Hypothesis: The use of mechanical circulatory support (MCS) during repair of traumatic aortic injuries is associated with a decreased incidence of postoperative paraplegia and mortality.

Design and Setting: Historical cohort study with contemporaneous but nonrandomized controls in a tertiary care hospital from July 1, 1988, through December 31, 1999.

Patients and Interventions: Consecutive cases undergoing operation for traumatic aortic injuries. Use of MCS (with or without systemic heparinization) determined by surgeon preference.

Main Outcome Measures: Incidence of postoperative paraplegia and mortality.

Results: Twenty-two patients underwent repair of traumatic aortic injuries using MCS, resulting in no paraplegia but 4 deaths, 3 of them from cerebral ischemia. Thirteen patients had their traumatic aortic injuries repaired using a “clamp-and-sew” or passive shunt technique with no deaths but paraplegia in 2. Compared with an earlier report from our group from January 1, 1975, through June 30, 1988, the annual incidence of traumatic aortic injuries has decreased, whereas the age of patients and proportion of operations using MCS have increased. A review of the recent literature on traumatic aortic injuries reveals an average postoperative paraplegia incidence of 1% with MCS and 16% without MCS. Overall mortality is similar, but others have also reported cases of cerebral ischemia after aortic repair.

Conclusions: The use of MCS during repair of traumatic aortic injuries is associated with a decreased incidence of postoperative paraplegia. The occasional occurrence of cerebral ischemia deserves further study.

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The optimal technique for repair of traumatic aortic injuries to minimize operative mortality and the incidence of spinal cord injury continues to be debated. Advances in mechanical circulatory support (MCS) now allow for distal aortic perfusion with minimal or no systemic heparinization. Multiple reports have demonstrated improvement in outcome with MCS, but these are limited by the size of the study populations.

In this article, we revisit our previously published series with the addition of another 11 1/2 years of experience and provide a compiled review of the recent literature to compare mortality and paraplegia using MCS vs simple “clamp and sew” or passive shunting.

From January 1, 1975, through December 31, 1999, 105 proven cases of blunt injury to the thoracic aorta were seen at MMC and are summarized in Table 1. With respect to operative technique and outcomes, our group previously reported the experience at MMC from January 1, 1975, through June 30, 1988. The main focus of this article will therefore be on the cases managed operatively since that time.

Fifty-one patients were admitted between July 1, 1988, and December 31, 1999. Of these, 16 patients, for a variety of reasons, did not undergo repair of their aortic injuries. One was admitted in cardiac arrest and had a futile thoracotomy in the emergency department. Three were transferred in extremis from other hospitals directly to our waiting operating room, but could not be resuscitated. Three became unstable due to hemorrhage while undergoing radiologic evaluation at MMC and could not be resuscitated despite immediate operation. Two elderly patients were not subjected to thoracotomy because of other lethal injuries identified on admission. One patient had an attempted thoracotomy performed that was techni-
METHODS

The Maine Medical Center (MMC), Portland, is the largest hospital in Maine and has been one of 3 state-designated trauma centers since 1997. Before 1990, MMC was the only institution in the state with a cardiothoracic surgical service. Blunt aortic injuries have been a subject of interest at MMC for a quarter century, during which time case records have been diligently collected and periodically reviewed. In particular, operative techniques and outcomes were evaluated for this study.

In addition, hospitalization data were requested from the Maine Health Data Organization for the years 1980 through 1999, under the rules and confidentiality restrictions permitted by Maine law for public health research. These data included inpatient discharge abstract information for all cases in which the principal International Classification of Diseases, Ninth Revision, Clinical Modification diagnosis code indicated an injury to the thoracic aorta (901.0).

To avoid duplication, cases in which the disposition was recorded as transfer to another acute care hospital were excluded.

Table 1. Characteristics of Maine Medical Center Patients With Blunt Injury to the Thoracic Aorta*  

<table>
<thead>
<tr>
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</thead>
<tbody>
<tr>
<td>Total No. of cases</td>
<td>54</td>
<td>51</td>
</tr>
<tr>
<td>Mean age (range), y</td>
<td>28 (15-70)</td>
<td>43 (14-88)</td>
</tr>
<tr>
<td>Males, No. (%)</td>
<td>37 (69)</td>
<td>39 (76)</td>
</tr>
<tr>
<td>Motor vehicle occupant</td>
<td>42</td>
<td>41</td>
</tr>
<tr>
<td>Motorcycle rider</td>
<td>9</td>
<td>4</td>
</tr>
<tr>
<td>Snowmobile rider</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Boat rider</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Struck by vehicle</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>Fall</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>Crush</td>
<td>0</td>
<td>3</td>
</tr>
</tbody>
</table>

*Data are given as number of patients unless otherwise indicated.

