Hypothesis: This study was undertaken to identify mechanisms of injury, diagnostic modalities, surgical management, and outcome in children with traumatic aortic disruptions.

Design: Retrospective study.

Setting: University-affiliated private hospital.

Patients: All patients younger than 17 years listed in the trauma registry.

Intervention: Operative repair of thoracic aortic injuries.

Main Outcome Measures: There were 8 boys and 3 girls ranging in age from 12 to 17 years (mean, 14.8 years). Seven children were motor vehicle passengers; 3 were pedestrians struck by vehicles; and 1 was thrown from a bull. Aortic injuries were suspected on the basis of the mechanism of injury and abnormal chest x-ray films (mediastinal widening). Aortic injuries were confirmed in 9 patients by arch aortography and in 2 patients by computed tomography. The injuries involved the isthmus of the aorta in 9 patients (complete transections) and the aortic arch in 2 patients (avulsions of the great vessels). Isthmus injuries were repaired by means of left heart bypass with direct cannulation of the distal thoracic aorta in 8 patients and femoral venous to femoral arterial bypass in 1 patient. Arch injuries were repaired during hypothermic circulatory arrest. The injured aortic segments were replaced with interposition grafts. There were no direct complications of anticoagulation. Ten patients (91%) survived. The only death was caused by a severe closed head injury. There were no instances of paraplegia related to aortic repairs.

Conclusion: Good outcomes resulted from early diagnosis based on mechanism of injury, prompt aortography, and computed tomography and operative management that included distal aortic perfusion with left heart bypass.

Arch Surg. 1999;134:759-763

RESULTS

There were 8 boys and 3 girls ranging in age from 12 to 17 years (mean, 14.8 years). All patients sustained blunt trauma. Three patients were drivers and 4 were passengers in motor vehicle accidents; 3 patients were pedestrians struck by vehicles; and 1 patient was thrown from a bull. Two patients were ejected from the vehicles in which they were passengers. Five patients were transported directly to our trauma center and 6 were transferred from other institutions. The initial patient assessments and outcomes are presented in Table 1.

Findings on chest radiographs at admission were mediastinal widening in 11 patients, rib fracture in 6, obscure aortic knob in 5, nasogastric tube deviation in 2, and bronchial depression in 1. Nine children underwent arch aortography to es-
PATIENTS AND METHODS

The trauma registry of Clarian Methodist Hospital, Indianapolis, Ind, was used to identify all children (<17 years) with acute traumatic disruption of their thoracic aortas. Between June 1, 1981, and January 31, 1998, 11 children with blunt disruptions of their thoracic aorta were treated. This represents 12% of all thoracic aortic disruptions treated during that period. Mechanisms of injury, initial assessments and care, radiographic findings, associated injuries, management of aortic injuries, and complications were reviewed.

Table 1. Initial Injury Assessment and Outcome

<table>
<thead>
<tr>
<th>Patient No./Sex/Age, y</th>
<th>Revised Trauma Score</th>
<th>Glasgow Coma Scale Score</th>
<th>Injury Severity Scale Score</th>
<th>Outcome</th>
<th>Length of Stay, d</th>
</tr>
</thead>
<tbody>
<tr>
<td>1/F/16</td>
<td>12</td>
<td>15</td>
<td>22</td>
<td>Alive</td>
<td>20</td>
</tr>
<tr>
<td>2/F/16</td>
<td>12</td>
<td>14</td>
<td>27</td>
<td>Alive</td>
<td>12</td>
</tr>
<tr>
<td>3/M/12</td>
<td>10</td>
<td>7</td>
<td>34</td>
<td>Alive</td>
<td>46</td>
</tr>
<tr>
<td>4/M/17</td>
<td>1</td>
<td>4</td>
<td>57</td>
<td>Dead</td>
<td>7</td>
</tr>
<tr>
<td>5/M/17</td>
<td>12</td>
<td>15</td>
<td>41</td>
<td>Alive</td>
<td>101</td>
</tr>
<tr>
<td>6/M/13</td>
<td>12</td>
<td>15</td>
<td>24</td>
<td>Alive</td>
<td>21</td>
</tr>
<tr>
<td>7/M/15</td>
<td>12</td>
<td>15</td>
<td>27</td>
<td>Alive</td>
<td>8</td>
</tr>
<tr>
<td>8/M/13</td>
<td>12</td>
<td>15</td>
<td>27</td>
<td>Alive</td>
<td>7</td>
</tr>
<tr>
<td>9/M/15</td>
<td>11</td>
<td>15</td>
<td>16</td>
<td>Alive</td>
<td>4</td>
</tr>
<tr>
<td>10/F/13</td>
<td>8</td>
<td>5</td>
<td>41</td>
<td>Alive</td>
<td>80</td>
</tr>
<tr>
<td>11/M/16</td>
<td>11</td>
<td>13</td>
<td>41</td>
<td>Alive</td>
<td>30</td>
</tr>
</tbody>
</table>

