

# SYMPOSIUM: Hypothermic Cardiopulmonary Bypass and Circulatory Arrest in the Management of Thoracoabdominal Aortic Disease

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- Moderator** ■ James A. DeWeese, MD
- Panelists** ■ Mortimer J. Buckley, MD
- Denton A. Cooley, MD
- Ronald C. Elkins, MD
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**This symposium is adapted from a session at the 7th Annual Meeting of the Senior Cardiovascular Surgical Society, Tarpon Springs, Fla., March 1998.**

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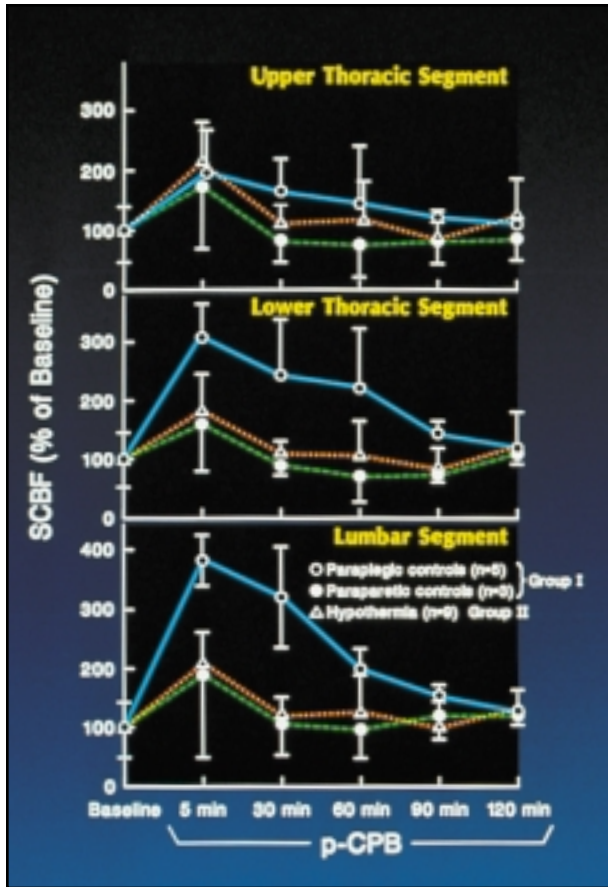
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**KOUCHOUKOS:** Clear evidence dating back a number of years supports the use of hypothermia as an adjunct for spinal cord protection during operations on the descending thoracic and thoracoabdominal aorta.<sup>1-4</sup> These investigators found that with the use of hypothermia, the duration of aortic clamping could be extended without increasing the frequency of ischemic injury to the spinal cord.

In clinical studies carried out in the mid-1950s by Julian et al,<sup>5</sup> DeBakey, Cooley et al,<sup>6</sup> and Adams et al,<sup>7</sup> in which surface cooling primarily was used, the body temperature was reduced to about 28°C. Although no spinal cord injuries were noted in any of the patients in these series, other problems associated with the use of hypothermia were observed. Consequently, the use of hypothermia for spinal cord protection remained dormant for a significant period of time.

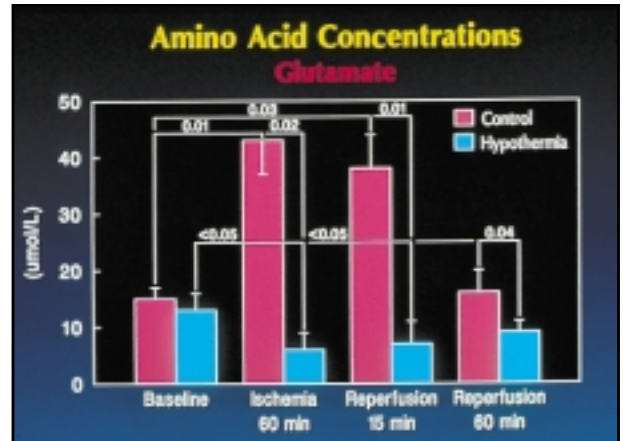
In addition to surface cooling, other methods can be used to induce hypothermia for spinal cord protection. With intra-aortic perfusion, a clamp is applied to the segment of the aorta that is to be excluded, cold saline is injected to perfuse the intercostal arteries,



**Figure 1. Spinal cord blood flows (SCBF) expressed as percentage of baseline (mean ± standard deviation). (Rokkas CK, Sundaresan S, Shuman TA, Palazzo RS, Nitta T, Despotis GJ, et al. Profound systemic hypothermia protects the spinal cord in a primate model of spinal cord ischemia. *J Thorac Cardiovasc Surg.* 1993;106:1024-1035. Reprinted by permission.)**

and the operation is performed. Continuous irrigation of the epidural or subarachnoid space is another method of inducing hypothermia. However, the technique that we favor for the induction of hypothermia and circulatory arrest is cardiopulmonary bypass.

The use of hypothermic circulatory arrest to treat an aortic arch to innominate artery fistula through a posterolateral exposure was first reported by Borst in 1964.<sup>8</sup> Mahfood reported a small series in 1985 in which 3 of 5 patients with arch and descending aneurysms survived without spinal cord ischemic injury.<sup>9</sup> In 1986, Massimo described the use of this technique in patients with arch and thoracoabdominal dissections.<sup>10</sup> In a 1987 report of the largest series until that time, Crawford indicated that 21 of 25 patients survived.<sup>11</sup> Hypothermic circulatory arrest in this se-



**Figure 2. Glutamate levels and control and hypothermia groups at baseline during ischemia and after reperfusion.**

ries was used primarily to control bleeding and to obviate the need for aortic isolation and aortic clamping, not for protection of the spinal cord. Although the experience was positive, there was a high incidence of pulmonary complications. Consequently, Crawford reserved the technique for specific indications, and he was not enthusiastic about recommending its use on a wider basis.

In 1989, Caramutti reported his experience with the use of hypothermic circulatory arrest in a series of 10 patients with acute aortic dissection.<sup>12</sup> There were 8 survivors in this group, and none of the patients developed paraplegia.

