

Original Article

Descending Aortic Aneurysm Repair Utilizing Moderate Hypothermia (30°C) in Conjunction with Left Heart Bypass

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ABSTRACT

Thoracic and thoracoabdominal aortic aneurysm repair are frequently associated with ischemic paraplegia, renal failure and death. In order to decrease the incidence of ischemic events and allow for a longer aortic cross clamp time, we combined our previous technique of segmental sequential repair, left heart bypass and cerebral spinal fluid drainage in conjunction with moderate hypothermia (30°C). Twenty-seven adult patients underwent elective thoracic (n=6) or thoracoabdominal (n=21) aortic aneurysm repair from January 1992 to September 1993 utilizing this hypothermic technique. A heat exchanger was integrated in the centrifugal left heart bypass circuit to achieve moderate hypothermia (30°C) and regain normothermia (37°C) prior to partial bypass termination. Cannulation for left heart bypass was aorta-femoral artery (n=10) or left atrium-femoral artery (n=17). The surgical technique of segmental sequential repair helps to minimize visceral, kidney and spinal cord ischemia. Among these 27 patients, one developed delayed paraplegia on postoperative day #3 and three suffered postoperative death. The average aortic cross clamp time was 76 ± 7 minutes. Previous studies have demonstrated a significant increase of ischemic morbidity (11-25%) when cross clamp times exceeded 30 minutes. We conclude that the combination of left heart bypass, moderate hypothermia and cerebral spinal fluid drainage allow for a longer duration of aortic cross clamp time and a relatively low incidence of ischemic complications.

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INTRODUCTION

The occurrence of detrimental ischemic events to the spinal cord, kidneys, and viscera continue to plague surgical teams during thoracic and thoracoabdominal aortic aneurysm repair. The nature of the lesion and surgical repair requires clamping of the aorta and cessation of blood flow in the aorta distal to the branch of the left subclavian artery. Interruption of blood flow leads to extended periods of ischemia to the spinal cord, and frequently to paraplegia. In the largest reported series (605 patients), the incidence of paraplegia ranged from 11% - 25% depending on patient age, surgical technique, aortic cross clamp duration, and aneurysm length and location (1). Cerebral spinal fluid (CSF) drainage (2), shunts (3-5), pharmacological intervention (6,7), and hypothermia (8-10) are various adjuncts that have increased spinal cord protection and the prevention of paraplegia.

Although the idea of hypothermic preservation of the spinal cord during aortic repair is not new, it is usually associated with full cardiopulmonary bypass (9,11). Various animal studies have shown spinal cord protection utilizing hypothermia (18°C - 29°C) during aortic occlusion without full cardiopulmonary bypass (12-14). Tabayashi et al showed a decrease in spinal cord injury by utilizing epidural space cooling (14). Through observation and histological examination they observed a two-fold increase in the tolerated cross-clamp time associated with ischemic injury, when dogs were cooled to 29°C.

In our series of 27 patients undergoing elective descending aortic aneurysm repair we utilized moderate hypothermia (30°C) along with our previous technique of staged segmental repair, cerebral spinal fluid drainage, and left heart bypass.

MATERIALS AND METHODS

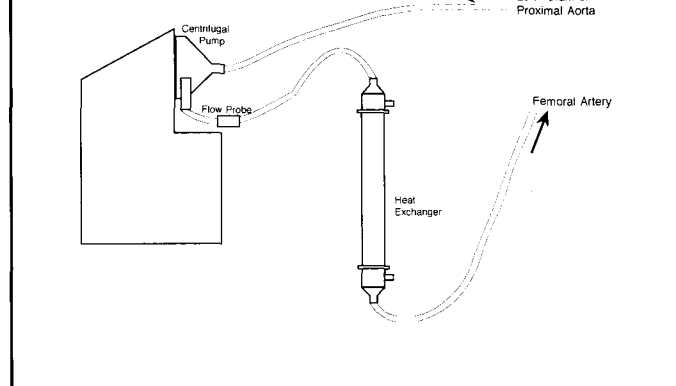
Eighteen male and nine female adult patients undergoing elective thoracic (n=6) or thoracoabdominal (n=21) aortic aneurysm repair from January 1992 to September of 1993 were included in this series. The patients ranged from 32 to 84 years old with a mean age of 67 ± 2 years. Data collection began in the operating room and was continued until discharge (Table 1).