Table 2. Operative Management of Traumatic Aortic Injuries

<table>
<thead>
<tr>
<th>Patient No.</th>
<th>Location</th>
<th>Technique *</th>
<th>Cross-Clamp, min</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Isthmus</td>
<td>Fem-Fem</td>
<td>35</td>
</tr>
<tr>
<td>2</td>
<td>Isthmus</td>
<td>LA-DA</td>
<td>43</td>
</tr>
<tr>
<td>3</td>
<td>Isthmus</td>
<td>LA-DA</td>
<td>15</td>
</tr>
<tr>
<td>4</td>
<td>Arch</td>
<td>CPB/DHCA</td>
<td>22†</td>
</tr>
<tr>
<td>5</td>
<td>Isthmus</td>
<td>LA-DA</td>
<td>30</td>
</tr>
<tr>
<td>6</td>
<td>Isthmus</td>
<td>LA-DA</td>
<td>35</td>
</tr>
<tr>
<td>7</td>
<td>Arch</td>
<td>CPB/CP</td>
<td>14‡</td>
</tr>
<tr>
<td>8</td>
<td>Isthmus</td>
<td>LA-DA</td>
<td>22</td>
</tr>
<tr>
<td>9</td>
<td>Isthmus</td>
<td>LA-DA</td>
<td>24</td>
</tr>
<tr>
<td>10</td>
<td>Isthmus</td>
<td>LA-DA</td>
<td>27</td>
</tr>
<tr>
<td>11</td>
<td>Isthmus</td>
<td>LA-DA</td>
<td>37</td>
</tr>
</tbody>
</table>

*Fem-Fem indicates femoral venous to femoral arterial cardiopulmonary bypass; LA-DA, left atrial to descending thoracic aorta active shunting with a centrifugal pump; CPB/DHCA, total cardiopulmonary bypass with deep hypothermic circulatory arrest; and CPB/CP, total cardiopulmonary bypass with antegrade carotid perfusion.
†Total circulatory arrest time.
‡Total antegrade carotid perfusion time.

establish the diagnosis of aortic injury. The other 2 had the diagnosis established by contrast-enhanced computed tomography (CT). Injuries were located at the aortic isthmus in 9 patients and at the aortic arch involving the brachiocephalic trunk and left common carotid artery in 2 patients.

Two patients required celiotomies. In 1 patient a splenectomy was performed, and in the other patient a hepatorrhaphy, a splenorrhaphy, and retroperitoneal exploration for a renal laceration were performed. Associated injuries were femoral fracture in 6 patients, pelvic fracture in 4, closed head injury in 3, splenic laceration in 2, renal contusion in 2, and liver laceration, clavicular fracture, elbow dislocation, bronchial transection, and mangled extremity in 1 each.

All children underwent repairs of their aortic injuries immediately on diagnosis. Table 2 summarizes the operative technique used during the period of review. Left heart bypass with a centrifugal pump (Bio-Medicus, Eden Prairie, Minn) with drainage from the left atrial appendage and the blood return into the distal descending aorta was used in all isthmus disruptions except for the first patient, for whom femoral venous to femoral arterial bypass was used (Figure 1). Injuries to the aortic arch were repaired with full cardiopulmonary bypass and deep hypothermic circulatory arrest. In 1 child, direct antegrade carotid perfusion was used during the repair of the aortic arch injury.

There was 1 death in this series. A 17-year-old boy, who was an unrestrained driver, sustained an injury to the aortic arch, a transected left main bronchus, and a severe closed head injury. He experienced a cardiac arrest during transportation from a referral hospital, and he required cardiopulmonary resuscitation for 30 minutes before aortography. He underwent repair of the transected brachiocephalic trunk and left common carotid artery by means of a bifurcated graft interposed from the ascending aorta to each of the distal vessels. A left pneumonectomy was performed for extensive left main bronchial injury. He died secondary to anoxic brain injury on the seventh postoperative day.

There were no incidences of paraplegia in the survivors. Sacral plexopathy was observed in 1 patient who sustained a severe pelvic and femur fracture. This injury was present on admission and was believed to be related to a stretch injury of the sciatic nerve. Postoperative magnetic resonance imaging of the spinal cord did not demonstrate cord infarction. His aortic injury extended into

Figure 1. Schematic representation of left heart bypass used for descending thoracic aortic transections. Blood is drained from the left atrium and is actively shunted into the distal thoracic aorta.
the distal aortic arch and required reimplantation of the left subclavian artery into the graft repair. The patient required prolonged ventilatory support and subsequently developed an aortic graft infection, which was treated with antibiotics for 4 months. The graft was replaced with an aortic homograft. Follow-up at 4 years demonstrated no evidence of infection and full recovery of his lower-extremity neurologic injury. Two patients with severe closed head injuries underwent extended neurologic rehabilitation with recovery of function.