We studied hypothermic cardiopulmonary bypass in a primate model in the late 1980s, simulating the conditions that would be encountered with extensive resection of a descending thoracic or thoracoabdominal aneurysm. The aorta was clamped distal to the subclavian artery and above the renal arteries. The animal was then placed on cardiopulmonary bypass, either at normothermia or with hypothermia. Spinal cord blood flow was measured, looking for evidence of ischemia and reactive hyperemia. The segment of the excluded aorta was vented to simulate opening this area during the procedure, but keeping the intercostals intact, which simulated reimplantation of the intercostals.

In this group of 9 primates, the aorta was clamped at 60 minutes with the animals on bypass at 37°C. Animals in the hypothermia group were cooled to a rectal temperature of 15°C prior to application of the clamps. They were maintained at that temperature until the aorta was unclamped, then they were slowly rewarmed.

Among the 8 surviving baboons in the control group, 3 were paraparetic and 5 were paraplegic. In the hypothermia group, no animals developed either paraplegia or paraparesis, a significant difference.

The hyperemic response to severe ischemia was most pronounced in the lumbar segment, less pronounced in the lower thoracic, and minimal in the upper thoracic segments (*Figure 1*). The animals in which paraplegia developed had the most significant reactive hyperemia. The control animals with paraparesis were more similar to the animals that were cooled. Spinal cord blood flow was the only parameter measured in these animals.

### ■ SPINAL CORD FUNCTION

Some interesting information in terms of understanding spinal cord ischemic injury has emerged from our colleagues in the neurosciences. It has been known for a number of years that an ischemic insult to the brain results in the release of glutamate, an excitatory amino acid transmitter (*Figure 2*). Other amino acids are also released, but glutamate appears to be the most toxic. When the glutamate exits the cells and enters the extracellular fluid, it becomes a potent neurotoxin that kills nerve cells. Several hypotheses have been proposed to explain why this happens, but it probably is related to the influx and efflux of calcium through these injured cells.

In an effort to determine if this was part of the ischemic injury pattern that is produced in the spinal cord, we used the experimental model mentioned previously in pigs. Cervical laminectomies were performed, and the extracellular concentration of glutamate and other amino acids was measured. There were no long-term survivors because the laminectomies were extensive. Therefore, central nervous system function was assessed differently. After a 6-minute ischemic interval, there was a substantial release of glutamate into the extracellular space in the lower spinal cord that persisted into the reperfusion period. In the animals that were cooled, the concentration of glutamate in the extracellular space was lower than the baseline level, suggesting that either synthesis or release of glutamate was reduced by hypothermia.

Spinal cord function was measured using somatosensory and motor-evoked potentials. To measure sensory potentials, the sciatic nerve is stimulated

and the response in the brain is recorded. Motor function is assessed by applying a stimulus proximally and measuring the evoked potentials distally. With progressive ischemia, there is a prolongation of these potentials, which eventually flatten and disappear, in both the motor and sensory modes. Among the hypothermic animals, there was a slight delay in the impulses, but they persisted throughout the period of clamping and reperfusion, both in the sensory and motor modes. This suggests that spinal cord function was maintained, and it correlates with the absence of the release of glutamate, whereas evidence of significant ischemia did develop in the animals in whom there was release of glutamate.

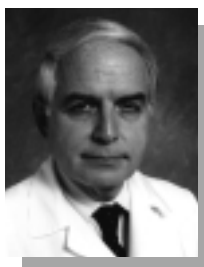
Other toxins may be released with ischemia, but the release of glutamate in the brain has been identified as an important factor in stroke. Even a slight degree of hypothermia in stroke preparations will prevent brain cell death, and that appears to apply in the spinal cord.

In 1986, we began a clinical study to evaluate the role of hypothermia induced with cardiopulmonary bypass and a period of circulatory arrest in two situations.<sup>13</sup> In one group of patients, the severity of aortic disease precluded placement of clamps on the aortic arch or the proximal descending thoracic aorta. In the other group, the risk of spinal cord ischemic injury was judged to be increased because extensive resections of the descending thoracic and thoracoabdominal aorta were necessary.

Crawford's experience with simple aortic clamping clearly demonstrated that Type I or II aneurysms, the most extensive of the descending thoracic and abdominal aorta, were associated with the highest risk of spinal cord ischemic injury.<sup>14</sup> Type III probably is associated with a significant risk, but Type IV is not. We did not include any patients with Type IV aneurysms, which are primarily intraabdominal. Since most Types I, II, and III aneurysms were associated with a 10% or higher risk of paraplegia, we elected to use hypothermia with all of these patients.

