doi:10.1510/icvts.2007.163261

INTERACTIVE CARDIOVASCULAR AND THORACIC SURGERY

Interactive CardioVascular and Thoracic Surgery 7 (2008) 146–148

www.icvts.org

Negative results - Vascular thoracic

Spinal cord malperfusion caused by using the segmental clamp technique during descending aortic repair for chronic type B aortic dissection

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Received 16 July 2007; received in revised form 17 September 2007; accepted 18 September 2007

Abstract

Several effective strategies for spinal cord protection have been advocated in descending and thoracoabdominal aortic repairs. The segmental clamp technique has been known as a useful adjunct to shorten the duration of spinal cord ischemia. However, we experienced two cases of spinal cord malperfusion during segmental aortic clamping in descending aortic repair for chronic type B aortic dissection. In these patients, the intercostal arteries including the Adamkiewicz artery had originated from the false lumen. In one patient, spinal cord ischemia was initially detected as decreased motor-evoked potentials. Transesophageal echocardiography simultaneously revealed blood flow congestion in the false lumen during segmental aortic clamping and spinal cord ischemia had developed due to malperfusion of the intercostal arteries branching from the false lumen. Segmental clamping in patients with aortic dissection may not always be useful for shortening the duration of spinal cord ischemia. Transesophageal echocardiography as well as motor-evoked potentials is a useful modality for obtaining the details of intraoperative blood flow in dissecting lumens and malperfusion of the intercostal arteries related to spinal cord injury.

Keywords: Spinal cord malperfusion; Aortic dissection; Segmental clamp technique

1. Introduction

The segmental clamp technique has been reported as a useful adjunct to shorten the duration of spinal cord ischemia in descending and thoracoabdominal aortic repairs [1]. However, we experienced two cases of spinal cord malperfusion during segmental aortic clamping.

1.1. Case 1

An 82-year-old male was diagnosed with chronic type B aortic dissection. Its maximum size was 58 mm in diameter at the level of the proximal descending aorta. Enhanced computed tomography (CT) revealed that the false lumen was not thrombosed and that the primary tear was located at the proximal descending aorta. Magnetic resonance angiography (MRA) revealed that the Adamkiewicz artery had originated from the 11th intercostal artery and the patent intercostal arteries had almost branched from the false lumen. Graft replacement of the entire descending aorta was performed. After establishing a partial cardiopulmonary bypass with a femoro-femoral circuit, the core temperature of the patient was reduced to 32 °C. The proximal aortic clamp was applied immediately distal to the left subclavian artery, and the second aortic clamp was applied at the level of the 6th intercostal space for the proximal aortic anastomosis. During aortic clamping, distal aortic perfusion at a pressure above 60 mmHg was maintained by partial cardiopulmonary bypass. The dissecting aneurysm was incised, and the primary tear with a diameter of 20 mm was detected between the clamped sites. Five minutes after the commencement of the proximal anastomosis, the amplitude of motor-evoked potentials (MEPs) disappeared. The double-barreled distal anastomosis as well as the proximal anastomosis was rapidly completed with the preservation of the 8th intercostal artery. The 3rd and 7th intercostal arteries were additively reattached to the graft because the MEP amplitude was not restored. Further, steroid and naloxone were administrated along with cerebrospinal fluid drainage. During surgery and the three days postoperative period, cerebrospinal fluid pressure was maintained at 10 mmHg or less, while cerebrospinal fluid was drained. However, paraplegia was an eventual complication occurring during the postoperative course.

1.2. Case 2

A 75-year-old female was referred for the treatment of an aneurysm of the descending thoracic aorta. Her CT revealed chronic type B aortic dissection associated with a

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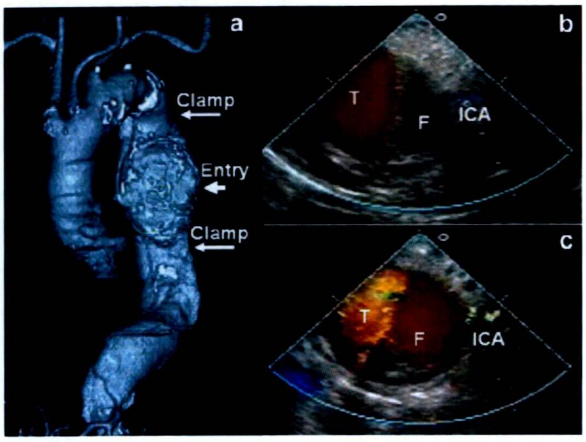

Fig. 1. A three-dimensional computed tomography image (a). The aortic dissection extends from the distal arch to just proximal to the superior mesenteric artery. The primary tear is located at the mid descending aorta. The mid descending aorta exhibits an aneurysmal change, and its maximum diameter is 61 mm. The false lumen is not completely thrombosed. Arrows indicate the segmental aortic clamping and the entry sites. A transesophageal echocardiography image (b, c). It shows blood flow congestion in the false lumen and decreased flow in the intercostal arteries originating from the false lumen during segmental aortic clamping (b). After releasing the segmental clamps, the blood flow in the false lumen and intercostal arteries recovered (c). T; true lumen, F; false lumen, ICA; intercostal artery.

true aneurysm at the mid descending aorta (Fig. 1a). The false lumen was not completely thrombosed, the primary tear existed in the true aneurysm, and the maximum diameter of the descending aorta was 61 mm. Moreover, the small reentry and three lumens were detected around the phrenic level. MRA revealed that the Adamkiewicz artery had originated from the left 10th intercostal artery that had branched from the false lumen. Under partial cardiopulmonary bypass with a core temperature of 32 °C, she underwent replacement of the entire descending aorta. Segmental clamping was put on the proximal and distal sites to the true aneurysm and this clamped segment included the primary tear. During aortic clamping, distal aortic perfusion pressure was maintained at 60–70 mmHg by partial cardiopulmonary bypass. Thereafter, the amplitude of the MEPs diminished, and transesophageal echocardiography (TEE) revealed blood flow congestion in the false lumen in the part distal to the segmental clamp, from where the intercostal arteries had originated. After the segmental clamps were released, the blood flow in the false lumen and intercostal arteries recovered (Fig. 1b,c). The core temperature of the patient was reduced to 20 °C for spinal cord protection, and the entire descending aorta was replaced with the reconstruction of the 10th, 11th, and 12th intercostal arteries under hypothermia circulatory arrest. The postoperative recovery was uneventful, and paraplegia did not occur.

2. Comment

Spinal cord injury is of a major concern in descending or thoracoabdominal aortic repairs. Various strategies for spinal cord protection have been advocated, such as distal perfusion with left heart bypass [2] or partial cardiopulmonary bypasss [3], preoperative identification of the Adamkiewicz artery and intraoperative monitoring of spinal cord ischemia with MEPs [4], reattachment of the intercostal or lumbar arteries [1, 5], cerebrospinal fluid drainage [6], and epidural cooling [7]. The segmental clamp technique has also been reported as a useful method for preventing spinal cord injury [1]. In Case 2 described above, spinal cord ischemia was initially represented as decreased MEPs. Simultaneously, TEE confirmed the malperfusion of the intercostal arteries due to segmental clamping that was related to spinal ischemia. When aorta was unclamped, antegrade and adequate flow from the heart perfused into the false lumen via the large entry (Fig. 2a). However, in our consideration, with proximal aortic clamping, reversal of the aortic flow via the small reentry from the femoral artery during the partial cardiopulmonary bypass might not be adequate for the false lumen perfusion to prevent from spinal cord ischemia (Fig. 2b). In Case 1, malperfusion of the intercostal arteries arising from the false lumen probably occurred because the clamped segment contained the primary tear. In conclusion, the segmental clamp technique in the surgery for aortic dissection may not always be helpful to shorten the duration of spinal cord ischemia during descending and thoracoabdominal aortic repairs. In particular, we should consider cases in which the intercostal arteries, including the Adamkiewicz artery, branch from the false lumen. TEE as well as MEPs is useful for obtaining the details about the blood flow in both the lumens and malperfusion of the intercostal arteries that may cause spinal cord injury.

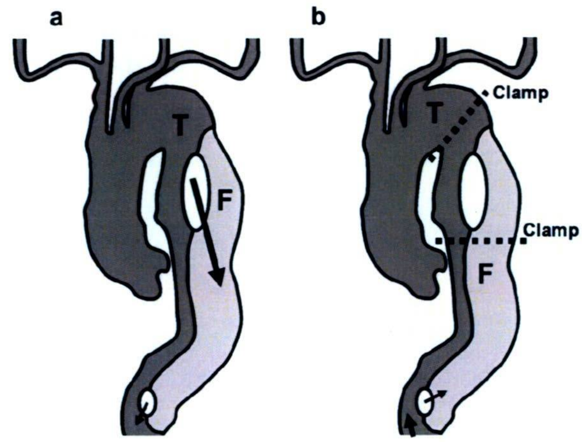

Fig. 2. Flow directions are indicated (arrows), when aorta is unclamped (a). With aortic clamping, the flow directions change as indicated (arrows, b). Dashed lines show the clamping sites. T; true lumen, F; false lumen.