**COMMENT**

Traumatic aortic disruptions in children are exceedingly rare. A review of 551 accidental deaths in children during a 13-year period identified only 12 traumatic disruptions.\(^7\) These injuries accounted for only 2.1% of deaths from blunt trauma. This is much lower than the 12% to 30% incidence of traumatic aortic injuries in adults who die of trauma.\(^8\) The National Pediatric Trauma Registry, with more than 53,000 registrants 17 years of age and younger, includes only 29 patients with traumatic aortic disruptions. The mortality rate in this group was 51% (Carla DiScalla, PhD, oral communication, 1998). Of the 8000 people who sustain blunt injury to the thoracic aorta each year, only 15% arrive at hospitals alive.\(^9\) Prompt diagnosis and expeditious treatment are needed to maximize survival.

The forces that result in disruption of the thoracic aorta are the same for adults and children. These include horizontal and vertical deceleration and extreme compression of the thorax. Despite similar forces, the incidence is significantly less in children than in adults.\(^13\) There are thought to be 2 reasons for this. Most children are not driving and do not receive the direct, focused impact of the steering wheel to the chest. They are passengers or pedestrians, in whom the force of impact is distributed over the entire body, thereby protecting the aorta.\(^7\) In addition to the distribution of the forces of impact, the increased compliance and elasticity of the pediatric chest wall contributes to the relatively low incidence of this injury.\(^4\)

As in adults, 85% to 90% of the thoracic aortic injuries in children resulting from blunt trauma are located in the isthmus distal to the left subclavian artery. The remaining injuries are located in the ascending aorta, origin of the great vessels, and the distal descending thoracic aorta. Less than 5% of the patients have more than 1 site of injury.\(^9\)

Management of the injured thoracic aorta continues to challenge the surgeon. The key to the diagnosis is a high index of suspicion. The mechanism of injury is very important. Vehicular ejection is reportedly associated with an incidence of aortic injury approaching 30%.\(^14\) Two of our patients were ejected from vehicles.

Only half of the patients will exhibit signs or symptoms of chest injury.\(^5\) These may include rib, sternal, or clavicular fractures or thoracic spine injury. Six of our patients had associated thoracic injuries. Clinical examination may reveal upper-extremity hypertension, paraplegia, or lower-extremity pulse deficit.\(^13\)

The initial chest x-ray films suggest aortic injury in 93% of the cases.\(^16\) The most common radiographic clue is a widened mediastinum. All of our patients had widened mediastinums. Associated diagnostic signs include fractures of the first and second ribs, obliteration of the aortic knob, deviation of the trachea to the right, presence of a pleural cap, depression of the left main bronchus more than 140° from the tracheal midline, and pleural effusion.\(^17\) Five of our patients had obscure aortic knobs, and 1 had depression of the left main bronchus.

Once aortic disruption is suspected, it is important to confirm the diagnosis expeditiously and effectively.\(^18\) Arch aortography \((\text{Figure 2})\) remains the gold standard, with a sensitivity and specificity approaching 100%.\(^4\) However, arch aortography may not be available immediately. Dynamic CT is being used increasingly to evaluate the abnormal mediastinum. Its improved resolution with contrast enhancement, the rapidity with which the test can be performed, and the accessibility have made dynamic CT an effective tool in screening and diagnosing traumatic aortic disruption. Aortic injuries were detected in 2 of our patients with dynamic CT scans. In each patient, thin-sectioned (5 mm) dynamic scans were obtained, and the findings were unequivocal for aortic injuries.

The CT findings described in aortic rupture correspond to the following pathologic features: false aneurysms appear as localized increases in aortic diameters, and intimal flaps appear as linear lucencies within opacified aortic lumens.\(^20\) Figure 3 illustrates a localized periaortic hematoma and intimal disruption in 1 of our patients. Arch aortography was not obtained because of hemodynamic instability. These radiographic findings were confirmed at the time of thoracotomy and aortic repair. During the past 6 years, we have selectively used dynamic CT scanning to evaluate the abnormal mediastinum. It was used in patients with low suspicion of aortic injury or in those with hemodynamic instability with severe closed head injury who had an abnormal mediastinum on the plain chest x-ray film. Three
The management of the disrupted thoracic aorta in children continues to challenge the surgeon. Because of the infrequent occurrence of this injury and the scarcity of physical signs and symptoms of chest injuries, the surgeon must maintain a high index of suspicion when examining injured children. When the mechanism of injury and the radiographic clues (widened mediastinum) suggest major blunt force injury, further diagnostic investigation must be undertaken. In our series of children we used dynamic CT scanning to evaluate the abnormal mediastinum. When the CT findings are unequivocally diagnostic of isthmus injuries, surgical repair may be performed without further investigation. Once the diagnosis of aortic disruption is established, immediate operative intervention is recommended. However, if there is hemodynamic instability secondary to intra-abdominal hemorrhage, selective delay in aortic repair is advised.