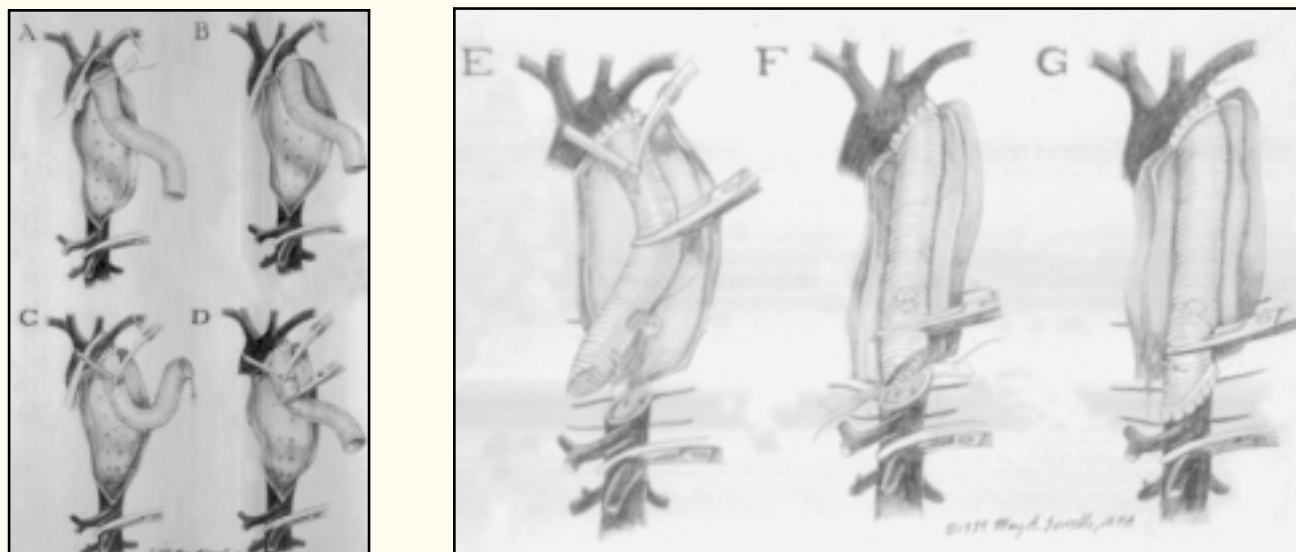
### ■ OPERATIVE TECHNIQUE

With regard to the operative technique, we used standard anesthetic induction with fentanyl and isoflurane. A double-lumen tube is essential. The procedure usually is performed through a single incision



The technique that we favor for the induction of hypothermia and circulatory arrest is cardiopulmonary bypass.

—Dr. Kouchoukos



**Figure 3.** (A, B) After occlusion of the aorta between the left subclavian and left carotid arteries and occlusion of the left subclavian artery and the abdominal aorta below the celiac artery, the graft is anastomosed to the proximal aorta during circulatory arrest. Clamping of the proximal aorta and left subclavian artery is not mandatory. (C) Second arterial perfusion cannula is inserted into the graft and blood is infused to remove air. (D) Graft is occluded below the cannula and flow is reestablished through both arterial lines. (E) Button of aorta containing pairs of intercostal arteries is sutured to the graft. (F) Aortic clamp is repositioned to permit perfusion of intercostal arteries. Graft is beveled to preserve lower intercostal and upper lumbar arteries. (G) Distal aortic clamp is removed, and air is released from the graft. (From Kouchoukos NT, Wareing TH, Izumoto H, Klausung W, Abboud N. Elective hypothermic cardiopulmonary bypass and circulatory arrest for spinal cord protection during operations on the thoracoabdominal aorta. *J Thorac Cardiovasc Surg* 1990;99:659-664. Reprinted by permission.)

in the fifth or sixth left intercostal space. The incision is extended across the abdomen obliquely to just above or below the umbilicus to provide exposure of the entire thoracoabdominal aorta.

We use methylprednisolone as an adjunct for central nervous system protection, and also thiopental is administered during cooling, just before the period of circulatory arrest. A cannula is inserted into the left common femoral artery. Initially, a cannula was inserted into the left femoral vein and a second cannula was inserted in the pulmonary artery after the chest was opened for venous return to the pump oxygenator. With the improved cannulas that are now available, it is possible to get adequate flow through a single venous cannula inserted through the left common femoral vein that is positioned in the right atrium with the use of transesophageal echocardiography (TEE). The left side of the heart is vented through the apex of the ventricle or through the left inferior pulmonary vein. Decompression of the heart is important.

Cardiopulmonary bypass is established, and cooling is begun immediately. While this is being done, the abdominal aorta is exposed by dividing the di-

aphragm to prepare for the induction of circulatory arrest. When the EEG is isoelectric and the nasopharyngeal temperature is 12°- 15°C, circulatory arrest is established. We do not place a clamp on the aorta. We perform an open anastomosis to the proximal aorta, which takes 10-15 minutes. It can be done very precisely because it is an open procedure and there is no blood in the field.

The intercostal arteries are assessed to determine need for implantation. In patients with dissections, the intercostal arteries usually are patent, and they generally are preserved by implanting those below the level of T5-T6. In dissections, it usually is possible to make one long cuff, incorporating all of the patent intercostal arteries as well as the upper lumbar arteries if they are involved. Sometimes it is possible to avoid implanting the arteries separately by beveling the distal anastomosis obliquely to incorporate them with the remaining portion of the aorta.

Once the extent of the resection has been determined, a second arterial cannula is placed into the graft to evacuate air. This can be done easily using retrograde venous perfusion to assist in the evacuation of air from the upper part of the circulation.

A clamp is applied to the graft distal to the site of cannulation, and cardiopulmonary bypass is reestablished. It is important to keep the lower clamp in place to allow distal perfusion as well, because there are important collaterals to the spinal cord from the iliac and hypogastric system as well as from above. The nasopharyngeal temperature is increased to 20°C, and it is maintained at or just below that level until the anastomosis of the graft to the intercostal arteries is completed. If other vessels need to be implanted, the clamp is moved down the graft as these anastomoses are completed. Once they have been completed, re-warming to 37°C is begun and the procedure is completed.

#### ■ EXPERIENCE

We have successfully attached intercostal arteries in patients with Type I aneurysms as well as in patients with extensive Type II and Type III aneurysms involving all of the descending thoracic aorta (*Figure 3*). In approximately 85% of patients, the intercostals are either preserved or reimplanted. Although it is considered to be unnecessary by some surgeons, we believe that reimplantation of the intercostals is an important part of the procedure and that it should be done whenever possible.

Our experience from January 1986 through May 1997 included 96 patients, predominantly males (63%), ages 22-79 years (mean, 60 years). Among these patients, 61% were symptomatic, 14% had Marfan's syndrome, and 13% of the procedures were done either urgently or emergently for rupture or acute dissection. The etiology of the disease was degenerative in 51 patients, and 38 patients had dissections (6 acute, 32 chronic).

In 5 patients who had complications related to previous coarctation repair, the procedure was done with a single period of circulatory arrest, which avoids concerns about proximal control of the aorta. There was 1 false aneurysm in a patient who had a ringed intraluminal prosthesis inserted for an acute Type B dissection that became obstructed. This procedure had been done at another hospital, and we replaced the prosthesis and the obstructed segment. Many of these patients had undergone previous operations, including either thoracic or thoracoabdominal aortic resections (44%), valve replacement (30%), and bypass grafting (13%).

