between the proximal Z stent and second stent,
allowing the device to curve along the distal arch; at
the same time there is a risk of the graft kinking and/or invagi-
nating. Another solution is to make a fenestration in the
proximal side of the stent–graft along the zigzag of the
Gianturco stent to prevent inflation of the lesser curvature
side by the blood stream17,18 (Fig 2). In the present series, 5
of 6 patients had a type I endoleak from the proximal side
of the lesser curvature after initial implantation of the
stent–graft, which we treated by balloon dilatation and
stenting with an extra-large Palmaz stent that makes the
proximal neck of the aorta forcibly adapt to the stent–graft.
However, forcing this adaptation between the stent–graft
and aortic wall creates a new source of anxiety about
degeneration and/or necrosis of the aortic wall. Although

<table>
<thead>
<tr>
<th>Patient no.</th>
<th>Size of device (mm)</th>
<th>Additional procedure</th>
<th>Outcome</th>
<th>Prognosis</th>
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<tbody>
<tr>
<td>1</td>
<td>ø18 L58</td>
<td>–</td>
<td>Proximal type I endoleak</td>
<td>Alive</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>□ additional Palmaz stent implant</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>□ Exclusion</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>ø26 L110</td>
<td>–</td>
<td>Exclusion</td>
<td>Alive</td>
</tr>
<tr>
<td>3</td>
<td>ø24 L70</td>
<td>Palmaz stent</td>
<td>Exclusion</td>
<td>Alive</td>
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<td>4</td>
<td>ø26 L105</td>
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<tr>
<td>6</td>
<td>ø22 L110</td>
<td>Palmaz stent</td>
<td>Exclusion</td>
<td>Alive</td>
</tr>
</tbody>
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ø, diameter; L, length.
all endoleaks disappeared in the acute phase after this additional treatment and stent–graft related aortic events have not occurred to date, careful follow up is essential. Second generation, commercially available stent–grafts, such as the Cook Zenith thoracic stent or the Gortex Excluder; which adjust to the curvature of the distal arch, will soon be used widely in Japan.

Vascular access is another determinant of the technical success of the endovascular procedure and it is sometimes difficult in emergency situations to precisely assess the arterial vascularization of the lower limb. Stenosis, tortuosity, calcifications or a femoral axis less than 7 mm in diameter can make the progression of an 18–20Fr sheath very hazardous, as we found in the case of iliac artery rupture. We used an 18Fr sheath for this rather small woman and the operator felt strong resistance while inserting and withdrawing the sheath. Although her blood pressure dropped below 50 mmHg on removal of the sheath, the patient recovered immediately after insertion of a balloon and occlusion of the abdominal aorta, which we had prepared for because of a previous experience of iliac artery rupture during vascular access of stent–graft implantation. If the operator feels strong resistance while inserting the catheter sheath during an emergency, the insertion point should be changed from the femoral artery to the common iliac artery or abdominal aorta, or there should be a treatment plan for any bleeding complications that occur after withdrawing the sheath.

Because we use a homemade stent–graft, there can be an unavoidable delay before stent–graft insertion because of individualized design for each patient or gas sterilization of the device.\(^{6-10}\) We have stocked stent–grafts of various diameters and lengths and if the correct size is available we can perform the procedure without any delay; if not, the delay can vary from 24 to 72h. Fortunately in the present series, there was not a case of rupture during the waiting period; however, prompt treatment after diagnosis is very important with respect to subsequent operations for traumatic complications, as well as rupture of the pseudoaneurysm. From our experience of only 6 cases, the variations in the size of stent–graft required are not so great: diameter is limited to 20–26 mm and length to approximately 100 mm. Therefore, 3 or 4 sizes of the stent–graft should be prepared for emergency use in BAI patients: diameters of 20, 22, 24 and 26 mm and length 100 mm.

A substantial advantage of endovascular treatment is that it can be performed soon after the management of another life-threatening lesion, in contrast to invasive open surgery, which requires recovery from any prior major intervention and/or intensive treatment for the life-treating complications of trauma.

Stent–graft repair is an evolving technology that offers a safe and effective alternative to standard surgical repair for the patient with BAI. Our limited experience also shows that it can be used in the acute trauma setting, with an acceptable time between diagnosis and repair. Further follow-up is mandatory, however, particularly in relation to graft durability, before this technology can be recommended to all patients. If stent–graft repair continues to fulfill its promise as a valuable tool in aortic surgery, it could become the treatment of choice for severely injured patients with BAI.