HEPARINLESS PARTIAL CARDIOPULMONARY BYPASS FOR THE REPAIR OF AORTIC TRAUMA

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Objective: We hypothesized that partial cardiopulmonary bypass with a heparin-bonded system would be a technically simple, effective adjunct for reducing paraplegia during repair of traumatic aortic rupture. It avoids the risk of heparin, but, unlike left atrial–arterial bypass, it can heat, cool, oxygenate, and rapidly infuse volume if needed.

Methods: A retrospective review was conducted of patients admitted for aortic trauma from July 1994 to December 1999. Bypass consisted of femoral venous (right atrial) cannulation, a centrifugal pump, and an oxygenator-heater/cooler. Arterial return was to the femoral artery or distal aorta. The entire system was heparin-bonded and no systemic heparin was given.

Results: Heparin-bonded partial bypass was established in 50 patients (mean age 43 ± 17 years). Crossclamp time was 32 ± 11 minutes (range 14–70 minutes), mean flow 3.0 ± 0.8 L/min, and bypass time 64 ± 43 minutes. During repair, 58% of patients received volume through the system (mean 1.1 ± 1.9 L). Core temperature rose slightly ($35.9^\circ\text{C} \pm 0.7^\circ\text{C}$ to $36.3^\circ\text{C} \pm 0.8^\circ\text{C}$). Three of the 15 patients who underwent percutaneous femoral arterial and venous cannulation concomitant with their angiograms had vessel injury, with one limb loss, and this procedure was discontinued. Thirty-five patients underwent percutaneous femoral vein and direct distal aortic cannulation without event. The mortality rate for patients supported by bypass was 10%, and all deaths were due to other injuries. There were no new cases of paraplegia and no worsening of intracranial or pulmonary injuries.

Conclusions: Heparin-bonded bypass is technically simple to use and avoids the risk of anticoagulation. Paraplegia was avoided. The ability to correct hypothermia, oxygenate, and rapidly infuse volume may simplify management and improve outcomes. (J Thorac Cardiovasc Surg 2000;120:1104-11)

Despite advances in care, repair of a traumatic aortic rupture is still associated with mortality rates as high as 40% and new-onset paraplegia rates of up to

33%.¹⁻¹³ The optimal technique for the repair of traumatic aortic rupture is a subject of great controversy. The simple clamp-and-sew method of repair has many strong advocates, with several groups having reported low paraplegia and mortality rates.^{2,7,14,15} However, the safety of this approach is dependent on a short cross-clamp time (<30 minutes). Such a brief crossclamp time cannot be guaranteed,^{16,17} and most surgical groups do not meet this mark.^{1,4,5} Active distal circulatory support is very effective in reducing the risk of paraplegia, particularly when crossclamp times are longer than 30 minutes. A large body of literature supports the use of distal circulatory support as the method of choice for the repair of traumatic aortic rupture.^{1,3-5,11-13,18,19}

The two most common methods of distal circulatory support are partial cardiopulmonary bypass (CPB) with full heparinization and left atrial to aortic or femoral

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bypass (LA-arterial) without heparin. CPB is flexible and has the ability to oxygenate, scavenge shed blood, and heat and cool as desired.^{5,18} However, the use of full anticoagulation in a multiply injured patient may increase the risk of bleeding and death.^{1,14} LA-arterial bypass does not require heparin but has several limitations. Because of the risk of air embolization in these closed systems, physicians are reluctant to rapidly infuse volume through them. Most LA-arterial systems do not incorporate a heat exchanger and are dependent on adequate pulmonary function for oxygenation. Additionally, cannulation of the left atrial appendage or pulmonary vein can sometimes be difficult in the presence of an extensive mediastinal hematoma.

Partial CPB with a heparin-bonded system (HB-PCPB) offers a third option that can provide adequate distal circulatory support with very simple cannulation.²⁰ It eliminates the need for anticoagulation, and it can heat, cool, oxygenate, and transfuse as required. HB-PCPB has been used at the University of Maryland for the repair of traumatic aortic rupture since 1994. We retrospectively reviewed our results to test the hypothesis that HB-PCPB is an effective adjunct for minimizing the risk of paraplegia and mortality during repair of traumatic aortic rupture.