Of MCS as an adjunct to repair. Three of these had preoperatively recognized injuries to the ascending aorta or aortic arch, which were repaired using full cardiopulmonary bypass. One of the patients with an aortic arch injury died as a result of intraoperative cerebral ischemia, related to the unrecognized presence of an aberrant right subclavian artery. Three patients had injuries at the isthmus repaired using femoral-femoral bypass, and one of these patients, who had a moderate head injury but was awake and alert preoperatively, emerged from a technically uncomplicated aortic repair with evidence of a severe cerebral ischemic insult and was declared brain-dead 2 days later; autopsy in this fatal case did not show evidence of significant intracranial hemorrhage. For the remaining 16 patients with injuries near the isthmus, their injuries were repaired using left heart bypass with a centrifugal pump, one of these was urgently converted to full bypass with hypothermic arrest when the tear was found to extend into the arch, and this patient also experienced a fatal cerebral ischemic injury. Many other injuries and postoperative complications required management, and one 88-year-old man died of multiple organ failure. The only instance of paraplegia in this group was present when the patient arrived, as the result of a thoracic spinal injury.

The use of other adjuncts during aortic repair varied somewhat from surgeon to surgeon. Heparin sodium was used in all of the cases with full cardiopulmonary bypass and most of those with a centrifugal pump, although in the latter cases the dose did not exceed 5000 U. No attempt was made to cool patients before aortic cross-clamping or to warm them actively after MCS with heat exchange in the circuitry, except in the cases where full cardiopulmonary bypass was used. Spinal fluid drainage was not used.

Hospital discharge data from 1980 through 1989 reported 43 cases at MMC and 10 at other hospitals (Table 2). Of the 10 cases at other hospitals not transferred, there were only 2 survivors, neither of whom had undergone a thoracic surgical procedure. Since 1990, cardiac surgery has been available at a second hospital in Maine. For 1990 through 1999, hospital discharge data reported only 24 cases at MMC and 9 at other hospitals. Of the 9 cases not treated at MMC during this decade, there were 6 survivors, 4 of whom had undergone a thoracic surgical procedure. Mechanisms of injury and...
Comparison of our data from January 1, 1975, through June 30, 1988, with our data from July 1, 1988, through December 31, 1999, gives evidence of a significant increase in the age of patients with aortic injury and a somewhat increased variety of injury mechanisms. Because of the geographic and medical resource situation in Maine, these should be essentially all the cases surviving to hospitalization for this population of about 1.2 million people and are thus of epidemiologic interest. A study of aortic injuries in North Carolina found that administrative data had limited value in case ascertainment and quality assurance.2 Nevertheless, our review of discharge data from the past 2 decades at least confirms the impression that the incidence of hospitalization for aortic injury has decreased over this time and especially since 1993 (Table 2). We would speculate that this reduction is real and related to the increased use of safety belts and air bags in automobiles.

Two of our 3 patients who exsanguinated in the hospital while undergoing initial evaluation were seen during the second half of 1988 and were included in a previous study from our institution addressing this problem.3 We believe this sort of catastrophe has become less frequent because of increased recognition of the risks, avoidance of hypertension, and faster diagnostic techniques (spiral computed tomography and transthoracic echocardiography). For the Maine trauma system as a whole, the availability of another hospital with cardiac surgical services has been an additional resource to help reduce delays in the past decade.

The technical aspects of aortic repair in the setting of an acute tear obviously depend on the condition of the patient and the exact location of the tear. If the patient is not actively bleeding and the tear is distal to the left subclavian artery, the main concern has been to repair the injury without compromising blood flow to the spinal cord. In addition to mortality, the focus of this article is therefore on the avoidance of paraplegia, a term we use for simplicity, while recognizing that not all spinal cord ischemic injuries result in complete paraplegia.

A thorough review by von Oppell et al4 of articles published in the English language from 1972 through 1992 found that the reported probability of acquired paraplegia was 19.2% for the clamp-and-sew technique, 11.1% with the use of passive shunts, and 2.3% when active augmentation of distal perfusion was used. Mortality for patients who survived long enough to undergo repair was 16.0%, 12.3%, and 15.0% for the 3 methods, respectively. Since 1992, there have been numerous reports in addition to our own that collectively confirm these approximate proportions; some of the recent studies are summarized in Table 3.5-19 Whereas others lacked sufficient detail for these basic comparisons,20,21

A statistically valid meta-analysis cannot be based on uncontrolled studies. However, the repeated similar results in our own and others’ experiences strongly suggest that differences in the incidence of paraplegia related to technique are real. Despite numerous studies that support this conclusion, some authors continue to believe that there is no difference in outcome related to technique14,19; in one instance, this belief appears to be contradicted by the authors’ own data.22 In the successful Houston series using only the clamp-and-sew technique, it may be of importance that no patient was more than 56 years old and that 4 surgeons managed a total of 80 cases during 8 years.14 Although such an experience may be considered high volume, it still means that each surgeon operated on only 2 or 3 such patients per year. A different group of surgeons at the same institution routinely use MCS while repairing aneurysms of the descending thoracic aorta in stable patients.23

