Surgical Treatment of Aortic Arch Aneurysms in Profound Hypothermia and Circulatory Arrest

Martin Grabenwöger, MD, Marek Ehrlich, MD, Fabiola Cartes-Zumelzu, MD, Martina Mittlböck, PhD, Günther Weigel, MD, Günther Laufer, MD, PhD, Ernst Wolner, MD, and Michael Havel, MD

Clinic of Surgery, Department of Cardio-Thoracic Surgery, University of Vienna, Vienna, Austria

Background. This study was undertaken to define the factors that influence mortality rate and neurologic outcome after repair of the aortic arch and various portions of the thoracic aorta in patients with profound hypothermia and circulatory arrest.

Methods. Between November 1986 and January 1996, 105 patients were treated surgically for aortic disease involving the transverse aortic arch. Profound hypothermic circulatory arrest and selective brachiocephalic perfusion was used in all patients. In 19 patients retrograde cerebral perfusion was instituted during the period of circulatory arrest. Independent predictors for 30-day mortality and permanent neurologic deficits were evaluated by multiple logistic regression.

Results. Thirty-day mortality for the entire group was 19% (20/105); 21.2% for urgent versus 15.4% for elective cases, respectively. Statistical analysis showed that age is the most important factor that significantly influences mortality rate \((p < 0.0145)\) and neurologic outcome \((p < 0.006)\). Variables such as circulatory arrest time \((p < 0.24)\), previous cardiac or aortic operations \((p < 0.19)\), and sex \((p < 0.55)\) failed to show any influence on mortality rate. Permanent neurologic deficits were diagnosed in 12.9% \((11/85)\) of the patients.

Conclusions. The incidence of permanent neurologic dysfunction as well as the mortality rate are predominantly related to the age of the patient. In this patient group, statistical analysis failed to show a direct correlation between duration of circulatory interruption and neurologic outcome.

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Surgical correction of aneurysms involving the transverse aortic arch is still a great challenge for cardiac surgeons. Since the first successful replacement of the aortic arch by DeBakey and colleagues in 1957 [1], various methods had been developed to preserve cerebral function during this operative procedure [2, 3]. In the last two decades, the clinical introduction of profound hypothermia and circulatory arrest in operations on the thoracic aorta has resulted in a significant decline in morbidity and mortality [4, 5].

The technique of profound hypothermia and circulatory arrest increases the tolerance of neural tissue to ischemic injury and offers a bloodless operative field without application of clamps on the friable aortic tissue [6]. Nevertheless, the incidence of neurologic complications remains high. In recent years the introduction of retrograde cerebral perfusion (RCP) during the period of circulatory arrest further improved neurologic outcome after replacement of the thoracic aorta [7, 8].

The current study is a retrospective review of a contemporary group of 105 patients who underwent surgical treatment of the aortic arch and various portions of the thoracic aorta. Particular emphasis was placed on mortality rate and neurologic outcome.

Patients and Methods

Patients

From November 1986 to January 1996, 105 patients underwent surgical repair of the aortic arch and various portions of the ascending and descending aorta. There were 67 men and 38 women in the series with ages ranging from 16 to 81 years (average, 57 years). The cause of aortic disease was dissection type A in 81 patients (63 acute, 18 chronic), dissection type B in 5 (2 acute, 3 chronic), and degeneration with an aortic diameter of more than 6 cm in 19 patients (2 acute, 17 chronic). Marfan’s syndrome was present in 10 patients. Thirty-one patients (29.5%) underwent emergency operation because of aneurysmal rupture. Of the 105 patients, 17 had previous cardiac or aortic operations. These procedures included aortic valve replacement \((n = 8)\), replacement of the ascending aorta \((n = 5)\), root replacement with a composite graft \((n = 1)\), mitral valve replacement \((n = 1)\), and repair of a thoracoabdominal aneurysm \((n = 2)\).