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eComment: Features of the spinal cord collateral pathways in presence of pathology and opportunity of their usage during main stage of surgical procedure

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doi:10.1510/icvts.2007.163261A

We would like to show our appreciation to the authors for this up-to-date publication, and also for the openness and determination to discuss the negative results in a wide press [1].

The problem of paraparesis and paraplegia following surgical procedures on thoracic and thoracoabdominal aorta could not be limited to discussion of methods of intra-operative spinal cord defense (assisted circulation; mild hypothermia; CSF drainage; medical defense). Besides well known anatomic features of spinal cord blood circulations (variety of arteria radicularis magna (Adamkewicz) origin; inconstancy and intermittence of anterior spinal artery, limited number of radiculo-medullaris arteries and terminal branches of anterior spinal artery in diameter and intermittence of its pathway) in such patients we should also be aware of individual features (number of radiculo-medullaris arteries and placement of their origins, opulence of collateral spinal cord circulation pathway, length of aortic lesion; critical aortic zone blood supply features; suspected time of aortic clamping in the zone of 'critical arteries' origin).

We completely share the author's opinion in analysis of spinal stroke development in the patient in the first case history. Adequacy rate of the reasons analysis we were able to note in positive results of operative intervention in the second case history, in which the previous negative experience was considered. But we should note that the method of hypothermic circulatory arrest suggested by the authors has limits and high risk of complication development, particularly in patients with diffuse thoracoabdominal aortic lesion.

We would like to congratulate the authors for the computed solution they found positive results in the second case history. Still it should be repeated that this problem could not be limited to discussion of the intraoperative methods of spinal cord defense. The more detailed analysis of anatomic and individual features of spinal cord blood circulation due to manifested possibilities of the preoperative diagnosis of spinal cord circulation by means of CT and MRT should be performed. Such a detailed analysis allows to evaluate the existence of spinal stroke risks, review features of the spinal cord collateral pathways in presence of pathology and opportunity of their usage during main stage of surgical procedure.

In connection with the above-stated information we are to come back to discussion of anatomic features of spinal cord blood circulation and to bring to your attention the review on the given subject.

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Ann Thorac Surg
2008;85:1784–7

FEATURE ARTICLES

Hemolytic Anemia After Operation for Aortic Dissection Using Teflon Felt Strips

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We report three cases of hemolytic anemia caused by anastomotic stenosis after surgical treatment for aortic dissection in which internal and external Teflon (DuPont, Wilmington, DE) felt strips were used for reinforcement of the aortic stump. To detect this complication, laboratory findings typical of red cell fragmentation syndrome

Accepted for publication Nov 19, 2007.

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Published by Elsevier Inc

0003-4975/08/$34.00
doi:10.1016/j.athoracsur.2007.11.057

as well as appropriate imaging modalities are necessary. As a precaution, it is necessary to be meticulous when stitching the internal felt strip.

(Ann Thorac Surg 2008;85:1784–7)

Operative survival for aortic dissection has recently improved with advances in surgical techniques and perioperative management; however, there are still several potential early and long-term postsurgical complications. Since 1986, we have used internal and external Teflon (DuPont, Wilmington, DE) felt strips for the reinforcement of the aortic stump. Here, we report three cases of hemolytic anemia caused by anastomotic stenosis after surgical treatment for aortic dissection using felt strips for the reinforcement of the aortic stump.

Case Reports

Patient 1

A 48-year-old man underwent emergency ascending and total arch replacement with an elephant trunk technique for acute type A dissection at the National Cardiovascular Center. We reinforced the proximal stump using internal and external felt strips and gelatin-resorcin-formalin glue. The patient's postoperative course was uneventful. One month later, he presented with high-grade fever, anemia, and systolic murmur of Levine 3/6. The hemoglobin level was 7.3 g/dL, the lactate dehydrogenase (LDH) level was 650 IU/L, the reticulocyte percentage was 6.2%, and schistocytes appeared in the peripheral blood.

Two-dimensional computed tomographic (CT) scans failed to demonstrate any abnormalities at the anastomoses. The transesophageal echocardiography (TEE) showed an abnormal projection in the aortic lumen at the proximal anastomosis. Color Doppler echocardiography demonstrated an acceleration in flow, with a peak velocity of 3.4 m/s.

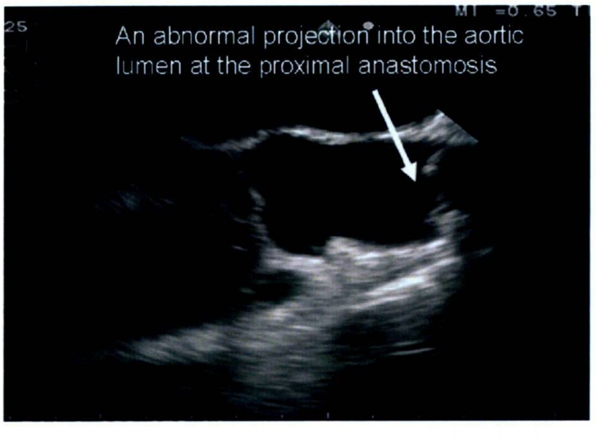

Fig 1. Transesophageal echocardiography image demonstrates an abnormal projection into the aortic lumen at the proximal anastomosis (arrow).

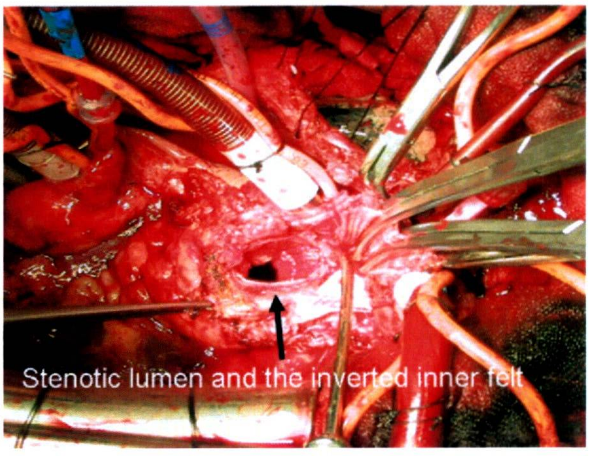

Fig 2. Intraoperative finding shows stenotic aortic lumen (arrow) caused by the circumferentially inverted internal felt strip.

During reoperation, we found the internal felt strip at the proximal anastomosis was turned upward, which reduced the inner diameter to 13 mm. We completely removed the internal felt strip and reanastomosed the previous graft to the ascending aorta. The LDH level decreased to 133 IU/L, and the patient was discharged at postoperative day 21.

According to the pathologic examination, inflammatory cells, including eosinophils, macrophages, and lymphocytes, infiltrated the aorta near the felt strip. During the follow-up for 6 years, laboratory findings have shown no sign of hemolytic anemia, and the latest LDH value was 175 IU/L.

Patient 2

A 60-year-old man underwent emergency ascending and total arch replacement for acute type A dissection at another hospital. Two months later, the hemoglobin level was 9.4 g/dL, the LDH level was 578 IU/L, and schistocytes appeared in the peripheral blood. Two years later, hemoglobin level was 8.7 g/dL, the LDH level was 1535 IU/L, and the reticulocyte percentage was 2.6%. A TEE showed an abnormal projection into the aortic lumen at the proximal anastomosis, which caused an acceleration in the flow, with a peak velocity of 4.2 m/s (Fig 1).

During reoperation, we found that the internal felt strip at the proximal anastomosis was stiff and turned upward, which reduced the inner diameter to 11 mm (Fig 2). We replaced the ascending aorta with a new graft and removed the internal felt strip. The patient's hemolytic anemia was cured, with a reduced LDH level that reached 251 IU/L at discharge. The patient has been followed-up for 1 year, and the LDH level is 167 IU/L now. The latest CT scans showed no sign of anastomotic stenosis.

Patient 3

A 79-year-old woman underwent emergency graft replacement of the descending aorta for acute type B

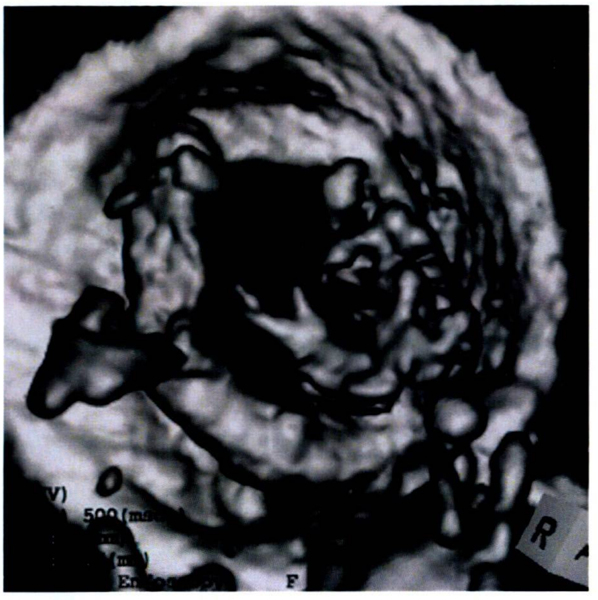

Fig 3. Computed tomographic scan demonstrates stenotic aortic lumen caused by an abnormal projection into the aortic lumen at the proximal anastomosis.

dissection at our hospital. We reinforced the proximal stump using internal and external felt strips and gelatin-resorcin-formalin glue. Two years later, she had dyspnea on exertion. Levels were hemoglobin, 6.6 g/dL, LDH, 1913 IU/L; reticulocyte percentage, 8.4%; and platelet count, 87000/μL. Computed tomography scans (Fig 3) and TEE revealed an abnormal projection in the aortic lumen at the proximal anastomosis, which caused the flow to accelerate. The estimated pressure gradient was 100 mm Hg. Indicator levels in further laboratory examination were fibrinogen, 109 mg/dL; fibrinogen degradation product, 51 μg/mL; thrombin-antithrombin complex, 46 μg/L; and D-dimmer, 23.7 μg/mL.