Clearly, the acuity of the presentation is an important determinant of risk. The overall hospital mortality rate for these 96 patients was 7%. Among the 84 patients in whom the procedure was done electively, the mortality rate was 3.6%; in patients with rupture or dissection, 33%.

Initially, we used aprotinin in an attempt to reduce bleeding. At that time, the protocol specified keeping the activated clotting time (ACT) level at 700 seconds, but it was not clearly recognized that aprotinin can prolong the ACT. Although it is conceivable that the heparin levels were not adequate, there are concerns about using aprotinin with circulatory arrest because of the stasis that is produced and because of potential problems with renal failure. After our initial experience, which was not a positive one, we no longer use aprotinin when hypothermic circulatory arrest is induced. The mortality rate among patients in whom aprotinin was not used was 4.5%, compared with 37.5% for the patients in whom it was used, a difference that was statistically significant.



The vast majority of surgeons who are doing these procedures are using different techniques.

—Dr. DeWeese

#### ■ COMPLICATIONS

**Paraplegia and paraparesis.** Among the 96 patients in whom this procedure was done, the overall incidence of paraplegia was 2% and the overall incidence of paraparesis was 1%. In the 19 patients who had arch and proximal dissections, the operation was used primarily for technical reasons. This group is not at high risk for the development of paraplegia and, not surprisingly, there was no incidence of spinal cord ischemic injury.

Paraparesis developed in one patient who had an atherosclerotic aneurysm and no patent intercostal arteries below T5 and T6. Although it was not possible to reimplant any intercostal vessels and virtually all of the descending thoracic aorta and distal arch was resected, she had complete recovery after about 1.5 years. There was no paraparesis among the patients with Type I, II, or III thoracoabdominal aneurysms. One patient with a Type I aneurysm and one with a Type III aneurysm developed paraplegia. Both of these patients had atherosclerotic aneurysms, and again it was not possible to reimplant any lower intercostal or lumbar vessels because all were occluded.

Paraplegia did not occur in any of the 28 patients with dissections. This experience is substantially different from that reported by Crawford and others

**Table: Blood-component transfusion requirements**

Blood component	Patients	Mean	Minimum	No. of Units			Max
				Percentile			
				25%	50%	75%	
<b>Intraoperative</b>							
Red blood cells	51	7.0	0	3	6	9	26
Fresh frozen plasma	51	4.2	0	2	4	6	15
Platelets	51	9.8	0	4	8	16	40
<b>Postoperative</b>							
Red blood cells	46	2.5	0	0	1	4	13
Fresh frozen plasma	46	1.6	0	0	0	2	10
Platelets	46	3.3	0	0	0	6	60

From Kouchoukos NT, Daily BB, Rokkas CK, et al. Hypothermic bypass and circulatory arrest for operation on the descending thoracic and thoracoabdominal aorta. *Ann Thorac Surg.* 1995;60:67-77.

not receive aprotinin, none have developed renal failure requiring dialysis.

Those surgeons who use simple aortic clamping or normothermic distal perfusion have found that multiple organ system failure is a significant cause of morbidity and mortality postoperatively. This may be related to ischemia of the liver and the other abdominal viscera, which can produce its own set of problems.

**Ischemia.** A study reported by Dr. DeWeese and his colleagues in 1997 demonstrated that the release of fibrinolytic

using simple aortic clamping, in which the incidence of paraplegia was 2-3 times higher in the dissection group than in the group with degenerative aneurysms.<sup>14</sup> In his experience with distal perfusion, Coselli also found that dissection is not an independent risk factor for the development of paraplegia.<sup>15</sup>

Through February 1998, 102 patients have undergone this procedure. Among the 25 patients with disease in the distal two-thirds or all of the descending thoracic aorta, 1 patient developed paraparesis (4%), and no patients had paraplegia. Only 2 of the 58 patients (3.4%) with thoracoabdominal aneurysms (one Type I and one Type III) developed paraplegia. Thus, the overall incidence of paraplegia in the higher risk group is 2.4%, and the incidence of paraparesis 1.2%. These complications occurred earlier in our experience, and none of the last 78 consecutive patients have developed paraplegia or paraparesis. Obviously, there is a learning curve, and we are more careful now about maintaining distal perfusion whenever possible and using other measures to increase the safety of this procedure.

**Organ system failure.** Protection of other organ systems is an important consideration when hypothermia is used. Assessment of renal function revealed that hypothermia provides substantial protection to the kidneys. Among the group of 96 patients, renal failure occurred in 1 of the 8 patients who received aprotinin. Among the 88 patients who did

agents is activated during superceliac aortic clamping, producing a coagulopathy.<sup>16</sup> In a study reported in 1996, Cambria and associates demonstrated that coagulation changes occur during simple clamping, resulting in increased fibrinolysis and the development of ischemia in the liver and intestines.<sup>17</sup> Another study reported in 1996 also demonstrated significant mortality and morbidity after simple aortic clamping.<sup>18</sup>

Surgeons who are proponents of distal perfusion and normothermia are now placing separate cannulas for perfusion into the celiac and superior mesenteric arteries and they also perfuse the kidneys with cold solution. The temperature of the perfusate is normothermic or slightly hypothermic. Cambria et al recently described a technique in which a limb from the proximal portion of the graft is used to perfuse the celiac and superior mesenteric vessels.<sup>19</sup> We have found that total cardiopulmonary bypass and hypothermia is a much simpler way to provide that protection, but that issue remains debatable.

In our initial analysis of 51 patients, the mean number of units of red cells transfused intraoperatively was 7, the mean number of units of fresh frozen plasma was 4, and the mean number of units of platelets was 9.8 (*see Table*). In 75% of the patients, fewer than 9 units of packed cells, 6 units of plasma, and 6 units of platelets were used. These figures do not differ substantially from those for other techniques.