ANESTHETIC TECHNIQUE

Anesthesia was accomplished by administration of fentanyl (10-50 mcg/kg), diazepam (0.1-0.5 mg/kg), pancuronium and isoflurane (0.2-1.0%). A left sided double lumen endotracheal tube was used for single lung ventilation. Proximal and distal aortic perfusion pressures were monitored through catheters placed in the radial artery and femoral artery, respectively. All patients received a pulmonary artery (PA) catheter for hemodynamic monitoring and core temperature monitoring. Tympanic, nasopharyngeal (NP), and bladder temperature probes were also inserted for additional temperature monitoring. Two separate 8.5 French catheters were placed in either the jugular or antecubital veins to administer fluids and blood products during the opera-

Figure 1

Left heart (partial) bypass circuit. Afterload reduction, lower body perfusion, and temperature regulation is achieved with this left heart partial bypass circuit. Arrows indicate blood flow direction.



tion from the Haemonetics Rapid Infuser System^a. The CSF drain consisted of a 3 French silastic subarachnoid drain inserted at the third and fourth lumbar interspace connected to a pressure sensitive 5 cm H₂O drain. Somatosensory evoked potentials were continuously measured by posterior tibial nerve stimulating electrodes.

SURGICAL TECHNIQUE

Surgical exposure was achieved through a left posterolateral thoracoabdominal incision. When necessary, the fifth rib was resected sub-periosteally to expose the proximal descending thoracic aorta. The lower thoracic and abdominal aorta were exposed through the ninth interspace. The left atrium (n=17) or proximal aorta (n=10) was cannulated with a 22 or 24 French Sarns^b arterial cannulae for return to the left heart bypass circuit (Figure 1). The left femoral artery was cannulated in all patients with a 22 French Sarns^b arterial cannulae for inflow from the bypass circuit.

Woven dacron grafts were used for all aortic aneurysm repairs. By moving the cross clamps from the proximal aorta, distally, during the aortic repair, segmental sequential repair minimized ischemic periods of the spinal cord, kidneys, and viscera (Table 2). Ischemic time was reduced by suturing the proximal end of the graft first while mechanically perfusing the intercostal (IA), superior mesenteric (SMA) and renal arteries (RA) (stage I).

During stage II the spinal cord was likely to be ischemic while two pairs of IA were being attached to the graft. At that time the SMA and RA were still being perfused mechanically through the native aorta. By stage III, the clamps were moved distally beyond the intercostals allowing the heart to reperfuse them via

a Haemonetics, Braintree, MA 02184

b Sarns 3M Health Care, Ann Arbor, MI 48103

Table 1

Patient data.