To reduce the stenosis at the proximal anastomosis, and considering her age and coagulopathy, we performed a palliative axillobilateral femoral bypass. The postoperative echocardiography revealed that the pressure gradient through the stenosis decreased to 30 mm Hg. The LDH level at discharge declined to 459 IU/L, but the bleeding tendency caused by coagulopathy continued. The patient was lost to follow-up after 9 months. The latest LDH level was 455 IU/L.

Comment

Teflon felt has been widely used in cardiovascular operations to reinforce the anastomoses; however, several reports have described complications related to the usage of felt strips. First, it is a foreign body that is subject to infection. Second, it may cause distal embolism. Sogawa and colleagues [1] reported a 60-year-old woman who had multiple cerebral infarctions after an operation for acute type A dissection caused by a mobile thrombus on the internal felt strip. Bedetti and colleagues [2] have also reported a patient presenting with coronary embolism of a felt used in the placement of a Bjork-Shiley aortic valve. Third, like in our patients, the use of felt strips may cause hemolytic anemia. Moreira Neto and colleagues [3] reported 2 patients presenting with hemolytic anemia after mitral valve plasty with the use of Teflon felt strip for posterior annuloplasty. Shingu and colleagues [4] have also reported a similar case to ours, although they did not mention the postoperative follow-up.

In 2 of the 3 patients presented in this report, the proximal part of the internal felt strip was turned upward circumferentially and had stiffened to form stenosis at the anastomotic site. It is unknown whether red cell fragmentation syndrome was caused by the stenosis or by the turbulence caused by the collision of blood with the internal felt strip that was turned upward. In the third patient, the pressure gradient through the stenosis decreased from 100 to 30 mm Hg by means of a palliative axillobilateral femoral bypass, but there still remained a mechanical destruction of red blood cells.

In terms of diagnosis of this complication, the clues are systolic ejection murmur at the anastomotic site, laboratory findings compatible with red cell fragmentation syndrome, including anemia, elevated LDH level and reticulocyte percentage, and schistocytes. Imaging studies are also needed for the diagnosis. In our series, TEE, which clearly demonstrated an abnormal projection in the aortic lumen at the anastomotic site, was more useful than CT scans. The degree of stenosis can be evaluated by a color Doppler technique. In addition, Garcia and colleagues [5] have advocated the efficacy of magnetic resonance angiography for the evaluation of complications in surgically treated aortic dissection.

Laboratory findings in our 3 patients had already shown red cell fragmentation syndrome within a few months after the first operation. We speculated that the syndrome had developed as the internal felt strip became stiffer over time. To prevent this complication, the internal felt strip should be narrow, and stitches should be put in the more proximal portion of the felt strip so that the proximal part will not turn upward.

In summary, hemolytic anemia caused by anastomotic stenosis after surgical treatment for aortic dissection using Teflon felt strips for reinforcement is a rare complication. To detect this complication, laboratory findings typical of red cell fragmentation syndrome as well as appropriate imaging modalities, such as TEE or CT scans, are needed, and necessary precautions should be exercised while stitching the internal felt strip.

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Published by Elsevier Inc

0003-4975/08/$34.00
doi:10.1016/j.athoracsur.2007.11.007

Evolving arch surgery using integrated antegrade selective cerebral perfusion: Impact of axillary artery perfusion

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Objective: The study objective was to determine the impact of integrated antegrade selective cerebral perfusion with right axillary artery perfusion during arch surgery.

Methods: All surgeries were performed through a median sternotomy. Direct cannulation of the right axillary artery in the axilla was used for cardiopulmonary bypass and antegrade selective cerebral perfusion under hypothermia. In addition, ascending aortic or femoral artery perfusion was used. The clinical records of 531 patients (median age, 72 years) between 1999 and 2006 were reviewed, of whom 137 patients (25.8%) underwent emergency surgery. There were 164 dissecting and 367 nondissecting aortic lesions. The surgeries included total arch replacement in 431 patients, partial arch replacement in 9 patients, and hemiarch replacement in 91 patients.

Results: The early mortality rate was 4.0% (2.3% of 30-day mortality and 1.7% of in-hospital mortality). The incidence of permanent neurologic dysfunction was 2.9% in all (3.3% in total arch replacement and 1.0% in hemiarch or partial arch replacement). The incidence of temporary dysfunction was 9.9% in all (10.6% in total arch replacement and 7.0% in hemiarch or partial arch replacement). Multivariate analysis demonstrated that the risk factors for early mortality were chronic renal failure, ruptured nondissecting aneurysm, and prolonged surgery. The midterm survival was 87.2% ± 1.7% at 3 years and 80.5% ± 2.6% at 5 years.

Conclusion: Right axillary artery perfusion is an advantageous adjunct to cardiopulmonary bypass and antegrade selective cerebral perfusion in arch surgery.

ACD

Surgery for various aortic arch pathologies, including acute aortic dissection or ruptured atherosclerotic aneurysms, still features high mortality and morbidity.[1-5] In particular, postoperative cerebral morbidities remain prevalent despite recent great advances in intraoperative brain protection.[1-5] We have routinely used antegrade selective cerebral perfusion (SCP) under right axillary artery (RAxA) perfusion in conjunction with deep or moderate hypothermia.[6] The aim of this retrospective study is to determine the early and midterm outcome of arch surgery using integrated SCP with RAxA perfusion and to analyze relevant risk factors for early mortality and cerebral morbidity.

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Received for publication Oct 17, 2007; revisions received Dec 21, 2007; accepted for publication Feb 19, 2008.

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J Thorac Cardiovasc Surg 2008;136:641-9

0022-5223/$34.00

doi:10.1016/j.jtcvs.2008.02.089

Patients and Methods

Patients

We reviewed the clinical records of 531 patients who underwent various aortic arch surgeries between 1999 and 2006 at the National Cardiovascular Center, Japan (Table 1). The median age was 72 years (19–89 years). Routine clinical history and physical examination, including evaluation of brain, coronary, and peripheral ischemia, were done preoperatively. Particularly in regard to cerebral ischemia, brain computed tomographic scanning and carotid ultrasound were routinely performed. With any positive findings, further magnetic resonance imaging/angiography and Diamox loading cerebral flow scintigraphy followed, together with consultation

Abbreviations and Acronyms

CPB = cardiopulmonary bypass
RAxA = right axillary artery
SCP = selective cerebral perfusion

with neurophysicians or neurosurgeons. In 3 patients with carotid artery stenosis, carotid artery endarterectomy in 1 patient and carotid artery stenting in 2 patients were performed before the arch surgery. For coronary ischemia, dipyridamole loading Thallium perfusion scintigraphy was a routine examination in the early series. Positive signs warranted coronary angiography. Since 2004, coronary angiography has been a routine examination. When coronary artery disease was detected, simultaneous coronary artery bypass grafting was carried out in almost all of the patients, or percutaneous catheter intervention was performed for some limited patients by cardiologists. On an emergency basis, including acute dissection or ruptured nondissecting aneurysm, these complete examinations were not feasible.

TABLE 1. Patient profile (n = 531)

Variable	No	%
Gender		
Male	363	68.4
Female	168	31.6
Aortic pathology		
Dissecting	164	30.9
Nondissecting (+ dissecting)	367 (39)	69.1
Cause		
Atherosclerosis	357	67.2
Dissection	151	28.4
Marfan syndrome	11	2.1
Aortitis	9	1.7
Infection	2	0.4
Urgency		
Elective	394	74.2
Emergency	137	25.8
Acute dissection	108	20.3
Ruptured nondissecting	21	4.0
Others[a]	8	1.5
Reoperation	42	7.9
Cerebrovascular disease		
History of cerebrovascular accident	120	22.6
Carotid disease	54	10.2
Intracranial artery disease	52	9.8
Coexisting disease		
Coronary artery disease	145	27.3
Chronic renal failure	53	10.0
Chronic obstructive pulmonary disease	99	4.0
Smoking	267	50.2
Diabetes mellitus	71	13.4
Lowest core temperature		
Deep hypothermia (20°C–22°C)	232	43.7
Moderate hypothermia (25°C–28°C)	299	56.3

[a]Others: unstable aneurysm (eg, symptomatic nondissecting aneurysm, infected aneurysm).

Surgical Techniques and Brain Protection

Bilateral temporal arterial lines were placed to monitor cerebral perfusion pressure. All aneurysms were approached through a median sternotomy.