In the entire series of 102 patients, 4% (6 patients)

required reoperation for bleeding. Early in our experience, 3 patients sustained a stroke. Initially, a clamp was placed proximally, usually between the subclavian and carotid arteries. Subsequently, TEE and epiaortic scanning revealed that these patients often have severe atheromatous disease in this area. We now uniformly avoid placing clamps proximally because there is a significant potential for dislodgment of atheromatous material into the brain from an atherosclerotic aorta.

In addition to the previously mentioned problems with spinal cord ischemia (4%) and renal failure requiring dialysis (1%), 22 patients (21%) required prolonged mechanical ventilation, 8 patients (7.6%) required a tracheostomy, and eight had low cardiac output, requiring inotropic support. Intraaortic balloons were not used in any of these patients.

We have been surprised by the adequacy of hypothermia for myocardial protection in these patients. We do not cross-clamp the proximal aorta, and we do not use cardioplegic solutions. The heart is simply allowed to fibrillate and to become quiescent, as it does at cold temperatures. Defibrillation usually occurs spontaneously with rewarming. In the absence of significant coronary disease, impaired cardiac function postoperatively is very unusual.

Using data accumulated from a number of studies, Svensson devised a nomogram demonstrating that the risk of spinal cord ischemic injury with simple aortic clamping begins to increase above 10% at 30 minutes (*Figure 4*).<sup>20</sup> After 60 minutes, this risk is substantial, and it is virtually certain at 80-90 minutes of ischemia. In contrast, no increase in the incidence of spinal cord ischemic injury was demonstrated in our patients with time even for periods extending as long as 105 minutes. Clearly, hypothermia is very protective (*Figure 5*).

Currently, we use hypothermia when there is an increased risk of paraplegia or paraparesis, which includes all patients who have Type I, II, and III thoracoabdominal aneurysms. We use it when the arch is resected through the lateral approach, when there is severe atherosclerosis of the aortic arch and the proximal descending aorta, and when proximal clamp placement is associated with increased risk. Hypothermia also can be used emergently for aortic rupture. The patient can be placed on bypass, cooled, and exsanguinated, allowing completion of the critical parts of the operation prior to resuscitation, which might not be possible with other techniques.

## ■ CONTRAINDICATIONS, MORBIDITY, MORTALITY

The contraindications to the use of our technique includes the presence of moderate or severe aortic regurgitation. When the heart fibrillates, it becomes distended, which can impair myocardial perfusion. In that situation, we have electively replaced the aortic valve through the anterior approach prior to operating on the descending or thoracoabdominal aorta.

Myocardial infarction remains the major cause of early death in this group of patients, and severe coronary disease should be corrected before the aortic surgical procedure, whenever possible. Dr. Crawford expressed concern about using hypothermia in patients with significant pulmonary dysfunction. However, we have operated on several patients who had severe emphysema with severely impaired pulmonary function studies, and they have tolerated this procedure remarkably well without significant problems.

Our technique minimizes the extent of aortic dissection. It completely eliminates the need for proximal aortic clamping. It allows access to the distal aortic arch and even to the ascending aorta, if necessary. Because it provides a bloodless field, much of the operation can be accomplished during the period of circulatory arrest in terms of the proximal anastomosis and assessing the need for implantation of the intercostals. As indicated previously, it clearly increases the tolerable duration of spinal cord ischemia. For patients with extensive Type I and II aneurysms who are at greatest risk, the data clearly suggest that the incidence of spinal cord ischemic injury is lower than with simple aortic clamping.

Some groups are using distal perfusion at normothermia and others are using topical hypothermia, e.g., irrigation of the spinal canal with cold solution. The results with these techniques are encouraging.

The incidence of renal failure in our experience is substantially lower than the incidence with simple clamping and even with some normothermic perfusion techniques. This difference, in our view, is attributable to the depth of hypothermia. Although it is very difficult to glean the information needed to make comparisons because not everyone reports their data in the same way, the incidence of other complications does not appear to be higher, and our technique does not appear to be associated with any greater risk or increased morbidity compared to other techniques.

Cambria et al have taken a different approach. They place a catheter in the epidural space to irrigate

the spinal cord continuously with cold saline while the operation is performed with simple clamping.<sup>19</sup> In their series of 70 patients in which this technique was used between 1993 and 1995, the 49% incidence of Type I and II aneurysms was slightly lower than in our series. The Type III aneurysms, while more prevalent in Cambria's series than in ours, are perhaps at decreased risk for spinal cord ischemic injury. Their series included a 19% incidence of dissections and an 11% incidence of ruptures. The spinal fluid temperature averaged 25°C during the period of clamping. The intercostals were implanted or preserved in approximately 50% of their patients. Although they did not have a concurrent control group for comparison, comparison with a group of historical controls treated during 1990-1993 demonstrated a substantial reduction in the frequency of spinal cord ischemic injury. In one patient, the irrigation technique induced a central nervous system injury with hemorrhage into the upper portion of the cervical cord. Although there may be some technical problems related to this technique, this experience adds support to the concept of using hypothermia. It is just a different way of achieving it.

The mortality rate in Cambria's series was 10%. It is of interest that multiple organ system failure and mesenteric ischemia were important causes of death. This probably is related to insufficient cooling or protection of the liver and intestines. As indicated previously, they are now using a graft from the proximal part of the aortic graft to perfuse the celiac and superior mesenteric vessels during the period of ischemia. Cold solution is also perfused into the kidneys. One could argue that this approaches total bypass. Their overall complication rate was similar to ours, with the possible exception of a slightly higher incidence of renal failure.

Without question, the experience from the large centers where these operations are being done using various techniques to protect the spinal cord indicates that the incidence of spinal cord ischemic injury is on the decline. In some centers, topical cold solution is used, while other centers use distal perfusion and serial clamping, with or without perfusion of the kidneys and the viscera. The most promising adjuncts appear to be either systemic or regional hypothermia and distal perfusion.



When the patient is in cardiac arrest after a revascularization procedure, is it possible to get access to the heart without disturbing the grafts?