Methods

Data collection. A retrospective review was conducted of all patients taken to the operating room for attempted repair of traumatic rupture of the proximal descending aorta at the University of Maryland from July 1994 to December 1999. This period covers the beginning of our use of HB-PCPB for distal circulatory support to the present time. Patients who died before chest incision and those who were treated with simple crossclamping or alternative methods of distal support were noted and excluded from further analysis. Hypotension was defined as a systolic pressure of 90 mm Hg or less with a heart rate of 100 beats/min or more. Associated injuries were assigned on the basis of the initial radiology results and the hospital discharge summary.

Patient management. All patients were admitted to the trauma service at the University of Maryland R. Adams Cowley Shock Trauma Center. This is a regional level 1 trauma referral center. Initial management was directed by the attending trauma surgeon. The diagnosis of traumatic aortic rupture was made by angiography or computed tomographic scanning. Life-threatening abdominal, pelvic, or intracranial injuries were treated first as indicated clinically. In the latter part of the study period, significant pelvic and intra-abdominal injuries were managed by angiographic embolization before aortic repair.

Patients were intubated with a double-lumen endotracheal tube. Pulmonary artery and right radial artery pressures were monitored. In 3 patients femoral artery pressure was also monitored. Repair was performed via a posterolateral thor-

cotomy in the fourth intercostal space. In the first 15 patients, 14F arterial and 17F or 19F venous cannulas (Medtronic, Inc, Minneapolis, Minn) were placed into the femoral artery and vein, respectively, at the conclusion of the diagnostic angiogram. The femoral vein catheter was advanced into the right atrium with fluoroscopic guidance. The patient was then transported to the operating room.

In the subsequent 35 patients, the right atrial catheter was placed percutaneously via the right femoral vein after the induction of anesthesia, before the patient was turned into the thoracotomy position, or via the left femoral vein after the patient was positioned, depending on surgeon preference. Arterial return was directly into the distal descending aorta via a metal-tipped right-angled cannula.

The cannulas were connected to a bypass system consisting of a centrifugal pump and an oxygenator/heat exchanger (Maxima; Medtronic). The cannulas and the bypass system were completely heparin-bonded. No systemic heparin was given. Bypass flow was targeted at 1.5 to 3 L/min. The heat exchanger was adjusted to maintain normothermia, with the water bath not exceeding 38°C. Shed blood was collected via a cell salvage device and returned to the patient. The aorta was clamped proximally between the left carotid and left subclavian arteries, with separate clamps on the left subclavian artery and distal aorta. Repair was completed by primary repair or interposition graft at the attending surgeon's preference.

Paired data were compared by *t* test (Microsoft Excel 97; Microsoft Corporation, Redmond, Wash).

Results

During the period from July 1994 to December 1999, 56 patients underwent attempted repair of a traumatic rupture of the proximal descending aorta. Two patients died before incision, 1 of rupture on arrival in the operating room and 1 of arrhythmia after the induction of anesthesia. One patient was already receiving pulmonary support with an extracorporeal membrane oxygenator at the time of his aortic repair, and that circuit was used for distal circulatory support. Two patients were treated with simple crossclamping based on the available surgeon and operating room resources at the time. These patients were excluded from further analysis.

One patient died of rupture immediately after the thoracotomy and was never placed on bypass. The records of the remaining 50 patients were further analyzed. There were 34 male and 16 female patients with a mean age of 43 ± 17 years. Associated injuries are summarized in Table I.

The aorta was repaired primarily in 24% (12/50) and an interposition graft was used in 76% (38/50). The operative parameters are summarized in Table II. The crossclamp time was 32 ± 11 minutes with a range of 14 to 70 minutes. The mean bypass time was 64 ± 43 minutes with an average bypass flow of 3.02 ± 0.8

Table I. Associated injuries

Associated injuries	No.	Percent
Hypotensive on arrival to hospital	7/50	14
Closed head injury	8/50	16
Abdominal injury	31/50	62
Pulmonary contusion	12/50	24
Pelvic injury	17/50	34
Other bone fracture	30/50	60

L/min. Hemodynamic stability was maintained, with a mean proximal blood pressure during aortic cross-clamping of 81 ± 10 mm Hg. The mean distal femoral artery blood pressure during aortic crossclamping was 54 ± 4 mm Hg ($n = 3$).