Pt*	Age	Sex	Extent**	Cannulation Site***	Lowest Nasopharyngeal Temperature On Bypass (°C)	Cross Clamp Time (Min)	Cardiac Rhythm During Hypothermia	Pulmonary Artery Temperature ICU Admission (°C)	Disposition
1.	79	M	II	At	28.5	28	Sinus	34.6	Expired
2.	79	F	TH	At	30.2	38	Sinus	33.7	Discharged
3.	56	M	IIIB	Ao	30.6	44	Sinus	34.4	Discharged
4.	72	M	II	Ao	30.1	113	Sinus	34.5	Discharged
5.	72	M	II	Ao	29.2	39	Sinus	34.0	Discharged
6.	84	M	II	At	30.2	85	Atrial Fib.	34.9	Discharged
7.	70	M	I	Ao	29.4	115	Atrial Fib.	33.8	Discharged
8.	61	M	TH	Ao	30.2	75	Sinus	33.6	Discharged
9.	78	F	II	At	30.6	70	Sinus	34.6	Expired
10.	46	F	IIIB	At	30.2	68	Atrial Fib.	33.8	Discharged
11.	58	M	IV	At	30.9	100	Sinus	34.1	Discharged
12.	65	M	II	Ao	30.8	95	Sinus	36.1	Discharged
13.	75	M	II	At	30.7	42	Sinus	35.1	Discharged
14.	65	F	I	At	30.3	70	Sinus	32.6	Discharged
15.	77	M	I	At	31.1	115	Sinus	35.1	Discharged
16.	74	F	TH	Ao	30.0	35	Sinus	35.8	Discharged
17.	72	M	II	At	30.2	51	Sinus	34.6	Discharged
18.	32	F	TH	At	30.3	94	Sinus	35.0	Discharged
19.	82	F	II	At	30.0	83	Sinus/V.T.****	34.1	Discharged
20.	52	M	IIIB	At	30.3	133	Sinus	34.7	Discharged
21.	73	F	III	Ao	30.0	61	Sinus	33.9	Expired
22.	58	M	TH	Ao	30.0	62	Sinus	35.9	Discharged
23.	67	M	TH	At	30.7	35	Atrial Fib.	35.5	Discharged
24.	66	F	I	At	31.2	50	Sinus	35.3	Discharged
25.	48	M	II	At	28.7	152	Sinus	35.0	Discharged
26.	69	M	II	At	30.0	95	Sinus	34.5	Discharged
27.	65	M	II	Ao	30.5	139	Sinus	35.4	Discharged

* Pt = patient number; ** I, II, III, IV = Crawford Groups; TH = entire descending thoracic aorta; IIIB = dissecting aneurysm involving the entire descending thoracic and abdominal aorta; *** At = left atrium; Ao = aorta; **** ventricular tachycardia

the dacron graft. The SMA and RA were sewn to the graft during stage III. Stage IV, the final stage, involved suturing the distal end of the dacron graft to the proximal descending aorta or the two iliacs depending on the extent of the aneurysm.

PERFUSION TECHNIQUE:

The left heart bypass circuit consisted of an Avecor heat-exchanger^c, a BP-80 BioMedicus centrifugal pump^d, and a Durafluo heparin coated 3/8" diameter tubing pack^e (Figure 1). The circuit was primed with approximately 500 ml of Lactated Ringers solution. A Haemonetics Cell Saver 4^f was used for autotransfusion on all cases. Partial bypass was initiated following cannulation and heparinization (100 u/kg). Pump flows were initiated at approximately 50% of the patient's baseline cardiac output. Additional heparin was administered when activated clotting

times fell below 200 seconds, or at the surgeons' discretion. Hypothermia (30°C) was produced via the heat exchanger and a Hemotherm Cooler/Heater^f, upon the initiation of bypass. Bypass flows were adjusted to maintain a mean blood pressure of 70-90 mmHg both proximally and distally during the repair. The mechanical pump flows were gradually reduced throughout the repair as the clamps were moved distally and the heart perfused more of the repaired descending aorta (Table 2). Rewarming was begun after the completion of the renal anastomosis during the

- c Avecor Cardiovascular Inc., Plymouth, MN 55441
d Medtronic BioMedicus, Eden Prairie, MN 55344
e Baxter Health Care Corp., Bentley Division, Irvine, CA 92714
f Cincinnati Sub-Zero, Cincinnati, OH 45241

Table 2
Staged segmental sequential repair for thoracoabdominal aortic aneurysm repair.

	Ischemic	Perfused by Heart	Perfused Mechanically
Stage I		IA, SMA, RA, FA	
Stage II	IA		SMA, RA, FA
Stage III	SMA, RA	IA	FA
Stage IV		IA, SMA, RA	FA

FA = femoral arteries and legs
IA = 2 pair of significant intercostal arteries
RA = renal arteries
SMA = superior mesenteric artery

thoracoabdominal aortic repairs, and after the distal aortic anastomosis during the thoracic aortic repairs. Partial bypass was terminated when the repair was completed and a NP temperature of 36-37°C was achieved.

Patients were monitored until discharge with the primary outcomes being paraplegia, renal failure, and death. Renal failure was defined as the requirement for dialysis. All data are expressed as means ± standard error means.

