Risk of replacement of descending aorta with a standardized left heart bypass technique

Replacement of the descending aorta for aneurysms (51 %) and dissection (49 %) was performed in 132 patients with a highly standardized left heart vortex-pump bypass. No adjuncts other than staged aortic clamping and intercostal artery reconnection were used to reduce spinal cord injury in extensive involvement. Four patients (3 %) died early, two of cardiac cause, and nine (7 %) died late. Complications of vital organ function occurred in eight patients, two having reversible renal failure and six spinal cord injury that was permanent in three (2.3 %). Cord injury occurred only in replacement beyond thoracic segment 8 and could not be completely avoided despite distal intercostal artery reconnection in two cases; in the other four cases such vessels either did not appear worth reconnecting or were sacrificed in emergency operations. We conclude that left heart bypass effectively unloads the proximal circulation during aortic occlusion while maintaining adequate perfusion of distal vital organs as evidenced by low rates of early mortality and renal failure. The remaining risk of spinal cord damage may be lowered by more aggressive reconnection of all distal intercostal arteries and by extending the permissible cord ischemic period by means of hypothermia. (J THORAC CARDIOVASC SURG 1994;107:126-33)

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Left heart bypass for replacement of the descending thoracic aorta remains controversial. Although some authors have routinely used simple aortic crossclamping, others prefer either pump-driven or passive shunts for perfusing the lower part of the body. Studies comparing these methods have been few.

The purpose of this investigation was to explore the potential of a highly standardized left heart bypass technique with respect to survival and vital organ damage. Aside from staged aortic crossclamping¹ and intercostal

artery reconnection, no other adjuncts proposed for the prevention of spinal cord complications were used.

Patients and methods

This series comprises 132 patients operated on between October 1986 and the end of 1992. The mean age was 47.5 years and the male gender predominated. The series is not entirely consecutive inasmuch as 10 patients had procedures in which brief periods of aortic crossclamping (18.6 ± 7.6 minutes) were expected. These included repair of circumscribed aneurysms or rupture of the proximal descending aorta.

The underlying diseases were nondissecting aneurysm and dissection in about equal proportions. All but one of the posttraumatic aneurysms were chronic. Of the 20 patients with aortic coarctation, 4 had concomitant aneurysms and 16 had previously undergone patch repair² (Table I). Twenty-five patients had proximal aortic dissection (type A), and the remainder had the distal variant (type B). Only 5 patients with dissection were in the acute stage of the disease. Perforation or rupture was present in 11%. Sixty previous aortic operations had been performed in 54 patients including 39 operations on the proximal aorta, 17 on the descending, and 4 on the distal aorta.

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Table I. Underlying disease

	No.
Nondissecting	
Atherosclerosis	22
Posttrauma	23
Coarctation	20
Others	2
	67 (51%)
Dissecting (type)	
Chronic (B)	36
Chronic (A)	24
Acute (B)	4
Acute (A)	1
	65 (49%)
Perforation/rupture	11%

Table II. Extent of aortic involvement versus period of left heart bypass

Intercostal space	No.	%	Bypass period (min)
≤T6	56	42.4	37.6 ± 14.3
≤T9	55	41.6	48.2 ± 16.5
>T9	21	16.0	58.3 ± 16.7
Mean			45.5 ± 18.0

Twenty-six subsequent procedures were done in 24 patients comprising 9 proximal and 17 distal aortic interventions without any deaths.

The left atrium was cannulated via its appendix with a 9 mm inner diameter straight side-holed tube. The blood was returned to the femoral vessels in two thirds of the patients; in the remaining patients the distal thoracic aorta was cannulated, this being the preferred route if the downstream vessel was free of disease. Perfusion was maintained with a vortex pump (Bio-Medicus, Medtronic Company, Bad Homburg, Germany) at a mean flow rate of 1.6 L/min per square meter body surface area and was so adjusted as to maintain the distal mean arterial pressure above 50 torr, the proximal pressure being held in the normal range. In hypertensive patients the administration of nitrates or, more recently, calcium channel blockers was sometimes required. No attempt was made to withhold heparin because the use or nonuse of this drug has been found to be irrelevant with the routine administration of aprotinin. Heparin 1 mg/kg was administered in all patients.