1. Cardiopulmonary bypass (CPB) establishment with RAxA perfusion: RAxA perfusion was routinely used to establish CPB and SCP.[6] The RAxA was exposed quickly through a 5 to 7-cm skin incision in the axilla (Figure 1). After full heparinization, a 10F to 16F straight thin-walled cannula (Medtronic, Minneapolis, Minn) was inserted into the RAxA, depending on the artery size. Empirically, even a 12F cannula allowed a flow of up to 1.5 L/min. In addition, the ascending aorta or femoral artery was cannulated for a total CPB flow of 1 to 2 L/min through the RAxA and 2.5 to 3.5 L/min via the ascending aorta or femoral artery. In the early series, femoral perfusion was routinely chosen. However, from 2003 to 2006, ascending aortic perfusion was predominantly used, although femoral perfusion was still an alternative for patients with a severely atherosclerotic ascending aorta. With severely atheromatous changes in the descending aorta, femoral perfusion was used to flush out debris that dislodged during the distal anastomosis. Bicaval venous drainage with left ventricular venting was performed. For patients with acute dissection, with standard femoral cannulation, RAxA perfusion was used to avoid the collapse of the true channel caused by retrograde femoral perfusion. In 4 patients whose left subclavian or innominate artery was occluded, left axillary perfusion was also used. In addition to RAxA perfusion, the ascending aorta was used in 141 patients, the ascending aorta and femoral artery were used in 57 patients, and the femoral artery was used in 333 patients.
2. Brain protection using SCP with RAxA perfusion (Figure 2, *A*): Alpha-stat management was used during hypothermia. We routinely used SCP combined with RAxA perfusion for brain protection.[6,7] Immediately after the induction of hypothermic circulatory arrest by discontinuation of the ascending or femoral perfusion, SCP with the constant flow through RAxA perfusion was easily commenced by clamping the innominate artery. The left common carotid and left subclavian arteries were also clamped. By means of this simple maneuver, sufficient perfusion of the right hemisphere with partial circulation of the left hemisphere through collateral vessels was quickly established. The ascending aorta was usually clamped, and cardioplegic solution was antegradely or retrogradely infused to attain cardiac arrest.

In the early series, the lowest bladder and nasopharyngeal temperatures were 20°C to 22°C. Both temperatures have been increased in stages up to the current lowest temperature of 28°C, except for high-risk patients with carotid or intracranial artery disease, or for patients with renal failure. For these patients, deep hypothermia was still used. The lowest temperature was 20°C in 151 patients, 22°C in 81 patients, 25°C in 141 patients, and 28°C in 158 patients.

3. Total arch replacement (Figure 2, *B*): The ascending aorta and transverse arch were opened, and a 12F or 14F SCP

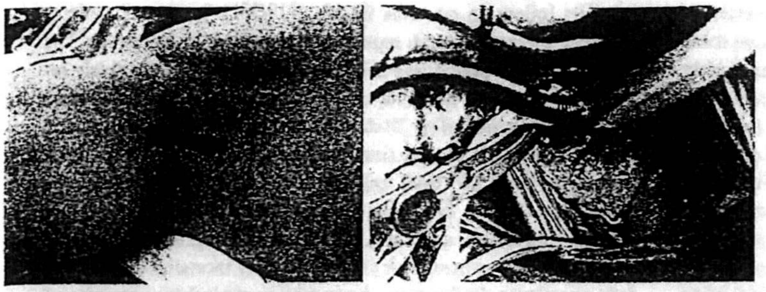

Figure 1. RAxA perfusion in the axilla. The distal part of the RAxA was exposed through a 5- to 7-cm skin incision in the axilla. A 10F to 16F straight thin-walled cannula was inserted depending on the size of the artery.

balloon-tipped cannula was inserted from within the aorta into the left common carotid artery. Between 1999 and 2002, SCP was instituted by RAxA and left common carotid artery perfusion, with the left subclavian artery clamped, at 20°C to 22°C. During SCP, the pressures of the bilateral superficial temporal artery or the balloon tips were maintained in the range of 30 to 50 mm Hg. Subsequently, SCP flows of 10 to 12 mL/kg/min were generated by a single roller pump separate from the systemic circulation. In 2003, left subclavian perfusion using another balloon-tip cannula was added, and the lowest temperature has been gradually increased from 25°C to 28°C. At 28°C, the SCP flow was also increased up to approximately 15 mL/kg/min to maintain perfusion pressure between 50 and 70 mm Hg. Through the aneurysm, the descending aorta distal to the aneurysm was transected from the inside using an electrical cautery, avoiding nerve and lung injury. Open distal anastomosis was performed during hypothermic circulatory arrest of the lower half body. "Stepwise distal anastomosis," with a short-length tube graft interposition, was frequently used for an easy and secure anastomosis. The details have been described.[6,7] An invaginated tube graft of 7 to 12 cm in length, composed of the multibranched Dacron graft, was inserted into the descending aorta. The proximal end was anastomosed to the descending aorta. The distal end of the inserted graft was then extracted proximally. The multibranched arch graft was connected to this interposed graft. Systemic circulation was resumed using a branch graft. The left subclavian artery was reconstructed, and the patient was rewarmed to 30°C to 32°C with an SCP flow of 1 to 1.5 L/min and a branch graft flow of 3 to 4 L/min. Then, the proximal aortic anastomosis above the sinotubular junction was made. Coronary circulation was initiated by unclamping. The other arch vessels were reconstructed, and the patient was fully rewarmed with a slightly higher total flow of 4 to 6 L/min. In patients with a risk of cerebral morbidity because of carotid or intracranial artery lesions, arch-vessel reconstruction was preferentially performed before the proximal aortic anastomosis. For 26 patients with extensive aneurysm involving the arch, 2-stage surgery was performed with stage I total arch replacement with an elephant trunk procedure. It was followed by stage II descending aortic replacement in 12 patients and by endoluminal stent grafting in 6 older patients with respiratory dysfunction.

4. Hemiarch or partial arch replacement: The proximal arch was beveled proximal to the innominate artery. SCP balloon-tipped cannulae were inserted from within the aorta into the left common carotid artery with or without the left subclavian artery perfusion. A 22 to 26-mm single-branched Dacron graft was anastomosed with an open aortic technique. Distal perfusion was commenced using a branch-graft, and the patient was rewarmed. Then, the proximal anastomosis was made. In case of partial arch replacement, the innominate artery was reconstructed using an 8 to 10-mm branch graft.
5. Acute type A dissection: Hemiarch repair was the procedure principally used for our tear-oriented surgery. The false channel was closed with inside-outside Teflon felt strips. Extended total arch replacement was attempted in the following settings: 1) tear in the arch or proximal descending aorta, 2) Marfan syndrome, 3) arch aneurysm or dilatation, 4) atheromatous arch, 5) massive arch dissection, and 6) relatively

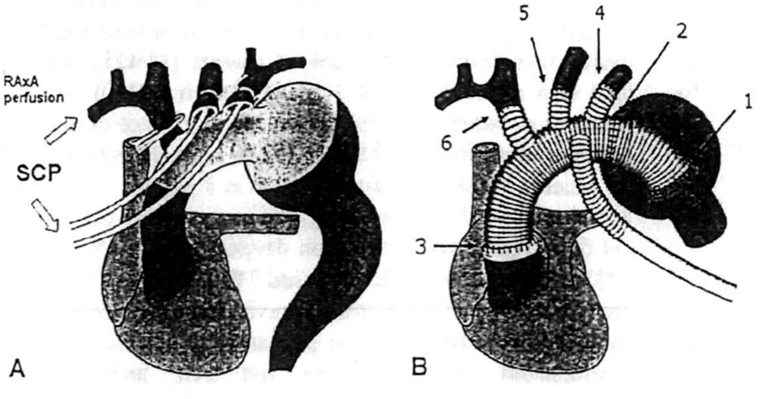

Figure 2. Total arch replacement using SCP with RAxA perfusion. A, Antegrade SCP with the perfusion through the RAxA, left common carotid artery, and left subclavian artery. B, Total arch replacement with a stepwise distal anastomosis using a multibranched Dacron graft. The numbers 1 to 6 show the turn of anastomosis. *RAxA*, Right axillary artery; *SCP*, selective cerebral perfusion.

young age (<70 years). The descending aorta was transected distal to the left subclavian artery. A modified elephant trunk technique was used for a secure anastomosis and early thrombosed closure of the distal false channel. A prosthetic graft of 16 to 24 mm in diameter was inserted into the distal true channel. The proximal end was attached to the descending aorta with the reinforcement with an external Teflon felt strip. Another multibranched arch graft was anastomosed to this aortic stump. Antegrade distal aortic perfusion was commenced with a branch graft. The left subclavian artery was reconstructed. At the proximal site, the ascending aorta was transected just around the sinotubular junction. The proximal false channel was closed with internal and external Teflon felt strips. In most, the proximal false channel was fixed using Gelatin-Resorcin-Formal glue (Cardial, Sainte-Etienne, France). The main graft was anastomosed to this end. Finally, the other arch vessels were reconstructed using branch grafts under SCP.