Operative Technique

Replacement of the proximal portion of the aortic arch with varying portions of the ascending aorta was done through a median sternotomy. A left posterolateral thoracotomy was used for operations on the distal arch with...
varying portions of the descending aorta. After heparinization (300 IU/kg body weight) and application of 1 million IU (140 mg) of aprotinin into the oxygenator of the extracorporeal circuit, the left femoral artery and the right atrium were cannulated and cardiopulmonary bypass was established. For operations on the distal arch the femoral artery and vein were cannulated and the tip of the venous cannula was placed in the right atrium. During cooling the difference between the blood and the esophageal temperature was not allowed to exceed 10°C. The pericardium was incised, the cannula for cardioplegic solution was placed in the ascending aorta, and the left ventricle was vented through the apex. To increase the tolerance of the neurologic tissue for ischemia, we packed the patient’s head in ice bags, and 1,000 mg methylprednisolone was given immediately before circulatory arrest (confirmed by absence of any cerebral electrical activity). At a rectal temperature of 18°C and a nasopharyngeal temperature of 11°C, circulatory arrest was established and 1,000 to 1,500 mL of blood was drained into the reservoir of the pump oxygenator system. Furthermore, the hemoglobin oxygen saturation in the brain tissue was monitored by spectroscopy in the 19 RCP patients by placing infrared patches on the patient’s forehead. During the period of circulatory arrest we implemented RCP in these patients. We did not use RCP with patients having distal arch replacement. The superior vena cava was cannulated and perfused by a second line, which was connected to the arterial line of the extracorporeal circuit. The mean flow rate was 277.7 mL/min and the central venous pressure was kept less than 25 mm Hg (mean, 21.1 mm Hg). For the repair we used albumin-precoated polyethylene terephthalate (Dacron) grafts (Vascutek, Sulzer Inc, Renfrewshire, Scotland; designed by M. Havel) which had a premanufactured 8-mm Dacron graft sutured end-to-side into the prosthesis. The anastomoses were performed with continuous 4-0 Prolene (Ethicon, Somerville, NJ) sutures and reinforced with a 3-mm-wide polytetrafluoroethylene felt, which was sutured around the aortic wall. Thereafter, RCP was discontinued and the arterial side graft of the extracorporeal circuit was connected to the 8-mm Dacron side graft of the prosthesis. In the case of proximal arch replacement, the aortic graft was clamped proximal to the junction of the side graft, and antegrade hypothermic perfusion was initiated (Fig 1). Rewarming of the patients was performed while the proximal anastomosis was done. In the case of distal arch replacement, the clamp was placed distal to the junction of the side graft and selective brachiocephalic perfusion was started (1.2 to 1.6 L/min) (Fig 2). According to the implantation of patent intercostal and lumbar arteries into the graft, the clamp was continuously moved downward. Finally the distal anastomosis with the native aorta was sutured with 4-0 Prolene and reinforced with Teflon strips. After local application of cefamandol, the edges of the aneurysmal wall were sutured around the graft to enhance hemostasis. Warming to a rectal or bladder temperature of 35°C required 65 to 143 minutes (mean, 89 minutes).

Definition

The extent of replacement was defined as three major groups according to the segment of the aorta that dominated the repair. Hemiarch replacement included patients with replacement of the proximal portion of the aortic arch with varying portions of the ascending aorta with or without replacement of the root or aortic valve. Total arch replacement was defined as those procedures involving the total aortic arch with reimplantation of brachiocephalic vessels. Procedures in these two groups were done through a median sternotomy. Replacements of the distal arch with varying portions of the descending or thoracoabdominal aorta were termed the distal arch group. Patients in this group were operated on through a left thoracotomy, with femoral vein and femoral artery cannulation.

Surgical Procedures

Eighty-one of 105 patients underwent hemiarch replacement. In 31 patients this procedure was combined with an aortic root replacement using a composite graft. In 5 patients the incompetent aortic valve could be reconstructed according to the procedure of David and col-

Fig 1. Hypothermic antegrade perfusion for proximal arch replacement: after the distal anastomosis is accomplished during the period of circulatory arrest, cardiopulmonary bypass can be initiated through the side graft.

Fig 2. Selective hypothermic antegrade brachiocephalic perfusion for distal arch replacement. Proximal anastomosis is performed during circulatory arrest. Thereafter the prosthesis is clamped distally and perfusion of the brachiocephalic vessels can be restored.
leagues [9]. Total arch replacement was performed in 17 patients, and 7 patients underwent distal arch replacement with various portions of the thoracic aorta.

**Neurologic Examination**
The neurologic status of the patient was assessed at the time of discharge from hospital.

**Statistical Methods**
The influence of age, sex, circulatory arrest time, previous cardiac or aortic operations, urgency of operation, and aneurysmal rupture on 30-day mortality was analyzed with multiple logistic regression. The effect of age, sex, circulatory arrest time, previous cardiac or aortic operations, urgency of operation, aneurysmal rupture, and RCP on permanent neurologic deficits of patients without 30-day mortality was evaluated with exact logistic regression using the statistical software StatXact (Cytel Software Corp, Cambridge, MA). This was necessary because no neurologic deficit occurred in the group of patients with RCP. Probability values are two-sided and \( p \) less than 0.05 is considered to be statistically significant.

**Results**
Thirty-day mortality for the entire group of 105 patients was 19% (20/105); 21.2% (14/66) for those requiring urgent operations versus 15.4% (6/39) for those having elective operations, respectively. The cause of death was cardiac in 8 patients (myocardial infarction in 3, myocardial failure in 5), multiorgan failure in 9, stroke of the brain stem in 2, and bleeding in 1 patient. Postoperative neurologic deficits were contributing factors in four deaths. In the group of patients who were operated on with the use of RCP no permanent neurologic dysfunction could be seen. These patients showed the same age distribution (mean age, 56 years) and exhibited no difference in mortality rate as compared with the others. Mean number of days in intensive care of the patients was 11 days and varied between 1 and 73 days. Circulatory arrest time ranged from 17 to 113 minutes (mean, 31 minutes). Circulatory interruption exceeded 40 minutes in 25 patients (24%) and 60 minutes in 5 patients (4.8%). Patients who were operated on with the use of RCP showed no significant difference in the duration of circulatory arrest. Early reoperation for bleeding at the site of operation was necessary in 9 patients (8.6%).