The operative technique involved a single standard incision in the bed of the fifth rib in 42% of the patients and a double thoracotomy in the fourth and seventh or eighth intercostal space in the remaining patients. The proximal aorta was occluded between the left common carotid and the subclavian arteries in the majority of patients (64%). In the more recent 48 patients undergoing crossclamping of the arch, the aorta was divided completely. We have found that transection of the aorta facilitates suturing the upstream anastomosis because the proximal aortic stump can be elevated from its deep location and also turns toward the surgeon. In addition, the recurrent nerve is easily dissected along its entire course, so that its inclusion in the posterior anastomotic suture line can be avoided. Difficulties

Table III. Results of linear regression analysis of variables potentially associated with spinal cord damage after replacement of the descending aorta

Variable	Pearson correlation coefficient (r)	p Value (two-tailed significance)
Level of distal aortic clamp	0.2782	0.001
Use of staged clamping technique	0.1727	0.048
Age at operation	0.1618	0.064
Reconnection of intercostal arteries	0.1107	0.207
Duration of aortic crossclamping	0.1043	0.234
Aortic pathology (aneurysm vs. dissection)	-0.0642	0.464
Duration of left heart bypass	0.0595	0.498
Gender	0.0507	0.564

p < 0.05 considered significant.

with the left subclavian artery occurred in only four instances, the vessel then being connected to the aortic graft either directly or via an additional graft. If the aortic wall was friable, strips of Teflon felt were included in the standard 3-0 continuous suture line. In ordinary type B dissection every attempt was made to anastomose the graft to the proximal uninvolved aorta. In retrograde type B dissection and the type A variant, the graft was connected to the true lumen or the outer aortic coat depending on the preferential flow channel in the arch. More recently, we glued the wall layers with gelatin-resorcinol-formal adhesive (GRF Colle Biologique, Gelatine-Resorcinol-Formal, Cardial Co., Marne-La-Valle, France). The distal anastomosis was made at the appropriate level, if possible, to uninvolved aorta. In dissection, the membrane was excised distally as far as it could be visualized. The pump was arrested briefly, and the anastomosis was then made to the outer coat of the aorta. An elephant trunk extension of the aortic graft³ was inserted into the downstream vessel in 19 patients because another operation appeared indicated.

Fifty-six patients had replacement of the descending aorta down to and including the sixth intercostal space and 55 to and including the ninth intercostal space. In 21 patients, the thoracic aorta was replaced subtotally or totally. The distal anastomosis can be placed just upstream of the celiac axis through a purely transthoracic approach. The approach to the vessel within the aortic hiatus is greatly facilitated by placing strong retracting sutures in the pars membranacea of the diaphragm. Aortic occlusion at this low level is best achieved by a curved clamp. The period of left heart bypass was related to the extent of the replacement (Table II).

Staged aortic occlusion was used in 40 cases. Proximal double crossclamping was applied while the anastomosis between the graft and the upstream aortic anastomosis was made, the downstream vessel being perfused during this period (Fig. 1). For occlusion of the upstream aorta a heavy slightly curved

Fig. 1. Mode of staged aortic crossclamping and intercostal artery reconnection.

Fig. 2. Neurologic deficits after replacement of the descending aorta. Spinal cord damage occurred in six patients, persisting in three (2.3%). *POD*, Postoperative day.

instrument was applied, whereas for distal clamping the standard device used on the ascending aorta was employed, its handle being out of the way of the surgeon. Subsequently, the aorta was clamped beyond the aneurysm, and large arteries (distal to the eighth intercostal space) were connected to the graft, which then was occluded with a Crafoord clamp, so that these vessels could be perfused before the downstream aortic anastomosis was done. Alternatively, an oblique distal anastomosis was made to preserve such vessels. In only half of the 40 patients undergoing proximal double clamping were intercostal vessels deemed large enough to warrant their reconnection.

The effects of demographic, morphologic, and intraoperative variables on the occurrence of spinal cord damage were examined by linear least squares regression analysis as a first step. This was extended by multivariate as well as logistic stepwise regression analysis as provided by the SPSS program (Berkeley, Calif.).