Ten percent (5/50) of the patients who were supported with CPB ultimately died: 2 died neurologic deaths related to their initial injury, 2 died of multisystem organ failure, and 1 died of multiple source sepsis.

One patient was paraplegic preoperatively because of a spinal cord transection, but no other cases of paraplegia, temporary or permanent, were observed in the other 49 patients. There was no worsening of intracranial injury immediately after aortic repair according to computed tomographic scan or clinical criteria. The mean Glasgow coma scale was 13.8 ± 2.3 before aortic repair and 14.7 ± 0.9 at discharge ($P = .69$). No instances of intraoperative pulmonary hemorrhage were recorded, and no worsening of pulmonary contusions was attributed to the aortic repair.

Fifty-eight percent of all the patients undergoing HB-PCPB had active volume resuscitation through the bypass system to maintain blood pressure or bypass flow. Twenty-five of 50 patients received crystalloid solution (average 1.5 ± 1.5 L) and 19 of 50 patients received blood (average 0.8 ± 1 L). The mean core temperature before the induction of bypass was $35.9^\circ\text{C} \pm 0.9^\circ\text{C}$; during bypass it was $36.2^\circ\text{C} \pm 0.7^\circ\text{C}$; and after bypass it was $36.3^\circ\text{C} \pm 0.8^\circ\text{C}$. The temperature after bypass was statistically different from the temperature before bypass ($P = .03$), but this was not believed to be a clinically significant difference (35.9°C vs 36.3°C).

Among the first 15 patients, 1 had a femoral artery pseudoaneurysm that required surgical repair, 1 had a femoral artery thrombosis that required surgical correction, and 1 patient had extensive femoral and pelvic venous thrombosis with primary or secondary arterial thrombosis that ultimately led to limb loss. Both of the patients with femoral vessel thrombosis had the cannulas in place for more than 6 hours because of a delay in operative therapy or in cannula removal. In the remaining 35 patients the proximal descending aorta was

Table II. Operative parameters

Parameter	Mean value $\pm$ SD
Crossclamp time (min)	32 ± 11
Bypass time (min)	64 ± 43
Bypass flow (L/min)	3.02 ± 0.8
Proximal aortic blood pressure (mm Hg)	81 ± 10
Distal aortic blood pressure (mm Hg)	54 ± 4

directly cannulated for arterial inflow. One of these patients required re-exploration for bleeding from the distal aortic cannulation site. No other vascular complications, arterial or venous, were observed in the latter group.

Discussion

Patients with traumatic aortic rupture are at a greater risk for paraplegia during aorta repair than patients with chronic aortic aneurysms or aortic coarctation. This heightened risk is likely due to the lack of preformed collaterals, along with the additional complications unique to trauma patients including pulmonary and cardiac contusions, shock, hypoxia, and hypoosmolality from fluid overload.¹⁸ Crossclamp times of greater than 30 minutes, in the absence of distal support, are associated with a significant increase in the risk of paraplegia.^{4,8,21} Active maintenance of distal perfusion reduces this risk.^{1,4,8,22} Additionally, active distal support provides proximal aortic unloading, which reduces cardiac strain.²³ It also helps minimize the risk of hypotension after crossclamp removal,²⁴ which is associated with an increased risk of paraplegia.^{14,22,25}

Advocates of the clamp-and-sew method point to the technique's simplicity, the low paraplegia rate if cross-clamp times are short, and a low mortality rate as compared with approaches that use heparin.^{2,7,14,15} Sweeney and associates¹⁵ recently reported a mortality rate of 12% and a permanent paraplegia rate of 1.3% with a mean crossclamp time of 24 minutes. However, a crossclamp time this brief cannot be guaranteed,¹⁶ and most surgical groups do not meet this mark.^{1,4,5} The average international crossclamp time as reported by Von Oppell and coworkers¹ is 41 minutes. Our average crossclamp time was 32 minutes, with 11 patients having clamp times of more than 40 minutes. Even advocates of the clamp-and-sew technique have patients with unexpectedly long crossclamp times who experience paraplegia.⁷ Most groups using the clamp-and-sew technique report paraplegia rates in the 5% to 33% range.^{1-4,6,7,12,14,16} This is in contrast to the 0% to