Arch repairs included total arch replacement in 431 patients, partial arch in 9 patients, and hemiarch in 91 patients. Concomitantly, coronary artery bypass (n = 95), composite root repair (n = 21), valve-sparing surgery (n = 6), sinotubular junction plication (n = 27), aortic valve replacement (n = 29), mitral valve repair (n = 3)/replacement (n = 3), tricuspid annuloplasty (n = 6), atrial septal defect closure (n = 1), arch-vessel reconstruction for the anomaly (n = 9), and peripheral bypass (n = 2) were performed. At the end, the cannula was removed from the RAxA, and the cannulation site was closed using a 6-0 polypropylene suture.

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Definition of Neurologic Deficits and Other Variables

Permanent neurologic dysfunction was defined as the presence of permanent deficits persisting at discharge. Transient dysfunction was defined as the occurrence of confusion, agitation, obtundation, or delay of full awakening. It was difficult to distinguish between transient neurologic dysfunction and frequently occurring delirium in the elderly. When delirium was severe, it was also included in transient neurologic dysfunction. Cerebrovascular event included old cerebral infarction (including asymptomatic one) in 116 patients and cerebral hemorrhage in 4 patients. Carotid artery disease was defined as the presence of more than 50% stenosis or multiple plaques on ultrasound examination. Intracranial artery disease was defined as more than 75% stenosis of intracranial vessels on magnetic resonance angiography or as hypoperfusion on Diamox loading cerebral flow scintigraphy. Chronic renal failure was defined as a serum creatinine level of more than 1.5 mg/dL or the requirement of hemodialysis. Chronic obstructive pulmonary disease was defined as forced expiratory volume in 1 second less than 70% of the normal value. Reoperation was defined as re-sternotomy surgery after cardiac or aortic root to arch surgery. The patients who had previously undergone proximal descending replacement through left thoracotomy were also included among the reoperation cases, because it was sometimes troublesome to make the distal anastomosis to the prosthetic graft of the previous proximal descending aortic replacement.

Data Collection and Statistical Analysis

All of the surgeries were identified from the Registry of Cardiovascular Surgery in the National Cardiovascular Center. The data in the registry were approved for use by the institutional ethical committee. The follow-up rate was 99.6% (529/531), because 2 patients who underwent total arch replacement were lost to follow-up. The mean follow-up period was 2.7 ± 1.8 years. We retrospectively reviewed the overall outcome and investigated the risk factors for early mortality, including 30-day and in-hospital mortality, and permanent neurologic dysfunction. Statistical analysis was carried out using StatView 5.0 (SAS Institute, Cary, NC) software. Values were expressed as the mean ± standard deviation or medians (range). Univariate and multivariate logistic regression analyses were used to investigate risk factors for early mortality and permanent neurologic dysfunction. According to clinical importance and the result of univariate analysis, advanced age, ruptured nondissecting aneurysm, coronary artery disease, chronic renal failure, diabetic mellitus, concomitant surgery, prolonged surgery, and deep hypothermia (20°C–22°C) were involved in the following multivariate analysis for early mortality. For permanent neurologic dysfunction, multivariate analysis was not performed because of a low event rate and strong association of atheromatous ascending aorta and arch. Kaplan–Meier estimate was used to calculate the survival.

Results

The hypothermic circulatory arrest for open distal anastomosis, myocardial ischemia, SCP, CPB, and surgery lasted 57.0 ± 19.9 minutes, 129.7 ± 45.8 minutes, 134.6 ± 62.3 minutes, 233.3 ± 106.3 minutes, and 483.3 ± 189.7 minutes, respectively. The early mortality rate was 4.0% (21/531). Within 30 days, 12 patients (2.3%) died: acute dissection in 3 patients (2.7%), chronic dissection in 1 patient (1.9%), nonruptured nondissecting aneurysm in 6 patients (1.8%), and ruptured nondissecting in 2 patients (2.7%). The in-hospital mortality was 1.7% (9/519): acute dissection in 1 patient (0.9%) and nonruptured nondissecting aneurysm in 8 patients (2.4%). Table 2 shows the result of univariate and multivariate analyses of risk factors for early mortality. The multivariate analysis demonstrated that the risk factors for early mortality were chronic renal failure, ruptured nondissecting aneurysm, and prolonged surgery.

The presence of cerebral complications could not be assessed in 8 patients who died immediately after the surgery without awakening. The incidence of permanent neurologic dysfunction was 2.9% (15/523): acute dissection in 4 patients (3.6%), chronic dissection in 1 patient (1.9%), nonruptured nondissecting in 7 patients (2.1%), and ruptured nondissecting in 3 patients (12.0%). Permanent neurologic dysfunction developed in 3.3% of patients (14/423) with total arch replacement and 1.0% of patients (1/100) with hemiarch or partial arch replacement. The incidence of temporary dysfunction was 9.9% (52/523): acute dissection in 10 patients (9.1%), chronic dissection in 3 patients (5.7%), and nonruptured nondissecting aneurysm in 39 patients (11.6%). Temporary dysfunction developed in 10.6% (45/423) with total arch replacement and 7% (7/100) with hemiarch or partial arch replacement. Univariate analysis demonstrated that the risk factors for permanent dysfunction were atheromatous ascending aorta and arch, arch-vessel

TABLE 2. Risk factors for early mortality determined by univariate and multivariate analyses

Variable	Univariate		Multivariate	
	P	OR (95% CI)	*P*	OR (95% CI)
Age (y)	.090	1.05 (0.99–1.11)	.096	1.06 (0.99–1.13)
Male gender	.434	1.50 (0.54–4.17)		
Dissecting aneurysm	.476	0.69 (0.25–1.92)		
Emergency surgery	.767	1.16 (0.44–3.05)		
Acute dissection	.881	0.92 (0.30–2.79)		
Ruptured nondissecting aneurysm	.023	4.56 (1.23–16.89)	.049	4.70 (1.00–22.03)
Acute dissection with critical malperfusion	.052	4.78 (0.99–23.07)		
Reoperation	.065	2.92 (0.94–9.12)		
Marfan syndrome	.393	2.50 (0.31–20.49)		
Chronic renal failure	.001	5.04 (1.94–13.13)	.007	4.82 (1.54–15.05)
Chronic obstructive pulmonary disease	.085	2.27 (0.89–5.79)		
Coronary artery disease	.001	4.65 (1.89–11.48)	.170	2.16 (0.72–6.46)
Diabetes mellitus	.010	3.48 (1.36–8.96)	.314	1.77 (0.58–5.41)
Concomitant surgery	.009	3.26 (1.35–7.90)	.843	1.12 (0.36–3.49)
Surgery (h)	<.0001	1.24 (1.14–1.36)	<.0001	1.31 (1.16–1.48)
Deep hypothermia (20°C–22°C)	.013	3.38 (1.29–8.84)	.228	1.93 (0.66–5.65)

OR, Odds ratio; *CI,* confidence interval.

malperfusion caused by acute dissection, chronic renal failure, and female gender (Table 3).

After surgery, various complications developed: bleeding in 7.5% (n = 40), low cardiac output in 6.2% (33), respiratory failure requiring tracheotomy or prolonged ventilation for 3 days in 14.1% (75), acute renal failure requiring hemodialysis in 2.3% (12), hepatic failure in 0.8% (4), gastrointestinal events in 3.0% (16), sepsis in 1.3% (7), mediastinitis in 1.3% (7), and disseminated intravascular coagulation in 0.9% (5). The median intensive care unit and hospital stays were 3 and 27 days, respectively. There were some complications related to the use of RAxA; motor palsy in 2 patients, muscle weakness in 8 patients, and numbness in 12 patients. Another 5 patients required repair of the RAxA for stenosis or thrombosed occlusion. However, except for 2 patients, most of these problems resolved. The midterm survival was 87.2% ± 1.7% at 3 years and 80.5% ± 2.6% at 5 years.

Discussion

Despite advances in brain protection, arch surgery continues to be a challenge because of the high mortality and morbidity, including neurologic sequelae.[1-5] To improve the outcome, we established the current SCP technique in 1999, which is physiologic and has a longer cerebral safety margin. This allows unhurried and secure arch surgery compared with the earlier retrograde cerebral perfusion.[6-8] Subsequently, the outcome was satisfactory with a low early mortality of 4.0% and low incidence of permanent or temporary neurologic dysfunction of 2.9% or 9.9%, even though high-risk emergency surgeries were involved.