Most of the cases in our own series and collective review underwent operation using MCS (Table 3), whereas the review by von Oppell et al4 found approximately equal numbers treated with MCS, passive shunting, or clamp and sew. Our data continue to support the assertion we made 10 years ago, that MCS was associated with a decreased incidence of postoperative paraplegia. In addition, our population-based data suggest that the incidence of blunt aortic injury may be decreasing and the population affected by this injury may be older. Even dedicated surgeons in major trauma centers are thus likely to see this injury with decreasing frequency and in more patients with preexisting vascular disease. These may be further reasons to consider MCS.

Although attention has properly been directed at reducing the incidence of paraplegia that results from aortic repair, we are also troubled by the occasional cerebral death following surgery for traumatic aortic rupture. In our current series, there were 3 cases in which a preoperatively alert patient failed to awaken from surgery and ultimately proved to have evidence of global cerebral ischemia. In our earlier series from 1975 through 1988, there had been no such events.1

From 2 of the centers whose reports are listed in Table 3, there have been more recent reports of cerebral ischemic injury associated with MCS, including one where an aberrant right subclavian artery was present (as in one of our cases).24,25 Among the other centers, one reported

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**Table 2. Population-Based Incidence of Aortic Injury in Maine Based on Maine Medical Center Trauma Registry and Hospital Discharge Data, 1980-1999**

<table>
<thead>
<tr>
<th>Years</th>
<th>Hospitalized at MMC (Trauma Registry)</th>
<th>Hospitalized at MMC (Discharge Abstract)</th>
<th>Hospitalized Elsewhere (Discharge Abstract)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1980-1981</td>
<td>11</td>
<td>10</td>
<td>1</td>
</tr>
<tr>
<td>1982-1983</td>
<td>9</td>
<td>6</td>
<td>2</td>
</tr>
<tr>
<td>1984-1985</td>
<td>11</td>
<td>9</td>
<td>0</td>
</tr>
<tr>
<td>1986-1987</td>
<td>13</td>
<td>10</td>
<td>5</td>
</tr>
<tr>
<td>1988-1989</td>
<td>9</td>
<td>8</td>
<td>2</td>
</tr>
<tr>
<td>1990-1991</td>
<td>17</td>
<td>12</td>
<td>4</td>
</tr>
<tr>
<td>1992-1993</td>
<td>13</td>
<td>6</td>
<td>1</td>
</tr>
<tr>
<td>1994-1995</td>
<td>3</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>1996-1997</td>
<td>6</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>1998-1999</td>
<td>7</td>
<td>3</td>
<td>1</td>
</tr>
</tbody>
</table>

*Data are given as number of incidents unless otherwise indicated. MMC indicates Maine Medical Center.
that all their patients with ascending or arch aortic injury had died, another mentioned a death due to proximal clamp injury, another acknowledged 2 deaths from brain ischemia, another listed a fatal hypoxic brain injury, and another cited anoxic encephalopathy in 1 fatal and 2 nonfatal cases. It is not explicitly stated in all injury, and another cited anoxic encephalopathy in 1 fatal and 2 nonfatal cases. It is not explicitly stated in all these reports that the instances of cerebral ischemia were attributable to the aortic operation, but in our cases the temporal association was clear even where the mechanism was not.

Clamp injuries that partially occlude cerebral flow can certainly occur even with normal anatomy, especially if the traumatic tear is relatively proximal. It is possible that cerebral ischemia might result from low flow during partial left heart bypass, especially if the proximal pressure and/or flow is not adequately monitored, but this seems a less likely explanation for ischemia after femoral-femoral bypass. Unsuspected clot or air embolism with any form of bypass is possible, but also seems unlikely. Whatever the explanation, these occasional events are certainly as tragic as the occasional occurrence of paraplegia due to inadequate perfusion of the spinal cord and deserve further consideration in discussion of techniques for repair of traumatic aortic injuries.

Traumatic rupture of the thoracic aorta continues to be a problem that challenges even the best trauma systems, centers, and surgeons. Continued reporting of results, technical innovations, and debate about methods have led to improved understanding of the optimal treatment, although uncertainty persists. Measures to prevent serious blunt thoracic injury, especially from motor vehicle crashes, may be reducing the incidence of this frequently fatal lesion and will ultimately be the most effective approach to this problem.

This paper was presented at the 82nd Annual Meeting of the New England Surgical Society, Providence, RI, September 21, 2001.