Results

Four patients died in the hospital, two of cardiac failure and one each of hemorrhage and of pulmonary insufficiency, for a 30-day mortality of 3%. Nine patients (7%) died late, three of aortic rupture, one of an unknown cause, and five of unrelated diseases. The study was terminated at the end of March 1993. The mean follow-up now stands at 36.1 (± 22.7) months with only 3 patients lost to follow-up.

There were no life-threatening postoperative complications except for the aggravation of renal failure traceable to malperfusion in a patient with acute dissection.

Fig. 3. Effect of staged aortic occlusion versus potential spinal cord ischemic period. *Potential cord ischemia* denotes the time of circulatory interruption in the aortic segment subsequently revascularized. *Prox XX*, Proximal aortic double crossclamping; *Dist X*, distal aortic crossclamping; *ICA*, intercostal arteries.

This was corrected by fenestrating the suprarenal membrane via the infrarenal aorta, which was then replaced. Another patient had temporary renal failure without an obvious mechanical cause. The rate of unexplained postoperative renal insufficiency therefore was 0.8%. Cerebral damage was not seen in this series.

Spinal cord complications occurred in six patients (4.5%) and persisted in three, corresponding to a rate of 2.3% (Fig. 2). Paraplegia was prompt or delayed in two patients each, and it persisted in three of the four. One patient died with full paralysis on the third postoperative day; the condition of the other two improved. The remaining patient completely recovered from the paraplegia. In addition, there were two cases of transient late paraparesis. All patients having spinal cord complications had had the aorta replaced beyond the eighth intercostal space, four for aneurysms and two for dissection.

The results of linear regression analysis of variables potentially associated with the development of spinal cord damage after replacement of the descending aorta are displayed in Table III. Overall, there is only a weak linear association among all variables shown and the occurrence of postoperative neurologic symptoms. This conclusion of a weak linear correlation between the

Table IV. Results of descending aortic replacement in several major series

Series	Period	Patients	EM (%)	Cord injury (%)	Renal failure (%)
Simple crossclamping					
DeBakey ⁴	1970-78	117	9.4	2.5	Not given
Crawford ⁶	1962-80	112	9.0	0.9	2.6
Livesay ²⁵	1973-83	263	11.0	5.0	5.0
Distal perfusion					
Reul ¹³ (fem-fem ECC)	1964-74	92	21.0	2.2	2.2
STSS ²⁸ (shunt/bypass)	to 1976	339	13.2	0.9	Not given
Kazui ²⁹ (fem-fem ECC)	1975-86	95*	14.7	2.1	Not given
Verdant ¹¹ (shunt)	1975-91	267	14.6	0.0	0.4
Present (left heart bypass)	1986-92	132	3.0	2.3	1.5

EM, Early mortality; fem-fem ECC, femorofemoral extracorporeal circulation; STSS, Samson Thoracic Surgical Society.

*Fourteen thoracoabdominal replacements included.

Table V. Patients with spinal cord complications

Patients	Age (yr)	Calcul. cord ischemia (min)	Prox XX	ICA reconnect	Onset	Outcome
1	67	10	+	+	delayed	(PL)
2	21	24	+	+	delayed	PP
3	68	55	+	—	prompt	(PL)
4	65	56	+	—	delayed	PL
5	67	78	—	—	prompt	(PL)
6	65	22	—	—	delayed	PP

Prox XX, Proximal aortic double crossclamping; ICA, intercostal artery; PL, paraplegia; (PL), permanent paraplegia; PP, paraparesis; +, yes; —, no.

investigated variables and the development of postoperative spinal cord damage was further supported by a subsequent multivariate regression analysis. Although both models containing the variables *aortic pathology* and *level of distal aortic clamping* ($f = 0.0005$ [analysis of variance]) and all variables ($f = 0.0291$ [analysis of variance]) result in a significant linear correlation to postoperative spinal cord damage, goodness-of-fit parameters indicate a poor linear association ($r^2 = 0.3563$ versus $r^2 = 0.0337$). According to a linear regression model all patients with neurologic damage are outliers. Therefore a linear model with the investigated variables is not appropriate to predict the occurrence of postoperative neurologic damage. The same is true when a logistic regression analysis is applied to detect principally responsible factors for the development of spinal cord damage. In terms of statistical significance, the small sample size of neurologic damage therefore remains problematic.