7% rates reported by those who use active distal support.^{1-6,9,11-13,19} In their meta-analysis, Von Oppell and colleagues¹ observed that active distal perfusion was associated with a 2.3% paraplegia rate versus a 16% paraplegia rate with simple crossclamping (even though the average crossclamp time was 32 minutes). Their results were confirmed by the prospective multicenter study reported by Fabian and colleagues,⁴ which showed the clamp-and-sew method to have a paraplegia rate of 16.4% versus 2.9% for active distal support. Hunt and colleagues⁸ noted that distal perfusion was particularly beneficial (as compared with the clamp-and-sew technique) when the crossclamp time exceeded 30 minutes. At the University of Maryland, the clamp-and-sew method was the primary repair technique used from 1986 to 1994 and was associated with a 26% paraplegia rate.²⁵

CPB for distal support has many theoretic advantages over simple clamping. It provides proximal cardiac unloading,²³ which may be helpful in elderly patients and in those with myocardial contusions. It provides reliable distal perfusion, it has the ability to collect and rapidly reinfuse shed blood, and it can heat and cool as needed.¹⁸ Several authors have reported good results with partial CPB.^{5,9,18} In 1995 Pate, Fabian, and Walker¹⁸ reported a 2.3% paraplegia rate and a 6.8% mortality rate for 88 patients supported with CPB. The major disadvantage of this technique is the requirement for full anticoagulation, which has been associated with an increased mortality rate and increased bleeding complications.^{1,26} Pate's group¹⁸ has pointed out that the risks of anticoagulation are not as high as they have traditionally been believed to be, particularly if other major injuries are stabilized before aortic repair. However, even their experience included several patients in whom intracranial injury worsened with anticoagulation and several patients in whom intraoperative pulmonary bleeding occurred.¹⁸ Their results suggest that heparinization still may have risks.

LA-arterial bypass also provides proximal unloading and reliable distal aortic perfusion but does not require anticoagulation. Published rates for paraplegia and mortality with LA-arterial bypass are consistently in the 0% to 7% and 7% to 20% ranges, respectively.^{1-6,9,11-13} These systems are simple, and the results are reproducible even at centers that do not perform large numbers of aortic repairs. LA-arterial bypass is, however, less flexible than CPB. It is dependent on the lungs for oxygenation, which can occasionally be problematic in a trauma patient.¹⁸ LA-arterial bypass systems generally do not incorporate a heat exchanger and thus cannot heat or cool as needed. Because of the risk of air embolism in these

closed systems, rapid infusion of volume through them is also not generally recommended. Additionally, when the mediastinal hematoma extends into the pulmonary hilum, the left atrial appendage or pulmonary vein can be a challenge to expose safely, and the cannula can intrude into the operative field. Tamponade from a bleeding left atrial appendage has also been reported,¹⁹ and there is a theoretic risk of cardiac air embolism.

HB-PCPB offers a third option for active distal circulatory support.²⁰ HB-PCPB has the ability to provide good distal perfusion, via simple cannulation. It can be used to heat, cool, oxygenate, and infuse volume, but it does not carry the risks of anticoagulation. Cannulation of the right atrium via the femoral vein is simple and provides a clear, unobstructed field in which to work.

In our first 15 patients we encountered 3 serious complications related to the cannulation technique—1 pseudoaneurysm, 1 arterial thrombosis, and 1 arterial and venous thrombosis that ultimately resulted in limb loss. These cannulas were placed percutaneously in the radiology department after the arteriogram, before the patient was transported to the operating room. The pseudoaneurysm probably could have been avoided if an open femoral cannulation technique had been used. The 2 patients who had thrombotic complications both had the cannulas in place for more than 6 hours. One had a delay in going to the operating room after cannula placement, and the other had a delay in cannula removal. Since switching to cannulation of the distal thoracic aorta through the chest incision, as described by Fullerton,²⁷ we have had no further arterial injuries. One patient required re-exploration for bleeding from the aortic cannulation site, but this was an avoidable technical error. Percutaneous femoral vein cannulation in the operating room, with prompt cannula removal postoperatively, has not been associated with any early or late venous complications. Several of our surgeons prefer to place the venous cannula percutaneously via the right femoral vein and pass it off to the perfusionist before turning the patient into the thoracotomy position. This avoids the potential difficulties encountered in passing the catheter via the left femoral vein after the patient has been turned into the thoracotomy position, when the orientation of the patient's pelvis and lumbar region can make catheter passage difficult. We have, however, had no actual difficulties in passing the catheter after the patient has been turned.