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REFERENCES

12. Nicolosi AC, Almassi GH, Bousamra M, Haasler GB, Olinger GN. Mortality and Table 3. Results From Repair of Blunt Injuries to the Thoracic Aorta Reported Since 1992*
Richard P. Cambria, MD, Boston, Mass: The authors have presented a large series of traumatic aortic tears accumulated over a long period of time at the Maine Medical Center. They also provide a literature review and claim that the findings in the literature review are consistent with their overall experience over the past 25 years with respect to risk of paraplegia and operative technique for repair of traumatic aortic tear. The manuscript that I read 10 minutes ago does provide some very interesting data on the epidemiology of traumatic aortic tear in the state of Maine. The authors’ findings and conclusions about the use of seat belts and air bags and an apparent decrease in the incidence of this lethal injury are very interesting data.

It is apparent from the presentation that the majority of the figures to which the authors ascribe statistical significance are culled from the literature and from the relatively high incidence of spinal cord ischemic injury accumulated in their earlier study. Dissecting out the data in the current 35 patients is somewhat difficult, and as I calculate the difference in paraplegia, it was 2 of 11 with a clamp-and-sew technique vs 0 of 22 with a left heart bypass technique. Alternatively, the mortality in the current group of 35 patients was 4 of 22 in the bypass group and 0 of 11 in the clamp-and-sew group.

I am familiar with the literature that they have cited about the apparent superiority of circulatory support in the circumstance of repair of traumatic aortic tear. This makes intuitive sense. There is perhaps no other lesion in the thoracic aorta where (a) 2 clamps are placed close together and (b) since most of these patients are young patients, the status of the intercostal arteries is presumed to be that of the normal circulation. This is, of course, quite a bit different from the circumstance of an extensive degenerative aneurysm, where resection of long segments of the thoracic or thoracoabdominal aorta may be necessary and many of the intercostal vessels may have been occluded by antecedent thrombus in the aortic wall.

The majority opinion that the use of left heart bypass is the way to go for traumatic aortic tear is in fact the right one, but I do not believe that the data in the last 35 patients that the authors have presented afford statistical proof of that conclusion. I have a few questions for the authors. First, they mention in the manuscript the issue of changing diagnostic imaging modalities to evaluate this injury and they also mention that several of their patients became unstable in x-ray and subsequently died. This is, of course, a constant threat in a patient who arrives at a referral center with a tentative diagnosis of aortic tear. The first question is, Dr Hochheiser, what is your current imaging diagnostic algorithm in the evaluation of these patients?

My second question is, you indicated that in the clamp-and-sew group of patients, in one of these patients an attempt was made to institute circulatory assist and this failed. What was the outcome in this patient, because rightly he should have been considered in the bypass group on an intention-to-treat analysis?

It is my own opinion that a flexible approach is the best in these patients. Clearly, the extent of the tear, the location of the tear, the presence of associated injuries, in particular central nervous system or intracranial injuries, will all influence the decision to use heparin and circulatory assist.

Erwin Hirsch, MD, Boston: My first question was just asked by the previous discussant. My next 2 questions relate to whether you can give us some idea as to the timing of these procedures from the time that the patients were first seen at your medical center and when they were taken to the operating room for this repair. Also, what are your thoughts or what is the experience of the Maine Medical Center as to the management of patients who come with thoracic injury in association with intra-abdominal injuries?

Philip Allmendinger, MD, Hartford, Conn: The circulation, as Dr Cambria has indicated, for the spinal cord is very complex. We do not completely understand the collateralization. Cooley and others have reported that probably one of the best protections for the spinal cord is a very quick clamp time so that the anastomosis is completed in under a half hour. I wonder if you compared the clamp times from the clamp and sew as opposed to when you had an opportunity to dissect out the aorta under the help of assisted circulation and if there is a difference there.

One other comment is that Dr Cambria just presented a very nice paper on probably the next step in this treatment, which is endovascular thoracic stent grafts. This is on its way as we speak.

Dr Hochheiser: To address your questions first, as far as our current algorithm for diagnostics of thoracic aortic injuries, computed tomographic scan is our first step, and that is done as a complete trauma, including the head, neck, chest, abdomen, and pelvis, as directed by our findings in the trauma room. Our next step has in the past been aortic angiography, but as our availability of transesophageal echocardiography improves and response time improves, we have been moving toward that. The second question you asked was regarding the single patient; that patient did survive without paraplegia, and you are correct that as an intention to treat, it would be in the other group.

To address Dr Hirsch’s questions, as far as the timing, we did not actually look at the timing from arrival to repair, but that was previously looked at in another study by Dr Martha Zeiger, and those results are in the literature, although the time from diagnosis to procedure in that study improved over the length of the study. As far as treating intra-abdominal vs thoracic aortic injuries, priority at this point goes to the intra-abdominal injuries, especially in the unstable patient.

Dr Allmendinger, we did not directly compare the cross-clamp times between our patients with mechanical circulatory support and clamp and sew, so I cannot comment on that. Thank you.