Discussion

The role of distal circulatory support has remained undetermined ever since 1970 when DeBakey,⁴ Crawford,⁵⁻⁷ and their associates first changed from left heart bypass to the routine use of simple aortic crossclamping. The use of left heart bypass did not seem to affect either early mortality or spinal cord complication rates in that

experience. In the meantime, however, numerous authors presented new and effective methods of passive⁸⁻¹¹ as well as pump-driven bypass¹²⁻¹⁴ and also proved the benefit of these devices in preserving distal organ function in animals.¹⁵⁻¹⁸ The present state of knowledge regarding left heart bypass recently was well summarized by Ergin and associates.¹⁹ Likewise, a multitude of adjuncts were explored with the aim of recognizing and preventing spinal cord damage, as recently reviewed in detail by Kouchoukos.^{20, 21}

A clear-cut investigation comparing distal circulatory support and simple aortic crossclamping unfortunately has never been presented. Studies comparing these modalities appear questionable for one of several reasons, being neither contemporary and randomized nor controlled in terms of underlying disease and extent of aortic replacement. Also, inadequate forms of left heart bypass sometimes were used, which in certain cases added their own complications.²² Thus no significant difference between left heart bypass and aortic crossclamping emanated from the comparative studies of Crawford and Rubio,⁵ Najafi and associates,^{23, 24} Carlson, Karp, and Kouchoukos,²² Livesay and associates,²⁵ and Hamerlinck and coworkers,²⁶ whereas our own results seemed to favor bypass.²⁷ Crawford and colleagues,⁷ in 1988, performed the only contemporary prospective study of this

sort. However, because aortic crossclamping was used whenever bypass was "unavailable, impossible, or inadequate," their study did not fulfill the objective of randomization. The rates of spinal cord complications of the relatively small number of replacements limited to the descending aorta were 9% in the pump group and 10% in the crossclamp group with a lower early mortality in the latter, both figures being higher than those previously reported by the Baylor University group (Table IV).

Because a fully reliable study comparing simple aortic crossclamping and distal perfusion is not available, we thought it useful to compile the results of the more recently published large series of replacements of the descending aorta (Table IV). From such an analysis it appears that early mortality has been in the 10% range or above that figure in all studies except for ours, where 3% of patients died early with only two of 132 patients dying of cardiac causes.

Permanent spinal cord complications after replacement of the descending aorta have ranged from 1% to 5% in the series contained in Table IV, except for the remarkable experience of Verdant and associates¹¹ using a passive shunt, in which cord injury never was observed. Again, there was no discernible difference between the results of simple aortic crossclamping and distal circulatory support. Similarly, the rate of renal failure did not seem to vary with the operative approach. Verdant's and our series showed the lowest rates of such complications (0.4% and 1.5%, respectively), with one of our two patients so affected having had malperfusion of the renal aortic segment from dissection.

These observations, however, need further qualification. It is generally recognized that the period of aortic occlusion, the extent of replacement, and the nature of the underlying disease have considerable bearing on the results of replacement of the descending aorta. The series depicted in Table III differ in these respects. Thus extraordinarily short aortic occlusion periods have been typical for the Baylor University group, which used simple crossclamping, and may not be easily duplicated by others. On the other hand, our series is weighted by more dissections and more extensive replacements. Importantly, the absence of spinal cord complications in the series of Verdant and associates^{10, 11} may, in part, be explained by the small proportion of extensive aortic replacements performed by that group.

Although our results do not prove the superiority of left heart bypass over simple aortic crossclamping, two items favoring the former need to be stressed. First, our rates of early mortality and renal failure have been extremely low and cerebral complications were not observed. These findings, we believe, are directly related to the unloading of the proximal circulation while perfusion of the lower

part of the body was maintained by a highly effective left heart bypass that was easily installed and did not produce any device-related complications. Second, spinal cord injury could not be totally avoided, with neurologic deficits occurring in six patients and persisting in three (2.3%). Importantly, cord complications did not occur in any patient undergoing replacement of the descending aorta down to and including the eighth intercostal space proximal to which side branches of the descending vessel were routinely sacrificed. The experience in this group of patients indicates that the essential vessels, feeding the spinal cord, must have originated below that level and obviously were effectively perfused during the aortic crossclamp period.