RESULTS

The mean bypass time was 147 ± 9 minutes with an aortic cross clamp time of 76 ± 7 minutes. The actual visceral ischemic time was approximately one-third of the aortic cross clamp time due to staged segmental surgical technique described earlier. Patients were cooled on bypass to a NP temperature of 30.2°C ± 0.1°C and were warmed to 36-37°C before the termination of bypass. Mean core temperature upon surgical intensive care unit admission was 34.6°C ± 0.2°C measured by the PA catheter.

Mean values for transfusion requirements were 13 ± 1 units of packed red blood cells, 16 ± 2 units of fresh frozen plasma, 7 ± 2 units of platelets, 3.8 ± 0.3 liters of crystalloid solution, and 1.1 ± 0.2 liters of colloid solution. Cell saver blood was included in the total packed red blood cell count (450 ml of cell saver blood was documented as one unit of packed red blood cells).

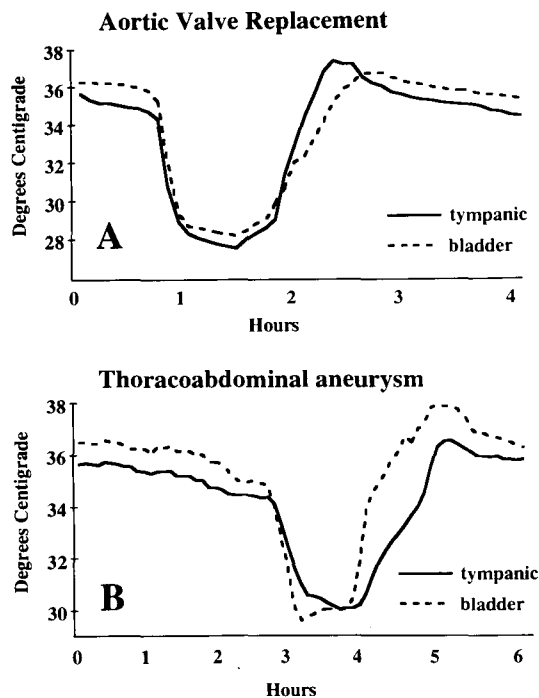
Partial thromboplastin times increased from 26 ± 1 to 31 ± 3 seconds (normal PTT <35 seconds) from preoperative laboratory values to the third postoperative day. Prothrombin times increased from 12 ± 0 to 13 ± 0 seconds (normal PT = 11.5 - 12.5 seconds) during this same interval.

The group's mean creatinine value rose from 1.3 ± 0 to 1.6 ± 0 mg/dl from the preoperative to the postoperative day 3 time period. None of the surviving patients required renal dialysis.

Four patients (15%) experienced new onset of atrial fibrillation during hypothermic left heart bypass. Three of these patients had atrial cannulation and one had aortic cannulation. Patient #19 experienced a 90 second run of wide complex ventricular tachycardia at 30.1°C, which was resolved with

Figure 2:

Upper (tympanic) and lower (urinary bladder) core temperatures are shown at five minute intervals. The top panel (A) is from a patient undergoing aortic valve replacement with full cardiopulmonary bypass from the right atrium to the ascending aorta. In this setting the tympanic temperature responds more rapidly to changes in perfusion temperature. The bottom panel (B) is from a patient undergoing thoracoabdominal aneurysm surgery with partial bypass from the ascending aorta to the left femoral artery. The response to cooling and rewarming is reversed in this setting most likely from the direct effects of perfusion temperature in the femoral and pelvic vessels. (From Frank SM, et al: Moderate hypothermia, with partial bypass and segmental sequential repair for thoracoabdominal aortic aneurysm. J Vasc Surg. 1994;19:687-697, with permission.)



lidocaine.

We observed a 0% incidence of surgical paraplegia (all patients woke up moving all extremities). Patient #27 developed paraplegia beginning on postoperative day 3 and later regained function of both legs after approximately one month of rehabilitation.