—Dr. Mackenzie

Although implantation of the lower intercostal and lumbar arteries is still the subject of debate, evidence continues to accumulate suggesting that these arteries should be implanted whenever possible. Because it is not possible to implant the arteries in every case, the incidence of paraplegia will never be zero, but in our view, implanting the arteries provides the opportunity to reduce the frequency of this complication.

We have learned a great deal from our neuroscience colleagues about what causes ischemic injury, and we are looking at other causes as well as some of the consequences of ischemic injury. Apoptosis or delayed cell death, which differs from necrosis, has been seen in the brain following ischemia. Working in conjunction with our neuroscience colleagues at Washington University, we demonstrated in the rat model that both necrosis and apoptosis, which is signaled by large clumps of chromatin in the nuclei, are seen after a period of spinal cord ischemic injury. Serial sections taken from animals sacrificed at different intervals following the ischemic injury demonstrated that this is a delayed phenomenon. It does not occur within the first 12-18 hours after an ischemic insult. It occurs 2-4 days later. This may be an explanation for the delayed paraplegia that has occurred postoperatively.

It is of interest that we have not seen delayed paraplegia in our experience with profound hypothermia. A spinal cord that is marginally perfused and continues to be ischemic may be subject to this type of cell death, which may explain the delayed

paraplegia.

It may be possible to use certain pharmacologic agents as adjuncts to reduce the frequency or severity of spinal cord ischemic injury. MK-801 and dextrorphan have been shown to inhibit the release of glutamate and cytotoxins in a baboon model. Unfortunately, these agents cannot be used clinically because they are very toxic. Cycloheximide prevents or retards the development of apoptosis, and it may be possible to use it or its analogs in conjunction with other agents to further reduce the frequency of spinal cord injury in the future.

**DEWESE:** In the Crawford classification, Type I thoracoabdominal aneurysms are located from just below the subclavian artery down to above the celiac

arteries. They are mainly within the chest itself. Type II are located just distal to the subclavian artery, extending down to and including all of the visceral arteries. Type III start in the midthorax, extending down as far as the iliac arteries. Type IV are within the abdomen below the diaphragm.

Cardiac surgeons have quickly accepted the fact that total cardiopulmonary bypass with hypothermia down to 10°-20°C degrees described by Dr. Kouchoukos is the preferred technique for arch aneurysms and aneurysms involving the descending aorta. However, the vast majority of surgeons who are doing these procedures, including the group in Houston, are using different techniques because they are easier to do, particularly if they are not thoracic surgeons. Vascular surgeons do not hesitate to work in the midchest, but they prefer not to get up around the subclavian artery.

**MACKENZIE:** Dr. Kouchoukos has made a good case for hypothermia and circulatory arrest.

However, I noticed the absence of drainage of cerebrospinal fluid, which seems to be an integral part of most regimens. What is the basis for this difference?

**KOUCHOUKOS:** In our baboon preparation, when bypass and hypothermia were used, the cerebrospinal fluid pressure actually increased during the period of low-flow hypothermia. None of the animals developed paralysis. Therefore, cerebrospinal fluid drainage in our view is not necessary either intraoperatively or postoperatively with this technique, and we have not used it in any of our patients.

Currently, there is interest in the role of cerebrospinal fluid drainage postoperatively. Some investigators have reported that drainage is associated with dramatic relief of spinal cord ischemia when the patient becomes unstable hemodynamically and there is an increase in the cerebrospinal fluid pressure. However, we have not seen delayed paraplegia. I believe postoperative ischemia probably is induced during the period of intraoperative ischemia. If an injury is not induced intraoperatively, ischemia is not a problem postoperatively.

**MACKENZIE:** As I recall, Dr. Griep minimizes

the importance of implantation of the intercostals.<sup>21</sup>

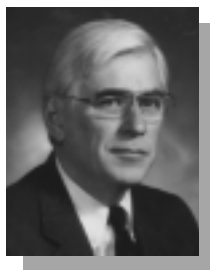
**KOUCHOUKOS:** Yes, he does. He actually has challenged the concept of a single artery of Adamkiewicz, and there probably is some merit in that hypothesis. In his technique, all of the intercostal arteries are isolated and serially occluded. Somatosensory evoked potentials are measured to determine which arteries are important and which are not. He concluded that in most cases, the intercostal arteries are not essential. He also determined that other adjuncts probably are necessary for extensive Type II aneurysms, which are associated with a high incidence of paraplegia. There is concern about the high incidence of false-positive and false-negative measurements when only the sensory-evoked potentials are measured.

**DEWEESE:** Dr. Ochsner, as one of those who has championed hypothermia and spinal cord drainage, do you think the fact that Dr. Kouchoukos has not seen paralysis in 100 cases is significant?

**OCHSNER:** We have used deep hypothermia on 3 chronic dissections, but we still use normothermia for degenerative Type II and III aneurysms. We only use deep hypothermic circulatory arrest in the descending aorta when it is difficult to get proximal control, either because of previous operations or a large proximal aneurysm that must be sutured, leaving the arch alone. When we use normothermia, we perfuse from below to avoid extended

visceral ischemic time, even if it is just a single anastomosis. We usually perform 1 proximal anastomosis and in the intercostals at T9-T12 on femoro-femoral or atrial-femoral bypass.

**KOUCHOUKOS:** The optimal degree of hypothermia is not known. Cambria's data suggests that even 25°C, which is certainly higher than the temperature with the deep hypothermic technique, may, in fact, be adequate.<sup>19</sup> If a period of circulatory arrest is needed while performing the proximal portion of the procedure, it still is necessary to go down to the lower temperature. We have not done our procedures at higher temperatures, but that certainly is a possibility, and it might reduce the cooling and rewarming time in some cases.



For aneurysms located closer to the distal descending arch, we are now using circulatory arrest and hypothermia.

—Dr. Buckley

**BUCKLEY:** For aneurysms located closer to the distal descending arch, we are now using circulatory arrest and hypothermia. However, at the level of the hilum, we use intrathecal or epidural cooling, and the incidence of the complications as you have outlined has been very low. Is the perfusion of the cord, not an isolated vessel, the major difference? Circulatory arrest should be reserved for complex lesions at a higher level, where less of the collateral circulation is lost.