In our series, spinal cord injury occurred only in patients undergoing aortic replacement beyond the eighth intercostal space. In 20 such operations, staged aortic clamping was successful in greatly reducing the period of potential spinal cord ischemia. The effect of proximal aortic double clamping with distal intercostal artery connection is seen in Fig. 3. Placement of two proximal clamps alone significantly reduced the time of potential spinal cord ischemia from that required in case the vessel had been occluded both proximally and distally from the beginning. When end-to-side anastomoses between intercostal arteries and the graft were constructed (11 patients), this period was minimized to 18 (± 8) minutes while construction of an oblique distal graft-to-aorta anastomosis (nine patients) reduced cord ischemia to 26 (± 6) minutes.

The calculated ischemic times in the six patients having spinal cord injury are described in Table V. The first two patients in this table are of particular interest because their ischemic time was below that generally considered dangerous.³⁰ Nevertheless, persisting paraplegia of delayed onset developed in one and transient paraparesis of delayed onset in the other. Obviously, vessels feeding the spinal cord must either have been missed or were not reconnected effectively. Alternatively, the distal aortic clamp may have compromised such vessels. The following two patients never received the benefit of intercostal artery reconnection. In these cases proximal aortic double clamping was ineffective inasmuch as no intercostal vessels were found to be worth reconnecting; the ischemic time was close to 1 hour and therefore in the high-risk range. The final two cases are exceptional because no attempt was made to revascularize the spinal cord circulation, the crossclamps being simply applied upstream and downstream to the aneurysm. In one of these patients, crossclamping was necessary because of brisk bleeding from an aortic rupture whose repair necessitated an excessive occlusion period. The patient clearly might have benefited from reconnection of two large distal intercos-

tal vessels. In the other patient undergoing a moderate period of aortic occlusion the intercostal arteries were deemed too small for reconnection.

Further reduction in the prevalence of spinal cord injury remains a challenge. An even more aggressive approach to reconnect any intercostal vessel below the eighth thoracic segment also in emergency cases may be indicated. Like others,^{21, 31, 32} we are now exploring femorofemoral bypass and deep hypothermia in the hope of reducing the remaining risk of spinal cord damage in extensive aneurysm of the descending and thoracoabdominal aorta.

We draw the following conclusions for the use of a highly standardized left heart bypass as used in this series:

1. It is easily installed and does not produce device-specific complications.
2. It is associated with low rates of early mortality and vital organ complications.
3. It prevents spinal cord damage in replacement of the proximal two thirds of the descending aorta.
4. It reduces but does not eliminate such injury in extensive replacement of the descending aorta despite special precautions.

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Discussion

Dr. Nicholas T. Kouchoukos (St. Louis, Mo.). Dr. Borst has presented a large series of patients with descending thoracic aortic disease managed with a standardized left heart bypass technique with impressive results: a low mortality rate, low rates of spinal cord ischemic injury and renal failure, and no brain injury. The results appear equal to or perhaps superior to those with simple aortic clamping or with other techniques for maintaining distal perfusion. The low mortality rate of 3% and the low incidence of spinal cord ischemic injury, however, may be related to the relatively young age of these patients, which averaged 48 years, and the inclusion of 43 patients, approximately a third of the total, whose aneurysms resulted from trauma or from previous patch repair of aortic coarctation.

A particularly important aspect of this study is the careful analysis of the patients who had spinal cord ischemic injury. Spinal cord injury did not develop in any patient whose aortic disease did not extend below the T8 level despite sacrifice of intercostal vessels above this level. Despite use of the double clamping technique with distal perfusion and implantation of intercostal arteries in two patients and in other patients in whom the intercostal arteries were not implanted, and in two patients in whom neither technique could be used, paraplegia or paraparesis occurred. These are obviously the patients who remain at risk for the development of spinal cord injury despite the use of distal perfusion, and other strategies for spinal cord protection must be devised for this group. I have three questions for Dr. Borst.

Do you believe that addition of hypothermia, which has been

clearly shown in the experimental setting to reduce the prevalence of spinal cord ischemic injury, will reduce it in a clinical setting? You indicated that you are now evaluating this and perhaps you could share your early results with us. Would you consider implantation of intercostal arteries above the T8 level if the lower intercostal arteries were occluded or could not be implanted into the graft? Finally, do you believe that there is still a place for simple aortic clamping in the management of aortic disease that involves the thoracic or the thoracoabdominal aorta?