The HC-PCPB system was used to infuse volume in 58% (29/50) of our patients. Seven of these received more than 3 L of fluid. This fluid was usually given in boluses to maintain pressure or flow. The ability to rapidly infuse volume enhances the hemodynamic sta-

bility of the patient. We were able to maintain an average proximal aortic pressure of 81 ± 10 mm Hg and a mean pump flow of 3 L/min. The risk of significant hypotensive episodes, which are known to increase the risk of paraplegia, was minimized.^{3,14,22,25} The risk of air embolism while fluid is being added into an HB-PCPB circuit is reduced by the oxygenator-heater/cooler, which has significant air-handling capacity. This is in contrast to LA-arterial systems, which have only a centrifugal pump as a trap. Although we observed no episodes of air embolism, caution must still be used to avoid entraining air.

Most patients in our series were slightly hypothermic at the start of their aortic repair and were actively warmed in an attempt to maintain normothermia. This may help to improve hemostasis and avoid cardiac arrhythmias. However, hypothermia, even by a few degrees, is known to reduce the risk of injury to the ischemic spinal cord.^{22,28} Theoretically, 38°C blood in the distal aorta could actually increase the susceptibility of the spinal cord to ischemic injury, but we noted no adverse outcomes. The reason may be that not a great deal of actual cord warming took place during the bypass run, during which the patients' core temperatures changed minimally from 35.9°C to 36.3°C. It is also possible that the ischemic insult to the spinal cord was not significant enough for temperature to be a factor in the outcome. Although active cooling of distal aortic blood to augment spinal cord protection is possible with this system, due to the mildly hypothermic state of many of our trauma patients, we have not used this strategy of spinal cord protection.

We observed no gross worsening of intracranial injury after repair of traumatic aortic rupture. There were no new episodes of intracranial bleeding or hypertensive crises in the early postoperative period that could have been attributed to aortic repair. The Glasgow coma scale measurement on arrival at the hospital was not significantly different from that at discharge (13.8 vs 14.7). These measurements included several patients with head injuries who could not have been operated on had heparin been required. Straight aortic clamping is known to raise cerebrospinal fluid pressures,²² which could exacerbate intracranial injuries. Unloading the proximal aorta with an active distal support system may minimize this rise. Three of our patients had intracranial pressure monitoring during the aortic repair. In 2 of these patients, intracranial pressure remained in the 10– to 14-cm H₂O range throughout the aortic repair. In 1 patient it rose slightly, from 17 to 21 cm H₂O, after the crossclamp was placed.

It is unclear whether the ability to oxygenate through the HB-PCPB system adds a significant benefit.

Anesthesiologists and surgeons generally believe that patients are easier to manage with single lung ventilation when they are supported by HB-PCPB. Adding fully oxygenated, hypocarbic blood to the circulation at a rate of 3 L/min can theoretically compensate for a significant decrease in pulmonary function. However, in cases of hemodynamic instability or hypoxia that responded to the initiation of HC-PCPB, other interventions were also made, thus limiting any conclusions that might be drawn about the additive effect of the oxygenator.

It is also unclear whether the use of distal circulatory support affects the mortality rate. Older series that used full heparinization during distal circulatory support had higher mortality rates than those that used simple clamping,^{1,14} but this does not seem to be true in more recent reports.¹⁸ The clamp-and-sew technique has been associated with an increased mortality rate in some series,^{6,8} but a decreased mortality rate in others.¹⁴ In most reports, survival is most heavily affected by the type and degree of the other associated injuries rather than the repair technique.^{2,4} Our observed mortality rate in patients placed on HB-PCPB for repair of traumatic aortic rupture was 10%. This is in the lower quartile of the range of published results.^{1,2,3,4,5-13} Prompt diagnosis and appropriate management of the most life-threatening injuries first²⁵ and the avoidance of anticoagulation and perioperative hypotension probably all account for these favorable results.