However, during SCP, the risk of cerebral embolism associated with arch-vessel cannulation remains and may even increase the incidence of stroke.[4,5] In arch surgery, other embolic phenomena may occur as the result of 1) cannulation or clamping of the diseased aorta and arteries, 2) a high-velocity jet caused by CPB via the ascending aorta across the aneurysm, 3) retrograde femoral perfusion through the diseased aorta, 4) external manipulation of the aorta and arch vessels, or 5) dislodgement of atheroma or clot inside the aorta.[9] To overcome these problems, we used an alternative perfusion pathway using the distal segment of RAxA for both CPB and SCP.[6-8] This part of the RAxA, which has less atherosclerosis or extension of aortic dissection, can easily be exposed and cannulated. In regard to AxA perfusion, there have been numerous reports on its routine or alternative use for CPB in cardiac surgery or for CPB and SCP in aortic surgery.[9-20] These reports also advocated some advantages: less likelihood of stroke from embolic material, less likelihood of malperfusion with aortic dissection, less disruption of atheroma or calcified plaques, and the ability of administration of SCP.[20] However, the cannulation site and techniques differ from ours, and the number of patients evaluated was smaller. In all, a proximal segment of the AxA below the clavicle (infraclavicular segment) is used, where larger-sized cannulae of 20F to 26F in size are accepted. However, the exposure was more time-consuming.[9,11,13-15,18,20] For an emergency operation, our technique is more advantageous. For example, in acute dissection, 3 surgeons can start 3 different procedures without any interruptions, namely, RAxA exposure in the axilla, median sternotomy, and femoral artery exposure. In some, aortic dissection may extend down to the infraclavicular AxA,[20] although it is rarely encountered on the distal segment. Furthermore, there is a potential risk of the right common carotid artery occlusion by an overly deep

TABLE 3. Risk factors for permanent neurologic dysfunction determined by univariate analysis

Variable	P	OR	95% CI
Age (y)	.082	1.06	0.99–1.14
Female gender	.007	4.51	1.52–13.42
Nondissecting aneurysm	.854	0.90	0.30–2.69
Emergency surgery	.070	2.60	0.92–7.31
Acute dissection	.507	1.48	0.46–4.76
Ruptured nondissecting aneurysm	.062	4.43	0.93–21.3
Arch-vessel malperfusion caused by acute dissection	.003	12.87	2.37–69.94
Atheromatous ascending aortic arch	<.0001	104.72	29.40–372.90
Chronic renal failure	.039	3.49	1.07–11.37
History of cerebrovascular event	.436	0.55	0.12–2.48
Carotid artery disease	.678	1.38	0.30–6.28
Intracranial artery disease	.188	2.40	0.65–8.79
Total arch replacement	.241	3.39	0.44–26.1
SCP (h)	.144	1.46	0.88–2.43
Open distal anastomosis with HCA (h)	.261	2.23	0.55–9.08
Deep hypothermia (20°C–22°C)	.191	2.01	0.71–5.74

OR, Odds ratio; *CI*, confidence interval; *SCP*, selective cerebral perfusion; *HCA*, hypothermic circulatory arrest.

cannula insertion.[13] In regard to the AxA perfusion technique, some authors performed direct cannulation of a straight[9,11,14,15,18,20] or right-angle cannula[13] for easy and quick CPB establishment, whereas others preferred a side-graft anastomotic technique to obtain sufficient CPB flow.[10,12,14-16,20] For small patients, the side-graft technique is more advantageous, and it has been widely used because of less neurovascular complications.[9,10,14,16] However, the side-graft procedure is more time-consuming and technically demanding. Bleeding from the anastomosis during the perfusion can become a nuisance. We therefore prefer simple and easy direct cannulation into the distal RAxA. It is the shortcomings of our technique that the distal RAxA is too small to accept larger-size cannulae. Therefore, additional (double) cannulation via the femoral artery or the ascending aorta is necessary for CPB. In the early series, femoral perfusion was routinely used.[6] In this combination, the downstream flow via the RAxA can compete with the retrograde femoral perfusion flow in the descending aorta, which may prevent the potential risk of cerebral emboli.[9,10,20] In acute dissection, this RAxA perfusion can prevent the collapse of the true channel in the proximal site.[17] On the other hand, retrograde femoral perfusion not only allows the flushing out of debris in the descending aorta but also serves to check for bleeding from the key distal anastomosis. Moreover, perfusion of the spinal cord and visceral organs is possible through balloon occlusion of the descending aorta.

In the later series, in the absence of atherosclerotic change, ascending aorta cannulation yielding antegrade systemic CPB flow became our first choice.[7,8] The proximal to mid-ascending aorta, away from the aneurysm, is generally safe. This strategy allowed us to avoid some drawbacks of femoral perfusion, including proximal emboli or retrograde dissection. Even in addition to the ascending perfusion, we still use the RAxA perfusion, because the switch from CPB perfusion to SCP is easy with no discontinuity by clamping the innominate artery, although in the standard SCP there remains by necessity a short period of circulatory arrest during insertion of the cannulae. With our technique, cannulation-induced emboli of the innominate artery or its new dissection can be avoided. Malposition of the SCP catheter in the innominate artery is not a rare event.[21] With the innominate artery cannulated, the presence of dissection or severe atherosclerotic changes would make the anastomosis more difficult. Under the reliable SCP with RAxA perfusion, we have therefore been able to increase the bladder and nasopharyngeal temperature to 28°C. If the ascending aorta is atherosclerotic, however, the femoral artery is still chosen for CPB. Femoral perfusion is added for patients presenting some difficulties with the distal anastomosis for severe atheromatous changes: to the combination of the RAxA and ascending perfusion, to perfuse the spinal cord and the visceral organs, or to flush out atheromatous debris.

In another setting, 5 patients required re-sternotomy surgery after the previous ascending aorta or arch surgery. There was a risk of aneurysmal rupture or graft injury at the re-sternotomy, even under femoro-femoral partial CPB, because the graft or enlarged aneurysm was attached to the sternum. We initiated CPB under RAxA and femoral perfusion and cooled them down. The sternum was reopened, immediately after the induction of deep hypothermia circulatory arrest, and brain protection was smoothly attained through SCP, which was easily established by just clamping the arch vessels under the RAxA perfusion.

The multivariate analysis demonstrated that chronic renal failure, ruptured nondissecting aneurysm, and prolonged surgery were the independent determinants for early mortality. All of these have been pointed out as risk factors. Svensson and colleagues[20] and Kazui and colleagues[22] also reported chronic renal failure as a risk factor for mortality. In general, patients with chronic renal failure tend to have severe atherosclerosis or calcification of the aorta and arteries.[23] Some of these patients also have diabetic nephropathy. Sepsis or mediastinitis tends to develop in patients during postoperative hemodialysis. Surgery then involves a potentially higher risk. In regard to permanent neurologic dysfunction, arch-vessel malperfusion with acute dissection and rich atheroma in the ascending aorta and arch were significant independent predictors, associated with female gender and chronic renal failure. Statistically, a history of cerebrovascular event and carotid/intracranial artery disease were not risk factors. This

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finding was expected. The majority of permanent neurologic dysfunctions are considered to be caused by an embolism resulting from atheroma or clot,[2-4] not cerebral hypoperfusion. Furthermore, in the cases with preoperative cerebral hypoperfusion caused by carotid or intracranial artery lesions, we modified our strategy to include a higher CPB perfusion pressure (>60 mm Hg), deeper hypothemia (20°C–22°C), and higher SCP flow rates by 20%. These refinements seemed to yield good outcomes empirically, avoiding critical cerebral hypoperfusion. On the other hand, adequate brain protection is still controversial for patients with severe atheromatous lesions in the arch and arch vessels. In our practice, 11 high-risk patients with an atheromatous aorta had permanent neurologic dysfunction, despite the SCP with RAxA perfusion aiming at avoiding stroke. SCP requiring arch-vessel cannulation may result in cerebral embolism.[4,5] Our strategy based on RAxA perfusion allows us to avoid cannulation, at least, of the innominate artery, which sometimes exhibits atheromatous changes or dissection. The left common carotid artery is less atheromatous in most, making its cannulation safe. The left subclavian artery often presents the most severe atheromatous changes, and cannulation is sometimes dangerous. Its cannulation must be carefully performed, removing some atheromatous parts, or patients should be cooled down to less than 22°C leaving the left subclavian artery uncannulated. In any case, even under RAxA perfusion, it is difficult to completely avoid cerebral emboli, particularly for high-risk patients with rich atheroma in the ascending aorta and arch, including the arch vessels. It is speculated that under RAxA perfusion, its high-velocity jet streaming retrogradely into the innominate artery might cause dislodgement of atheroma in the minor curvature of the arch, resulting in distal embolism. With a single inflow site via the AxA for CPB, as described in the other reports,[9-19] a higher-velocity jet is produced, which might adversely increase the risk of distal emboli. There is no way to completely avoid such cerebral emboli in patients with rich atheroma in the aorta, although its incidence would be reduced by our techniques. Our recommendation is to assess the ascending aorta and arch for atherosclerotic changes by epiaortic ultrasound imaging. In addition, arterial cannulation should be carefully performed with minimum manipulation of the aorta and arch vessels.

Cannulation into the distal RAxA was achieved in the overwhelming majority of patients (97.4%). However, during the same interval, attempted RAxA cannulation was abandoned in 14 patients (2.6%), who were excluded from this study. The cannulation was difficult because of the small size of the artery or the presence of stenosis. Thus, in these patients, the inflow site for CPB was shifted to the ascending aorta or femoral artery. For SCP, the innominate artery was also cannulated.[4,5] In this subset, 1 patient (7.1%) with an arch rupture associated with acute dissection died of low cardiac output, and 2 patients (14.3%) had permanent neurologic dysfunction. There were some local complications related to the RAxA perfusion, such as vascular and nerve injuries in 5.6% of patients. Two patients also had left hand weakness. We think that some nerve injuries might be due to nerve compression caused by wide opening of the sternum for the distal anastomosis. At any rate, the incidence of complications was higher than in other reports describing the use of an infraclavicular AxA.[9-20] The key to avoid these complications is gentle dissection and manipulation, while avoiding unnecessary traction of the brachial plexus. The RAxA is sometimes fragile and traumatized in younger patients and patients with aortic dissection or Marfan syndrome. For these patients, exposure and cannulation should be done carefully.