Dr. James W. Pate (Memphis, Tenn.). I caution against the all-too-often extrapolation of conclusions drawn from experience with chronic aneurysms to the problem of acute traumatic rupture of the aorta, in which the prevalence of postrepair ischemic myelopathy probably averages 15% and, in some subsets, may reach 35%. Development of collaterals in chronic aneurysms and the frequency of hypotension and hypoxia in severely traumatized patients probably account for this difference.

Ischemic myelopathy arises from two distinct anatomic mechanisms: first, permanent division of the cord blood supply, such as the ligation of lower intercostal arteries in thoracic aneurysms or of their radicular branches in extensive spinal surgery; second, temporary cord ischemia from proximal aortic crossclamping without any long-term interruption of blood flow. Obviously, when there is permanent interruption of blood flow, the time that the aorta is clamped at operation is of little significance. However, in temporary ischemia, time, primarily, as well as hypoxia, arterial blood pressure, spinal fluid pressure, reperfusion factors, and temperature, become critical determinants of myelopathy.

We have recently reviewed our 90 cases of acute traumatic rupture at the aortic isthmus repaired with femorofemoral partial cardiopulmonary bypass, with full heparinization. Ischemic myelopathy developed in only two cases, associated in both with profound hypoxia from pulmonary injury. Similar experiences, although in much smaller series, have been reported by others, particularly authors from Germany and France.

I would like for the authors to comment on two areas: What technique do they recommend for repair of acute traumatic rupture of the aortic isthmus? What has been their experience with left heart bypass without an oxygenator in patients with severe pulmonary insufficiency?

Dr. Lars G. Svensson (Burlington, Mass.). Dr. Borst, I agree with your conclusions because of some of our research that has shown that atrial-femoral bypass probably is protective with the longer clamp times. Unfortunately, you did not have a comparative group, as you pointed out. Two findings, however, are supportive evidence. First, using hydrogen in the atrial-femoral bypass pump, we have shown that during segmental clamping and resections, hydrogen still reaches the spinal cord until we get down to about the mid-descending aorta; after that, hydrogen does not reach the spinal cord. Second, we recently reviewed the case histories of 832 patients who had descending aortic aneurysm repairs, mostly operated on by Dr. Crawford. The results will be published shortly. In these patients the median aortic crossclamp time was 26 minutes, which has a bearing on the use of atrial-femoral bypass. In the 162 patients operated on since 1988, the survival was 98% and the paraplegia-paresis rate was 5%. We evaluated the effect of atrial-femoral bypass, cardiopulmonary bypass, and the use of neither in these patients. A total of 247 patients had atrial-femoral bypass. In these patients the mortality rate and the incidence of renal failure were signif-

icantly reduced, but on superficial examination there was no influence on the prevalence of paraplegia-paresis. However, on closer examination using logistic regression and the risk of paraplegia or paraparesis according to aortic clamp time, we noticed that the risk of paraplegia remained constant over time with atrial-femoral bypass, whereas with aortic crossclamping alone it markedly increased after 40 minutes; at that point atrial-femoral bypass became significantly protective both in patients with atherosclerosis and in those with aortic dissection.

My questions to you concern the use of moderate hypothermia. We found that if we started warming the patients on atrial-femoral bypass and kept them normothermic during aortic crossclamping, renal failure or paraplegia-paresis became more prevalent. I was wondering how you manage the patient's temperature during atrial-femoral bypass. Second, did you evaluate the influence of aortic crossclamp time on the prevalence of paraplegia-paresis with atrial-femoral bypass?

Dr. Jean E. Bachet (Suresnes, France). In our hospital we always use pulmonary artery-femoral artery bypass. My question focuses on the protection of the cord in patients in whom the aneurysm extends beyond the diaphragm. In those patients, we routinely assess preoperatively the vascularization of the cord, looking for the intercostal arteries, from which originates the artery of Adamkiewicz. Dr. Borst, have you used this technique? If not, how do you decide in the operating room which intercostal artery should be reimplanted and which should be discarded?