**KOUCHOUKOS:** At higher levels, circulatory arrest is used primarily for technical reasons. No one knows yet what the best approach is. Borst reported a series of descending thoracic aneurysms in which 2 or 3 patients had paraplegia when only distal perfusion with normothermia was used.<sup>22</sup> We also have seen this in a few cases. It often occurs because the distal intercostal vessels in the lower chest are occluded.

In that situation, a case could be made for implanting the arteries higher up at the T3-T6 level that are not occluded. If the distal aorta is degenerative and the lower vessels are occluded, I would implant the higher arteries. Although this takes more time, occasionally it might prevent a case of paraplegia. We don't know which arteries are essential to implant, and they probably differ from patient to patient. Therefore, we try to cover every possibility, and in that situation we would reimplant the higher arteries.

**ELKINS:** I was interested in your comments about the use of aprotinin. Obviously, your dissatisfaction occurred early on in your experience. We use aprotinin in a low-dose protocol in a number of situations. We use it routinely, for example, in redo patients who are undergoing a Ross procedure. We also use it routinely when hypothermic circulatory arrest is used in a patient with an ascending arch or descending aneurysm. We are careful about using the recommended ACT tubes, and we have not seen the problems you described. Are you still concerned about the use of aprotinin in hypothermic circulatory arrest?

**KOUCHOUKOS:** As I indicated, these problems occurred early in our experience. Certainly, other groups have used aprotinin successfully with circulatory arrest. However, my analysis indicates that the re-

sults are variable, and I still have some concerns about it.

Some groups have reported a higher incidence of renal dysfunction than might otherwise occur, and there may be other more subtle consequences that aren't necessarily appreciated. The reported series do not conclusively demonstrate that it has any major effect on blood replacement. With the impervious grafts and the perfusion systems we now use, bleeding problems are not as common as they were in the past.

**OSHSNER:** We use aprotinin with hypothermic arrest, and we haven't encountered any problems. Perhaps that is because of the amount of heparin that is given.

How do you measure the temperature when hypothermia is used in the spinal cord?

**BUCKLEY:** We measure the temperature of some of the effluent spinal cord fluid. We don't know what the temperature of the cord is, but the temperature of the bathing fluid provides evidence of cooling.

**KOUCHOUKOS:** We don't routinely measure the spinal cord temperature clinically. However, in a series of 13 patients in whom we inserted a small thermistor-tip catheter into the epidural space, the temperature correlated well with the nasopharyngeal temperatures.

**MACKENZIE:** When the patient is in cardiac arrest after a revascularization procedure, is it possible to get access to the heart without disturbing the grafts?

**KOUCHOUKOS:** We have done a coronary bypass to the circumflex system through this approach in several patients. If the patient clearly has significant anterior descending or right disease, we recommend that it be treated before the aneurysm procedure if possible.

**MACKENZIE:** If the patient has postoperative adhesions after having undergone a vascularization procedure a year or two previously and now has a thoracoabdominal aneurysm, how do you get access to the heart to restart it?



We use aprotinin routinely when hypothermic circulatory arrest is used in a patient with an ascending arch or descending aneurysm.

—Dr. Elkins

**KOUCHOUKOS:** The heart can be defibrillated through the pericardium. We have been surprised to find that defibrillation rarely is necessary at the end of the period of circulatory arrest. The heart usually starts beating spontaneously.

**MACKENZIE:** Do you incise the diaphragm radially or circumferentially?

**KOUCHOUKOS:** We have done it both ways. The radial approach is easier, but there probably is more diaphragmatic dysfunction postoperatively when it is used. In a patient with significant lung disease, we use the circumferential approach for detachment and reattachment.

**OCHSNER:** Do you enter the abdomen?

**KOUCHOUKOS:** We don't make an effort to stay out of the abdomen.

**DEWEESE:** According to a recent report, enlarging the aortic hiatus without incising the diaphragm can significantly decrease the incidence of postoperative respiratory failure. This is particularly true for Type II and III aneurysms, which can be managed from above and below the diaphragm.

**COOLEY:** I enjoyed hearing what Dr. Kouchoukos had to say, and I compliment him on continuing his work. Personally, I would only use hypothermic arrest in a descending aneurysm if the lesion extended farther proximally than the innominate artery.

Recently, my interest has focused on the single-clamp technique with exsanguination. During the period of exsanguination, the spinal fluid pressure decreases dramatically, and the proximal systemic pressure remains normal. If the period of ischemia can be restricted to less than 30 minutes, the incidence of spinal cord injury is quite low. We usually do not reimplant segmental vessels individually. We perform an oblique distal anastomosis to incorporate some of those vessels.

Many of us had previously given up on motor-evoked potentials because of their unpredictability. However, Michael Jacobs, one of our former trainees, is firmly convinced that motor-evoked potentials are more valuable than somatosensory potentials.<sup>22</sup> He

believes he can identify critical vessels prior to cross-clamping by dissecting them out and clamping them. I am still skeptical of his belief, but it shows how opinion varies with time.

When we first began using hypothermia in the treatment of aortic aneurysms 40 years ago, I was convinced that it would be the most protective method for descending aneurysms. However, the induction of hypothermia in these cases is not easily accomplished. Using cardiopulmonary bypass to induce hypothermia introduces other problems that we are just beginning to appreciate, including a total inflammatory response and changes in complement, platelet function, cytokines, and so forth.

When a patient who weighs 275 pounds undergoes hypothermic circulatory arrest, rewarming takes about 2.5 hours. My approach is much simpler. By using the single-clamp technique, a skilled surgeon can remove a descending aneurysm in 20-30 minutes of cross-clamp time. Therefore, my work will serve as a control because I avoid using hypothermia in such cases.