There are some limitations in this study. The logistic regression analyses were limited by the small number of events. This is a retrospective study in a single patient group who underwent aortic arch surgery with SCP through RAxA perfusion. To demonstrate the absolute (not theoretic) value of the RAxA perfusion, a multicenter prospective study is necessary.

Conclusions

RAxA perfusion in the axilla is an advantageous adjunct for CPB and SCP in arch surgery.

The authors thank Akiko Kada, biostatistician, for professional supervision on the statistical analysis.

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Discussion

Dr Joseph Coselli *(Houston, Tex)*. Congratulations on an excellent presentation. You report to us an incremental study regarding the Osaka experience with selective cerebral perfusion using axillary artery cannulation. Your approach is unusual in that you cannulate the distal axillary artery using an axillary artery incision and a small cannula, usually 10F to 16F. Because of this, you also cannulate either the ascending aorta or the femoral artery to achieve adequate inflow. Your results are outstanding, with an operation mortality of 4% and a permanent neurologic deficit of 3% and no significant difference between elective and emergency operations, albeit with less than 8% of patients undergoing reoperation.

As your title suggests, you've evolved your strategy over a number of years with variations in such things as temperature and cannulation techniques. Because your results have been excellent apparently all along, it is not exactly clear to me as to what the motivation for the incremental alteration in your techniques has been.

Were there any differences in the outcomes from a neurologic, renal bleeding standpoint from the 4 different groups with regard to target temperatures that you have alluded to? For which patients, if any, do you continue to use deep hypothermic circulatory arrest?

You focus on bladder temperature. Knowing the limitations of bladder temperature monitoring, why do you not also monitor temperature in an area more accurately reflecting brain temperature, for example, the nasopharyngeal?

You recommend routine evaluation of cerebral circulation to help guide your perfusion strategy. One fourth of your patients had emergency procedures. What proportion of these patients had the benefit of preoperative imaging and how did this, if any, alter your technique? And if you do not have this preoperative imaging, exactly what perfusion techniques do you suggest?

Finally, rewarming strategy is also an important aspect of neuroprotection. What is your current rewarming approach? Do you use bladder temperature for this as well? What ultimate temperature do you target in your rewarming process? If you could, just mention to us your pH strategy.

Dr Ogino. As you know, in the past, we used retrograde cerebral perfusion with profound hypothermia in arch surgery. However, because the cerebral safety margin was limited and the incidence of postoperative temporary neurologic dysfunction was higher, our brain protection technique was shifted to selective antegrade cerebral perfusion in 2000.

At the moment, as I mentioned, the routine temperature is 28°C, regardless of aortic pathology. However, for high-risk patients with cerebral ischemia or renal dysfunction, we still use deep hypothermia at approximately 20°C to 22°C for cerebral or renal safety. In terms of bleeding or hemostasis, we are currently looking at the difference by a randomized control study between deep and moderate hypothermia in arch surgery. Our impression is that the amount of bleeding is less in the patient group with moderate hypothermia.

In regard to the temperature, we monitored the nasopharyngeal and bladder temperatures. In this study, we focused more on the bladder temperature as the core temperature, because we had to pay attention to the safety of spinal cord and visceral organs under moderate hypothermia. Selective antegrade cerebral perfusion is physiologic and has been well established. Under these circumstances, we focused more on the bladder temperature than the nasopharyngeal temperature.

In regard to the next question about the preoperative examination of cerebral circulation, routinely, brain computed tomography scans or carotid ultrasound was performed to evaluate the cerebral circulation. With a positive sign of ischemia in these examinations, magnetic resonance imaging or single photon emission computed tomography followed with the consultation of neurophysicians or neurosurgeon. With remarkable cerebral ischemia, we chose deep hypothermia and maintained the higher blood pressure during CPB and selective antegrade cerebral perfusion to avoid cerebral hypoperfusion. As you pointed out, one fourth of our patients were on emergency bases, such as acute dissection or ruptured nondissecting aneurysm. In this setting, preoperative evaluation was incomplete.

So for those cases, we tended to choose a lower temperature because of less information on cerebral circulation. Exceptionally, for relatively young patients with acute dissection without cerebral malperfusion, moderate hypothermic surgery at 25°C to 28°C was performed because these patients unlikely had any atherosclerotic cerebrovascular diseases.

As you mentioned, the rewarming process is also important for brain protection. Slow rewarming to the nasopharyngeal temperature of approximately 30°C to 32°C was started after reconstruction of the left subclavian artery. Full rewarming was commenced after complete reconstruction of the arch vessels. In terms of pH strategy, we used alpha-stat strategy for cooling and rewarming.

THE ANNALS OF THORACIC SURGERY

Composite Valve Graft Replacement of the Aortic Root: Twenty-Seven Years of Experience at One Japanese Center

Tomohiro Tsunekawa, Hitoshi Ogino, Hitoshi Matsuda, Kenji Minatoya, Hiroaki Sasaki, Junjiro Kobayashi, Toshikatsu Yagihara and Soichiro Kitamura

Ann Thorac Surg 2008;86:1510-1517
DOI: 10.1016/j.athoracsur.2008.07.051

Composite Valve Graft Replacement of the Aortic Root: Twenty-Seven Years of Experience at One Japanese Center

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Background. The aim of this study was to evaluate the early and long-term results of a composite valve graft root replacement for various aortic root diseases.

Methods. Between 1978 and 2005, 273 patients with various disorders of the aortic root underwent a composite valve graft root replacement. The mean age of the patients was 47.5 ± 13.2 years. There were 93 patients with Marfan syndrome, 56 aortitis, and 63 type A aortic dissections. Thirty-nine emergency operations and 55 redo operations were included. For the proximal anastomosis, a skirted technique was used in 157 patients. For the coronary reconstruction, Bentall's original inclusion technique was utilized in 36 patients, a direct button technique in 159, and a graft interposition technique in 63. The mean follow-up was 106 months.

Results. The in-hospital mortality was 9.5%. An emergency operation emerged as a significant predictor of early death. The actuarial survival rate was 87.0% and 72.9% at 5 and 15 years, respectively. The age at the operation, aortitis, Marfan syndrome, and use of a standard proximal anastomosis emerged as independent determinants of late death. The actuarial reoperation free rate was 96.3% and 89.7% at 5 and 15 years, respectively. In the patients who underwent the skirted technique the incidence of late graft detachment was less frequent than that of the standard technique.

Conclusions. A composite valve graft root replacement is a safe and reliable procedure for various aortic root diseases with stable early- and long-term results. The skirted technique seems to be attractive to avoid late graft detachment even in cases with a fragile inflammatory pathology.

(Ann Thorac Surg 2008;86:1510–7)

A composite valve graft root replacement (CGR), first reported by Bentall and DeBono in 1968 [1], has been applied to a variety of aortic root diseases. During the last two decades, CGR, with various technical modifications [2–5], has become a standard procedure for aortic root disorders. This report reviews the experience of CGR over the past 27 years in this center to overview the broad profiles of this procedure, including risk factor analyses and an evaluation of the long-term results.

Patients and Methods

This study included 273 patients who underwent a CGR at the National Cardiovascular Center, Osaka, Japan, between October 1978 and October 2005. Patients who required preoperative cardiopulmonary resuscitation were excluded. Patients who underwent an aortic root replacement using an aortic homograft, pulmonary autograft, or a stentless bioprosthesis were also excluded. All of the surgeries were identified from the Registry of Cardiovascular Surgery in the National Cardiovascular Center. The data in the registry were approved for use by the Institutional Ethical Committee. Follow-up data were obtained using a postal questionnaire or telephone interview with patients and their physicians. The preoperative patients' characteristics are summarized in Table 1. There were 93 patients with Marfan syndrome, 56 with aortitis, and 63 with an acute or chronic type A aortic dissection. Thirty-nine emergency operations and 55 redo operations were included. The patients in this study had various aortic root diseases. The indications that prompted the CGR are listed in Table 2. The majority of the patients in this series had an annuloaortic ectasia as the primary pathologic lesion (200 of 273; 73.3%). Thirty-nine patients with annuloaortic ectasia were accompanied by an acute or a chronic type A aortic dissection. The second most frequent indication was an acute type A aortic dissection (25 of 273; 9.2%), which was defined as an aortic dissection which showed apparent symptoms and was treated surgically within seven days after the onset of the symptoms. Of the 16 patients with a prosthetic valve dysfunction, 12 had aortitis, one had Marfan syndrome, and one had a chronic type A aortic dissection.

Accepted for publication July 14, 2008.