Three patients died during the postoperative period. Patient #1 experienced a ruptured proximal aortic aneurysm that

had not been involved in the immediate repair. Patient #9 developed a terminal case of sepsis and pneumonia. The third death (patient #21) was secondary to intestinal ischemia occurring two weeks after the surgical procedure.

DISCUSSION

In an attempt to decrease the incidence of paraplegia during extensive descending aortic aneurysm repair we have implemented moderate hypothermia (30°C) with left heart bypass.

Livesay et al reported an incidence of paraplegia as high as 25% when the aortic clamp time exceeded 60 minutes (15). This series included 260 patients undergoing aortic cross clamping without bypass or shunt. Crawford et al showed that with more extensive aneurysms (Type II) and longer cross clamp times (median 54 minutes) the incidence of paraplegia was as great as 55% (16). These investigators emphasize the need for temporary cord protection during more extensive procedures requiring long cross clamp times. In the Crawford series of 605 patients, they mention a technique of injecting cold lactate solution in the renal arteries for hypothermic renal function preservation in a select group of patients. The outcome was not clinically significant but, he commented that a greater population would be necessary to prove or disprove the advantages of this technique.

Hypothermia has the ability of decreasing metabolic requirements during ischemic periods and therefore decreasing anoxic tissue damage. As early as 1954, hypothermia was employed in an attempt to decrease the ischemic damage during aortic occlusion, primarily death and paraplegia (17). Pontius et al circulated refrigerant through rubberized blankets to decrease the temperature to 24°C-27°C during 60 minutes of aortic occlusion in a dog model. Their hypothermic technique showed no change in overall mortality but a 0% paraplegic rate compared to 65% in the control (normothermic). Several independent animal studies have reported spinal cord preservation while using localized spinal cord cooling (18°C-29.2°C) during aortic occlusion times as long as 120 minutes (12-14). Hollier et al achieved moderate hypothermia by cooling the room to 15°C and not warming inspired gases or intravenous solutions (10). By cooling patients with this technique to 32°C-34°C they reduced the incidence of paraplegia from 6% to 0%.

Our technique of CSF drainage, segmental repair, and moderate hypothermia to 30°C, combined with partial left heart bypass has been effective in minimizing surgical paraplegia (0%) and death (11%). We feel the low incidence of poor outcomes is significant considering the advanced age of our patients (mean = 66 years) and the relatively long total cross clamp time (76 min). Fifty-five percent of the patients in this series were categorized as high risks due to the severity of their aneurysm. Twelve patients had Crawford type II (involving most of the descending thoracic aorta and most or all of the abdominal aorta) and three patients had DeBakey type IIIB (dissecting aneurysm involving the entire descending thoracic and abdominal aorta).

We hoped to increase spinal cord perfusion by maintaining

a CSF pressure < 5 cm H₂O achieved through CSF drainage. Relative spinal cord perfusion pressure is equal to the difference between aortic pressure distal to the clamp and either venous pressure or CSF pressure, whichever is greater.

Although a heat exchanger placed in the circuit during left heart bypass is useful in preventing hypothermia (4,5), we found it beneficial for inducing moderate hypothermia (30°C), and for rewarming after the surgical repair. Figure 2 shows the difference between upper and lower body core temperatures measured during two separate cases. The first is a routine aortic valve replacement utilizing full cardiopulmonary bypass and the second a descending aortic aneurysm repair utilizing left heart bypass (Figure 2) (18). The figure illustrates the relationship between tympanic and bladder temperatures utilizing different infusion sites from the bypass systems (aortic with aortic valve replacement and femoral artery with thoracoabdominal aneurysm). It is important for the perfusionist to recognize the reversed delay of the upper to lower body core temperature during the rewarming phase of the thoracoabdominal aneurysm.

The heparin coated left heart bypass circuit used in this series for body temperature regulation has also allowed us to decrease heparin requirements and achieve proximal unloading and distal circulatory support with oxygenated blood during aortic occlusion as reported by von Segesser et al (3).

Although the design of this series makes it difficult to identify one specific modality of spinal cord protection responsible for our favorable results, we believe the addition of moderate hypothermia is beneficial during complex aortic aneurysm repairs requiring lengthy periods of spinal, renal, and visceral ischemia.