The complete avoidance of new paraplegia in our patients strongly supports the use of active distal support. Our average crossclamp time of 32 ± 11 minutes is below the average published in multicenter reviews, but would still be expected to produce some cases of paraplegia if a simple clamp-and-sew method were used.^{1,4} Tatou and coworkers² reported a paraplegia rate of 5.7% with an average crossclamp time of 26.6 ± 10.9 minutes, and Von Oppell and colleagues¹ noted a 19.2% rate of paraplegia with a 32-minute crossclamp time using the clamp-and-sew method. In our current series, 13 patients had crossclamp times of 30 to 39 minutes and 11 patients had crossclamp times of over 40 minutes. None of these patients had a new spinal cord injury. Adequate distal perfusion, maintenance of hemodynamic stability during the repair, and the minimization of postclamp acidosis and hypotension all likely contributed to this favorable outcome.

In conclusion, we believe that active distal support is beneficial, particularly when crossclamp times are greater than 30 minutes. HB-PCPB avoids the risk of heparinization and is an excellent alternative to LA-arterial bypass. The cannulation is simple, and the ability to quickly add volume, heat or cool, and oxygenate may simplify intraoperative management. Using this

system, we observed no paraplegia in 50 patients and had a 90% survival.

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Discussion

Dr Irving L. Kron (Charlottesville, Va). I very much enjoyed this innovative approach to patients undergoing surgical treatment for traumatic aortic transection. The authors have excellent results. They have studied 50 patients with a mean clamp time of 32 minutes, a bypass time of 64 minutes, no new cases of paraplegia, and a 10% mortality. The mortality in their cases was undoubtedly related to the multiple trauma rather than to technical aspects of the operation. They have used a novel approach, which is a percutaneous femoral venous approach and direct aortic cannulation. They previously placed cannulas in the angiography suite, and I loved that idea; I am sorry it did not work.

They have suggested that their technique is better than a simple clamp-and-sew procedure. Their technique allowed some form of spinal cord protection, even when clamp times were prolonged. They also believe their technique compares favorably to LA-arterial bypass. Although our group has tended to use clamp-and-sew techniques until very recently, we have recognized the clinical importance of maintaining very short clamp times. Von Oppell in his 20-year meta-analysis clearly noted that the rate of paraplegia was greatly increased for clamp times above 30 minutes. In his analysis, only a clamp time of 20 minutes was free of any risk of paraplegia.

Although our group has some issues with manipulating diseased aortas, clearly this is not an issue with traumatic transection. We are beginning to favor LA-arterial bypass using very small pediatric Bio-Medicus cannulas (Medtronic Bio-

Medicus, Eden Prairie, Minn) placed in the inferior pulmonary vein and either percutaneously in the groin or in the aorta itself. I must say, we were not aware of the authors' technique until now. I have 3 questions for the authors.

The CPB times were twice the clamp times. Did you tend to leave the cannulas in for resuscitation? Can you explain why the bypass times were prolonged? You did not use heparin, instead choosing to use heparin-bonded circuits. We have used a small dose of heparin, which allows one to reclamp the aorta, and I would think that would eliminate any potential risk of thromboembolic events. You have not noted any.

However, our biggest concern relates to venous thrombosis. We had a recent case of a young man who had a leaking thoracic aneurysm requiring circulatory arrest. He did well originally, but the day he was supposed to be discharged he died of a pulmonary embolus. This clearly was related to the femoral venous cannulation site. Would you please discuss this particular issue and relate it to the multiple trauma patient, who clearly is hypercoagulable? Particularly if there is a head injury, the patient may not be in a position to receive subcutaneous heparin.

Dr Downing. Thank you for your comments. Regarding the prolonged bypass times, part of that relates to the beginning of the series when the patients were cannulated in the radiology department. When they arrived in the operating room, sometimes there was a fair time period between the initial cannula placement and surgery. To avoid clot, we believed it was necessary to institute bypass early. Thus, bypass was prolonged in a number of patients for that reason only.

Later in the series, we did not need to do that. Sometimes patients were placed on bypass to stabilize them, but that was not a common practice. It depended really on the surgeon's preference. If the hematoma was large and the aorta was difficult to get around, frequently they would be placed on bypass and the mobilization completed during that period. However, the majority of the longer bypass times come from the beginning of the series when we placed the cannulas early.