**KOUCHOUKOS:** Your points are well taken. If the operation can be done expeditiously, and it is not necessary to implant the distal intercostals or upper lumbar vessels separately, your approach certainly is appropriate. Unfortunately, at centers where the volume of surgery is considerably less than at your institution, the surgeons are not likely to be comfortable with that approach. However, I am asked frequently to review cases in which a patient has developed paraplegia after repair of an acute aortic transection using simple aortic clamping. The issue that always arises is how the spinal cord should have been protected during these operations. Determining the best way to do this remains a dilemma.

**COOLEY:** It is likely that the jury will be out permanently on that issue. So many factors are involved that it is difficult to determine which ones are the most critical. I do know that in a large patient, prolonged hypothermia introduces other complications that we should try to avoid, primarily coagulopathy.

**KOUCHOUKOS:** Most of us have had experience with hypothermic circulatory arrest for other opera-



In a large patient, prolonged hypothermia introduces other complications that we should try to avoid, primarily coagulopathy.

—Dr. Cooley

tions using other approaches, and we now find that there are fewer complications than there used to be. The coagulopathies are less frequent and severe than they were in the past. Even in the absence of aprotinin, there is some evidence that hypothermia actually may reduce the inflammatory response rather than aggravate it. Certainly, cardiopulmonary bypass can induce an inflammatory response, but hypothermia may be protective in terms of the effect on cytokines and other factors.

**BUCKLEY:** Improved control of anticoagulation and more vigorous heparinization when the patient is taken off the pump seem to have resolved the problems with bleeding after the procedure. Cambria et al used very little heparin in their technique for resection of an aneurysm. Although they thought the bleeding problems occurred because the liver was underperfused, inadequate anticoagulation can lead to moderate intravascular bleeding. Would you agree that much of this is attributable to having a better understanding of intravascular thrombosis and improved heparinization during the procedure?

**KOUCHOUKOS:** I think it is.

**BUCKLEY:** Our reduced incidence of rebleeding was coincident with an increase in the dosage of heparin.

**COOLEY:** In his cases, Crawford did not use heparin at all.

**BUCKLEY:** Initially, Cambria's group used no heparin at all. They began using early reperfusion of the abdominal organs, specifically the liver, because they believed that protein was being lost. The deficit seen in bleeding is very similar to the deficit in intravascular thrombosis.

**KOUCHOUKOS:** Three studies, including the study by DeWeese et al,<sup>16-18</sup> have shown that the ischemia in the viscera and liver induces a fibrinolytic cascade, so that there may be more bleeding without heparin than with it.

**OCHSNER:** If the superior mesenteric artery is damaged and visceral death occurs, it is impossible to

control the bleeding from a coagulopathy.

**COOLEY:** Dr. Kouchoukos, would it be possible to induce hypothermia without using an oxygenator in the circuit?

**KOUCHOUKOS:** That has been tried with lower levels of hypothermia. There is a risk of ventricular fibrillation. The Hopkins group reported good results in a series of patients in which the temperature was taken to 29°-30°C without an oxygenator.<sup>22</sup>



If the superior mesenteric artery is damaged and visceral death occurs, it is impossible to control the bleeding from a coagulopathy.

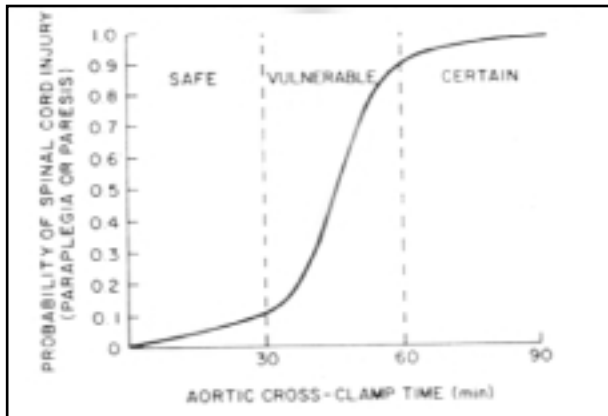
—Dr. Ochsner

**BUCKLEY:** During the 1960s, Drew had good results with the use of this technique to induce profound hypothermia, taking the temperature down to 15°C or 20°C, but it is a more complex technique that requires extensive monitoring. It is easier to do it with an oxygenator.

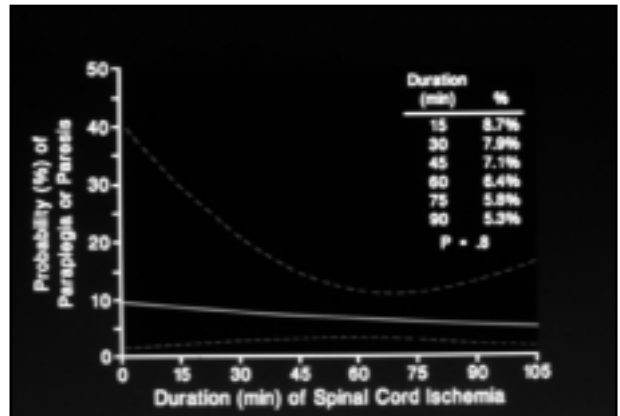
**DEWEESE:** Thank you very much for your contributions to this interesting discussion. We can still disagree, but we cannot disregard the good results presented by Dr. Kouchoukos.

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**Figure 4. Prevention of spinal cord ischemia in aortic surgery. (From Svensson LG, Crawford ES. *Cardiovascular and Vascular Disease of the Aorta*. Philadelphia, Pa: WB Saunders Co;1997. Reprinted by permission.)**



**Figure 5. Risk of paraplegia or paraparesis according to the duration of spinal cord ischemia.**

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CS

**Errata:** Because of an editing error, the photographs and CT scans on page 283 of last month's Symposium, "Changing Concepts in Managing Maxillofacial Trauma," were attributed to the wrong author. The credit should have read, "Figures courtesy of Chen Lee, MD."

Furthermore, the color photographs on that page were "flooded," causing the patient's injuries to the right zygoma to appear as if they were on the left side of his face.

The editors apologize to our readers as well as to Dr. Lee for any confusion these errors might have caused.