Dr. Denton A. Cooley (Houston, Tex.). Over the past several years, I have used a single proximal clamp with an open distal anastomosis as a technique of exsanguination. In a series of more than 55 patients, we have not seen any neurologic damage, regardless of the extent or location of the lesion. I would like to speculate that the pump bypass is actually harmful. Perhaps it does nothing more than increase spinal fluid pressure. We have found that spinal fluid pressure drops precipitously when open distal anastomosis is used. If the pump is used, spinal fluid pressure increases. I believe we would all agree that spinal fluid pressure plays an important role in the development of paraplegia.

Dr. Borst. Dr. Kouchoukos, you asked whether I think hypothermia might be useful. Yes, I certainly do, if only for the extra time it provides to attach any number of intercostal arteries to the graft. Your question concerning whether it is useful to reconnect proximal intercostal arteries is very well put. In atherosclerotic aneurysms, often there are no intercostal arteries below the aneurysm but large ones above. In extensive aortic replacement we probably should anastomose these intercostal arteries to the graft, whereas in limited aneurysm operations we can ignore the proximal arteries.

I would like to connect this problem to the question Dr. Bachet posed concerning the role of important intercostal arteries. We are not using angiography to evaluate the spinal cord feeders. We are impressed with your high rate of conclusive angiograms, Dr. Bachet. However, in your series, there were some cases of paraplegia that should not have occurred according to the angiographic findings. Clinically, the essential vessels are difficult to identify. I learned from Stanley Crawford to pay attention to the left-sided ones, the ones that do not bleed back

much, and the ones that produce dark blood. Those may be the most important vessels. We go by size and sometimes we may be wrong. Again, I think one should attach to the graft as many distal intercostal arteries as one sees in extensive aneurysms of the descending aorta.

Dr. Kouchoukos also asked about the present role we attribute to simple aortic crossclamping. Because of the shortness of time, I did not mention that ours was not a consecutive series. Ten patients during these 6 years underwent simple aortic crossclamping with proximal lesions, for example, a saccular aneurysm that could be repaired by patch insertion; the mean clamp time was 18 minutes. We would not install a left heart bypass for that type of lesion. Otherwise we restrict simple crossclamping to conditions in which distal perfusion seems useless, for example, aneurysms of the infradiaphragmatic aorta.

Dr. Pate, this is not a series dealing with trauma. In traumatic rupture, we clamp the aorta proximally and distally and then peel off the adventitia and the hematoma. In many instances we find a simple tear that can be closed directly in a short time, in which case we would not install bypass. I want to make it clear, however, that it takes only a few minutes to slip a tube into the left atrium and the distal aorta. In complete aortic disruption or pseudocoarctation we would insist on installing left heart bypass.

The question of preoperative pulmonary failure is difficult to answer. We use the 1-second expiratory capacity. That should not be lower than 1.2 L unless the patient has a huge aneurysm, because in many cases he may gain half a liter when the aneurysm is removed.

Dr. Svensson, I can only congratulate you on a mean aortic clamp time of 26 minutes. It proves your experience. On the other hand, that short a time is not feasible for the repair of dissections. Simple crossclamping for only 26 minutes would be compatible with the results that we obtained using left heart bypass. However, in type A dissection necessitating replacement of the descending aorta, the surgeon has to use imagination when reconstructing the terminal arch, and that may take time. I think time is a relative measure and depends on the surgeon's experience and the type and extent of the aneurysm. Regarding temperature, we sometimes direct a lamp on the pump circuit to prevent excessive cooling. Otherwise the temperature drops 3° to 4° C.

The risk of paraplegia depends on ischemic time, obviously, as shown by many groups. In our manuscript we pinpointed the calculated ischemic time for every one of these patients. In the group with intercostal arteries reconnected there were two with very short ischemic times. Thus time is not the only factor; other factors seem to be operating as well.

Dr. Cooley, I am fully aware of your new elegant technique. I think this needs further exploration and comparison with other techniques. It certainly sounds very simple. Your criticism of our method was the possible rise of spinal fluid pressure. Supposedly, spinal fluid pressure increases if the proximal circulation is not unloaded with the aorta clamped. If no pump is used, it may indeed be better to let it drop below normal. We take every measure to avoid proximal hypertension, thereby avoiding a critical rise of spinal fluid pressure.