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0003-4975/08/$34.00
doi:10.1016/j.athoracsur.2008.07.051

Table 1. Patients' Profiles

Profiles	No. of Patients	%
Gender (men)	181	66.3
Age (years)	47.5 ± 13.2	
Emergent operation	39	14.3
Marfan syndrome	93	34.1
Aortitis	56	20.5
Acute type A aortic dissection	25	9.2
Chronic type A aortic dissection	38	13.9
Endocarditis	6	2.2
Redo operation	55	20.1
Hypertension	91	33.3
Diabetes mellitus	7	2.6
Cerebrovascular disease	27	9.9
Coronary artery disease	16	5.9
Chronic renal failure	7	2.6
Chronic obstructive pulmonary disease	30	11

Surgical Technique

Through a median sternotomy, a cardiopulmonary bypass was established by ascending aortic and bicaval cannulation, which was performed in a routine manner. If the ascending aortic cannulation was considered difficult, such as in an aortic dissection, axillar or femoral arterial cannulations were utilized. Myocardial protection was maintained with antegrade and retrograde cardioplegia. When replacing the aortic arch simultaneously, either profound or moderate hypothermic circulatory arrest between 18°C and 28°C and selective or retrograde cerebral perfusion were utilized according to surgeons' preferences. The details of surgical procedures are summarized in Table 3. For the coronary reconstruction and proximal aortic root anastomosis, various different surgical techniques were utilized. The method of coronary reconstruction was Bentall and De Bono's original inclusion technique in the initial 36 patients, a direct button technique in 159, a graft interposition technique of the bilateral (45) or unilateral (18) coronary arteries in 63 [4], the technique of Cabrol and colleagues [5] in 9, coronary artery bypass grafting in 5, and unknown in 1. Bentall and De Bono's original inclusion technique, in conjunction with wrapping the aortic aneurysm wall around the composite graft, was utilized until 1987. This technique was abandoned after a report in 1986 by Kouchoukos and colleagues [6] of late complications associated with this technique. The technique of Cabrol and colleagues was utilized between 1984 and 1989. This technique was discontinued because one early coronary graft obstruction and two perioperative coronary-related deaths were observed. A direct button technique has been utilized since 1985, which has been adopted as the first line technique for the coronary reconstruction. A graft interposition technique has also been utilized since 1985 and is still one of the choices when the button technique is considered difficult to perform without tension on the suture line, especially in redo cases.

Table 2. Indications for Operation

Indications for Operation	No. of Patients	%
Annuloaortic ectasia	200	73.3
Acute type A aortic dissection	25	9.2
Prosthetic valve dysfunction	16	5.9
Pseudoaneurysm of ascending aorta or aortic root	9	3.3
Aortic valve regurgitation and ascending aorta aneurysm	6	2.2
Chronic type A aortic dissection and aortic regurgitation	5	1.5
Aortic valve stenosis and ascending aorta aneurysm	4	1.5
Aortic regurgitation and aortitis	3	1.1
Rupture of Valsalva sinus aneurysm	2	0.7
Coronary ostial aneurysm	2	0.7
Prosthetic valve endocarditis	1	0.4

Table 3. Details of the Operation

Details	No. of Patients	%
Pump time (minutes)	243 ± 129	
Aortic clamp time (minutes)	154 ± 47	
Mechanical valve	240	87.9
Bioprosthetic valve	33	12.1
Proximal anastomosis:		
Skirted	157	57.5
Standard	116	42.5
Coronary arterial reconstruction:		
Direct button technique	159	58.2
Graft interposing technique	63	23.1
Original inclusion technique	36	13.2
Cabrol technique	9	3.3
Others	6	2.2
Concomitant procedure:		
Aortic	58	21.2
Hemi arch replacement	26	9.5
Total arch replacement	32	11.7
Cardiac	40	14.7
Mitral	22	8.1
Aortocoronary bypass	15	5.5
Others	5	1.8

For the proximal anastomosis, two different techniques were utilized. In 116 patients (42.5%), the composite valve graft was made by attaching a prosthetic valve to the edge of the graft with a continuous 3-0 polyester suture. The sewing ring of the prosthetic valve was attached to the aortic annulus with 2-0 polyester interrupted everting mattress sutures ("standard technique"). In the other 157 patients (57.5%), a prosthetic valve was anastomosed to the graft at 5 to 10 mm above the edge of the graft with continuous 3-0 polyester sutures. The segment of the proximal end of the vascular graft was referred to as the "vascular skirt." Only this soft skirt was attached to the aortic

ADULT CARDIAC

Table 4. Univariate Analyses of Early and Late Results

	Hospital Mortality			Late Mortality			Reoperation		
Variables	*p*	OR	95% CI	*p*	OR	95% CI	*p*	OR	95% CI
Age at operation	0.514	0.990	0.960–1.012	0.130	1.018	0.595–1.043	0.964	0.999	0.962–1.037
Male gender	0.590	0.795	0.346–1.830	0.274	1.434	0.752–2.735	0.138	2.006	0164–0.960
Emergent operation	0.000	6.984	2.930–16.65	0.552	1.299	0.549–3.076	0.268	2.038	0.579–7.182
Type A dissection	0.055	2.288	0.981–5.334	0.229	1.486	0.779–2.831	0.601	1.314	0.473–3.653
Malfan syndrome	0.709	0.847	0.354–2.028	0.722	1.114	0.614–2.021	0.968	1.019	0.407–2.548
Aortitis	0.734	1.182	0.451–3.098	0.023	2.062	1.107–3.839	0.955	0.965	0.280–3.329
Redo operation	0.161	1.891	0.776–4.612	0.034	2.097	1.059–4.149	0.467	1.586	0.458–5.490
Hypertension	0.561	1.281	0.557–2.948	0.542	0.803	0.396–1.627			
Diabetes mellitus	0.667	1.607	0.186–13.89	0.888	0.867	0.119–6.304			
Cerebrovascular disease	0.024	3.229	1.169–8.918	0.356	1.626	0.579–4.572			
Coronary artery disease	0.207	2.348	0.623–8.846	0.527	1.585	0.381–6.591			
Chronic renal failure	0.106	4.033	0.742–21.92	0.000	9.534	2.844–31.96			
Chronic obstructive pulmonary disease	0.925	1.063	0.299–3.776	0.289	1.593	0.673–3.773			
Pump time (minutes)	0.002	1.004	1.002–1.007	0.032	1.002	1.000–1.003	0.632	1.001	0.997–1.005
Aorta clamp time (minutes)	0.940	1.000	0.991–1.009	0.136	1.005	0.998–1.011	0.348	1.006	0.994–1.017
Use of bioprosthesis	0.205	0.269	0.035–2.052	0.737	0.861	0.359–2.063	0.000	8.577	3.398–21.65
Skirted proximal anastomosis technique	0.222	0.603	0.268–1.358	0.092	0.592	0.321–1.090	0.056	0.332	0.108–1.027
Direct button technique	0.001	0.230	0.093–0.568	0.605	0.854	0.470–1.552	0.004	0.160	0.046–0.559
Concomitant aortic surgery	0.792	0.872	0.314–2.421	0.705	1.152	0.553–2.404	0.247	0.037	0.000–9.755
Concomitant cardiac surgery	0.081	2.308	0.902–5.903	0.936	0.965	0.409–2.281	0.298	0.343	0.046–2.572
Era of operation (after 1995)	0.376	0.692	0.307–1.561	0.775	0.912	0.485–1.716	0.023	0.172	0.037–0.788

95% CI = 95% confidential interval; OR = odds ratio.

annulus with everting mattress sutures using 2-0 polyester sutures ("skirted technique"). The primary purpose of the modification of the proximal anastomosis with skirted technique was to secure the intraoperative hemostasis at the proximal anastomosis and to reduce the incidence of late graft detachment.

Bioprosthetic valves were utilized in 33 patients; the Ionescu-Shiley valve (Shiley Laboratory, Irvine, CA) was implanted in 19 patients until 1984 and the Carpentier-Edwards bovine pericardial valve (Edwards Lifescience, Irvine, CA) in 14 since 1987. A mechanical valve was implanted in 240 patients, the St Jude Medical bileaflet prosthesis (St. Jude Medical, St. Paul, MN) in 149 patients, the CarboMedics bileaflet prosthesis (CarboMedics Inc., Austin, TX) in 54, the Björk-Shiley tilting disc prosthesis (Shiley Laboratory) in 22, and the ATS Medical bileaflet prosthesis (ATS Medical Inc., Minneapolis, MN) in 15.

Statistical Analysis

Data analyses were performed using SPSS 15.0 for Windows (SPSS, Chicago, IL). Data are expressed as the mean ± standard deviation, with the statistical significance determined at the 95% confidence level. The variables associated with an increased risk of early death were assessed using univariate and multivariate logistic regression analyses. Long-term survival and event-free rates were calculated using the Kaplan-Meier method. The endpoints were late death, reoperation, prosthesis dysfunction, thromboembolism, bleeding requiring in-hospital treatment or blood transfusion, coronary complications, graft infection, and graft detachment. Only the first occurrence of any specified complications was considered in the analyses. The variables associated with increased risk of late death and reoperation were assessed by the univariate and multivariate Cox proportional regression analyses.

Results

Early Mortality

Overall, the in-hospital mortality rate, defined as death prior to discharge or within 30 days of the operation in discharged patients, was 9.5% (26 patients). Eighteen of those patients died from postoperative heart failure. The other causes were refractory ventricular fibrillation in 3 patients, pulmonary hemorrhage in 2, prosthetic valve endocarditis in 2 and ischemic colitis in 1. A multivariate analysis showed that an emergency operation, the presence of preoperative cerebrovascular disease, and no use of a direct button technique were statistically significant predictors for in-hospital death (Tables 4 and 5).