Presented at the 106th Scientific Session of the Western Surgical Association, Indianapolis, Ind, November 18, 1998.

Reprints: David Hormuth, MD, 1801 N Senate Blvd, Suite 755, Indianapolis, IN 46202.

REFERENCES

DISCUSSION

Jorge I. Rodriguez, MD, Minneapolis, Minn: I think this work demonstrated the infrequency of the injury and the exemplary trauma care provided at the institution. I have several questions for the authors. I think the surgical technique and the outcomes are not for questioned, but in the manuscript, you suggest that 93% of your cases of aortic injury had a wide mediastinum and the other injuries that signified aortic injury were followed by either a first and second rib fracture or an obliterated aortic knob. How many patients with such findings did not have an aortic injury? In fact, if you look at the manuscript and the data, such data would be very helpful in assessing the mechanism of injury, the age distribution, and the outcomes. To assess the sensitivity and specificity of this clinical correlation, I think we need to understand the total database that was evaluated at Methodist Hospital.

What are your criteria for an equivocal CT scan that drives you to an aortic arch arteriogram? In fact, in following this vein of thought, how many CT scans of the chest were performed for wide mediastinums? How many equivocal findings forced the use of arteriography? It was not clear from the manuscript or from the presentation on how you managed your combined aortic and abdominal injuries or your combined aortic and closed head injuries. I think the membership would benefit from your experience in defining the algorithms that you used.

Last, this is a very interesting series with excellent outcomes, but I feel strongly that in view of the infrequency of this injury, the Association, the readership, and the trauma care systems that deal with this process would greatly benefit if you would correlate your experience within a larger database within your institution. That would help us clearly discriminate the variables that are in fact important in managing these patients. Even with these issues, I greatly enjoyed the presentation. I think this work will be evaluated very closely and trauma care systems will utilize its management schemes.

J. David Richardson, MD, Louisville, Ky: We have seen an 8-year-old and a 10-year-old, so I agree with you that this exists and it is something you have to be concerned about even in younger children than you had. Do you have enough follow-up to say whether or not there is a problem as kids grow with either distal ischemia or that sort of pseudocoarct problem that you can have with a small graft in a child that then grows? Could you comment on that at all?

Dr Hormuth: I will take the questions in reverse order. Dr Richardson, we do not have experience in long-term follow-up in our series with regard to children outgrowing their grafts. We recommend using the largest possible graft at the initial operation (14-16 mm). I feel that this may be the age group that may benefit from primary aortic repair, thus hopefully avoiding the possibility of aortic reoperation. To date we have had no experience in primary repairs in either our adult or pediatric age group. In following up these patients, careful evaluation for development of hypertension at a young age may indicate the need for further investigation. Ultrasound evaluation with estimation of pressure gradients across the graft or direct aortic catheterization may be useful if progressive upper-extremity hypertension is identified.

Dr Rodriguez, I do not know the exact number of children (<17 years of age) that have been evaluated with abnormal or widened mediastinums. Approximately 1500 trauma patients per year are admitted to the trauma service with multisystem trauma. Of these patients about 160 are children. Over the past 6 years we have used CT scanning to assess the abnormal mediastinum fairly liberally. It is available 24 hours a day and is merely 20 steps from our trauma receiving room. Prior to its use we were performing 60 to 65 arch aortograms per year, for abnormal mediastinum, with an 11% positive rate. We use CT scanning as the initial screening tool for the patient with an abnormal mediastinum when there is either low index of suspicion based on mechanism of injury or in the hemodynamically unstable patient prior to abdominal surgery in whom we are suspicious of an aortic injury. I recommend aortic repair without aortography only when the CT scan findings are unequivocal. If we have a high index of suspicion for aortic injury based on the mechanism of injury and abnormal admitting chest x-ray, we proceed directly to aortogram. In this series of children, only 3 of our patients had CT scans. The use of CT scans has decreased the use of arch angiography by about 50%.

We have used left heart bypass without heparin in patients who have had closed head injuries and in patients who are hemodynamically stable who have required celiotomy, without untoward sequelae.

The timing of multiple operations in the polytraumatized patient is critical. As in our adult experience, if there is hemodynamic instability, the organ system (mostly intra-abdominal hemorrhage) causing the instability should be addressed first, followed by repair of the aortic injury. If the patients were otherwise stable, then we would repair the aortic injury first.