We have not had a problem with thromboembolic events. I think many trauma patients are probably somewhat hypocoagulable from their volume resuscitation, and so they get some protection from their trauma. When we use this system for standard thoracic aneurysm resection, we do use low-dose anticoagulation.

The risk of pulmonary embolism is certainly a concern. These patients are managed by the trauma service after we finish with them, and this is a chronic issue for the team. The trauma service is very aggressive with anticoagulation, mobilization, thromboembolic disease stockings, and the like, and I think that that has contributed to the lack of problems. Pulmonary embolism is certainly a potential risk.

Dr Frank C. Spencer (*New York, NY*). I rise to emphasize the importance of monitoring distal aortic pressure when using a shunt. The authors report a 54 mm Hg pressure, but that figure was not in the abstract. Most articles describing shunts do not report the distal pressure. I think one reason the debate between the cut-and-sew technique versus use of a shunt has lasted so long is that the data have not been convincing in a trauma patient. The surgeon must hurry as much

as possible or take the risk of heparin in a trauma patient, and the data did not show a benefit.

As Irving Kron mentioned briefly, data are uniform about the hazards with crossclamping. The risk is virtually zero under 20 minutes, it rises slightly between 20 and 30 minutes, and then it steadily rises between 30 and 60 minutes. Your data with the crossclamp time show the importance, because when the surgeon tries to do the operation quickly, the patient takes a chance, not the surgeon.

The search has been underway for years to be able to shunt without heparin. Years ago, George Magovern's group in Pittsburgh briefly reported it and then stopped, I imagine because the technology was not good enough. This speaks for itself, with no paraplegia. I am astonished that you can get away with putting an oxygenator in the circuit without heparin. I wonder whether you measured any of the coagulation parameters, because that flies in the face of reason. That is why we use heparin—because of the surface on the oxygenator. You can get away with it for the heparin-bonded tubing, and if you did not want to oxygenate, you could simply use a left-sided bypass. I am interested to know whether you have any more data in that regard instead of stating that there were no thromboembolic complications.

To reiterate that point, measure the distal aortic pressure. We have done this at New York University for 20 or 30 years. The reason you need to measure this pressure is that the flow rate will vary from 2 to 4 L/m² for vasodilatation. If you keep the distal aortic pressure above 60 mm Hg, there is no need to rush. You can clamp 60 minutes, you can clamp 90 minutes, and distal perfusion is still perfectly adequate. Without measuring distal aortic pressure, you simply do not know where you are.

I have just one other question. Did you have to change your flow rate to keep that pressure up or was that just an observed phenomenon, because 54 is very close to 60? So, did you change your flow rate, and did you have any other measures of injuries to the coagulation mechanism?

Dr Downing. We initially targeted flow and not pressure. We now routinely measure distal pressure. We recognize the importance of maintaining the pressure and using that as a guide.

Regarding anticoagulation, the entire system was coated with Carmeda BioActive Surface (Medtronic), including the oxygenator and all the tubing and the cannulas. We did not measure anticoagulation parameters. Others, including Dr Turina's group, have done this and shown that systems coated with Carmeda BioActive Surface are fairly safe and effective.

Dr Ludwig K. von Segesser (*Lausanne, Switzerland*). I congratulate you for your excellent results. Along with the Zurich group, we have extensively advocated the use of low systemic heparinization, and we have also used no heparinization at all. Our patients were similar to yours, with trauma, and, in general, they had an increased activated clotting time before we started CPB. You have already stated that you did not measure anything.

Dr Jose M. Soto (*Bakersfield, Calif*). I have been involved in endovascular work in peripheral vascular

surgery. Let me urge most of the audience, particularly those involved in the management of this entity, that when the new endovascular techniques have been developed, and this will be in the near future, we should learn them very fast, because this particular entity will be taken care of by the radiologists. Once the transection is identified, it will be relatively simple to put in a covered stent or a Talent graft and take care of all these problems.

Echoing Dr Cosgrove's comments from his presidential address, we need to start getting training in additional aspects of evolving technology, including type III dissections. Some of the Japanese have replaced the entire ascending aorta through endoluminal techniques.

Dr Downing. It occurred to me when I was preparing the talk that this may be one of the last ones on this topic. We placed our first stent graft for aortic trauma last week.

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