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REFERENCES

1. Crawford ES, Crawford JL, Safi HJ, et al. Thoracoabdominal aortic aneurysms: Preoperative and intraoperative factors determining immediate and long-term results of operations in 605 patients. *J Vasc Surg.* 1986;3:389-404.
2. Bower TC, Murray MJ, Gloviczki P, Yaksh TL, Hollier LH, Pairolero PC. Effects of thoracic aortic occlusion and cerebrospinal fluid drainage on regional spinal cord blood flow in dogs: Correlation with neurologic outcome. *J Vasc Surg.* 1989;9:135-144.
3. von Segesser LK, Killer I, Jenni R, Lutz U, Turina MI. Improved distal circulatory support for repair of descending thoracic aortic aneurysms. *Ann Thorac Surg.* 1993;56:1373-1380.
4. Egener TH, O'Connor B, Leckie RS. Temperature maintenance during prolonged thoracoabdominal aneurysm repair by simple heat exchanger in a centrifugal perfusion

- circuit. *Anesth Analg*. 1993;76:1359-1362.
5. Ireland KW, Follette DM, Iguidbashian J, et al. Use of a heat exchanger to prevent hypothermia during thoracic and thoracoabdominal aneurysm repairs. *Ann Thorac Surg*. 1993;55:534-537.
 6. Robertson CS, Foltz R, Grossman RG, Goodman JC. Protection against experimental ischemic spinal cord injury. *J Neurosurg*. 1986;64:633-642.
 7. Kirshner DL, Kirshner RL, Heggeness LM, DeWeese JA. Spinal cord ischemia: An evaluation of pharmacologic agents in minimizing paraplegia after aortic occlusion. *J Vasc Surg*. 1989;9:305-308.
 8. Crawford ES, Coselli JS, Safi HJ. Partial cardiopulmonary bypass, hypothermic arrest, and posterolateral exposure for thoracic aortic aneurysm operation. *J Thorac Cardiovasc Surg*. 1987;94:824-827.
 9. Szentpetery S, Crisler C, Grinnan GLB. Deep hypothermic arrest and left thoracotomy for repair of difficult thoracic aneurysms. *Ann Thorac Surg*. 1993;55:830-833.
 10. Hollier LH, Money SR, Naslund TC, et al. Risk of spinal cord dysfunction in patients undergoing thoracoabdominal aortic replacement. *Am J Surg*. 1992;164:210-214.
 11. Kouchoukos NT, Wareing TH, Izumoto H, Klausling 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.
 12. Coles JG, Wilson GJ, Sima AF, et al. Intraoperative management of thoracic aortic aneurysm. *J Thorac Cardiovasc Surg*. 1983;85:292-299.
 13. Colon R, Frazier OH, Cooley DA, Mcallister HA. Hypothermic regional perfusion for protection of spinal cord during periods of ischemia. *Ann Thorac Surg*. 1987;43:639-643.
 14. Tabayashi K, Niibori K, Konno H, Mohri H. Protection from postischemic spinal cord injury by perfusion cooling of epidural space. *Ann Thorac Surg*. 1993;56:494-498.
 15. Livesay JJ, Cooley DA, Ventemiglia RA, et al. Surgical experience in descending thoracic aneurysmectomy with and without adjuncts to avoid ischemia. *Ann Thorac Surg*. 1985;39:37-46.
 16. Crawford ES, Svensson LG, Hess KR, et al. A prospective randomized study of cerebrospinal fluid drainage to prevent paraplegia after high-risk surgery on the thoracoabdominal aorta. *J Vasc Surg*. 1991;13:36-46.
 17. Pontius RG, Brockman HL, Hardy EG, Cooley DA, DeBakey ME. The use of hypothermia in the prevention of paraplegia following temporary aortic occlusion: Experimental observations. *Surgery*. 1954;36:33-38.
 18. Frank SM, Parker SD, Rock P, et al. Moderate hypothermia, with partial bypass and segmental sequential repair for thoracoabdominal aortic aneurysm. *J Vasc Surg*. 1994;19:687-697.