Statistical analysis by multiple logistic regression showed that patient’s age is the most important factor that significantly influences mortality rate (\( p < 0.0145 \)). Thirty-day mortality as a function of age is shown in Figure 3. A significant elevation in mortality can be seen in patients older than 60 years. Variables such as circulatory arrest time (Fig 4), previous cardiac or aortic operations, and sex failed to have any influence on mortality rate. Furthermore, the variables urgency of operation (\( p < 0.04 \)) and aneurysmal rupture (\( p < 0.035 \)) increased mortality rate and showed statistical significance.

Permanent neurologic deficits occurred in 11 of 85 surviving patients (12.9%). Neurologic deficits were caused by embolic strokes, which were verified by computed tomography. All surviving patients of the RCP group recovered without permanent neurologic deficit. However, for statistical analysis the RCP group was too small to gain statistically relevant results.

Circulatory arrest time had no significant influence on permanent neurologic dysfunction (\( p < 0.85 \)) (Fig 5), whereas the patient’s age was the most important predictor of permanent neurologic injury (\( p < 0.006 \)) (Fig 6). In addition to age, aneurysmal rupture (\( p < 0.042 \)) was related to the occurrence of permanent neurologic deficits.

**Comment**
Advanced age is the most important factor that influences mortality rate and neurologic outcome after oper-
ations on the thoracic aorta using profound hypothermia and circulatory arrest. Statistical analysis showed that in our patient group the duration of circulatory arrest did not significantly affect mortality rate and the occurrence of permanent neurologic dysfunction.

Previous operative techniques for aortic arch replacement associated with high mortality rates have included temporary tubes, temporary or permanent grafts, and separate perfusion of the carotid and subclavian arteries [3]. The introduction of profound hypothermia and circulatory arrest markedly reduced operative mortality and perioperative morbidity after aortic arch surgery [10, 11]. The technique of an open distal anastomosis during circulatory arrest permits an accurate inspection of the aortic arch, searching for intimal tears, and protects the fragile aortic wall from damage by aortic cross-clamps. The most frequently cited disadvantage of this technique is the hypothermia-associated coagulopathy and the time limitation induced by circulatory arrest [11]. Although the tolerance of the neural tissue is significantly increased by profound hypothermia [12], neurologic injury remains the most serious complication of aortic arch repair. The reported incidence of cerebral complications varies between 7% and 35% [13–15]. Previous studies suggest the “safe period” for interrupted circulation in profound hypothermia (10°C nasopharyngeal temperature) to be 40 minutes [16]. Svensson and coworkers [17] showed that cerebral ischemia times greater than 45 minutes were associated with a higher risk of stroke, and ischemic times greater than 65 minutes were associated with a higher mortality. In our study circulatory arrest times varied between 17 and 113 minutes (mean, 31 minutes). The incidence of permanent neurologic dysfunction was 12.9%. In contrast to other reports we did not find a statistically significant effect of cerebral ischemia time on permanent neurologic injury or mortality rate. These results are consistent with the results obtained by Ergin and coworkers [18], who were unable to find a significant effect of cerebral ischemia time and other perfusion parameters on mortality rate and permanent neurologic dysfunction. These results indicate that hypothermic circulatory arrest is an effective method for cerebral protection and permanent neurologic complications are caused by thromboembolic events [18]. In contrast to permanent neurologic dysfunction, the occurrence of transient neurologic dysfunction was attributed to the duration of circulatory interruption [18]. In our retrospective study, this important postoperative complication could not be evaluated.

In recent years retrograde perfusion of the brain through the superior vena cava was introduced as an adjunct to avoid cerebral thrombosis and embolism caused by debris or air [19]. Furthermore, it is suggested that this technique reduces ischemic damage during interruption of the circulation, although RCP cannot provide enough blood flow and oxygen to maintain aerobic metabolism in cerebral tissues [19]. In our institution we started using RCP in January 1995 and at the end of this series this technique had been performed in 19 patients. None of these patients suffered from permanent neurologic dysfunction. Despite these favorable early results with RCP, further experimental and clinical studies have to be undertaken to evaluate its clinical efficacy in aortic arch replacement. The question of whether the benefit of RCP is based on a simple wash-out effect of the brain or on a real nutrition of cerebral cells still remains to be determined. Because our study failed to demonstrate a correlation between circulatory arrest time and permanent neurologic dysfunction, it is assumed that the beneficial effect of RCP can be attributed primarily to the avoidance of cerebral embolism rather than to an increase of the “safe period” of circulatory interruption.

The overall 30-day mortality rate was 19%, which is comparable with other series [18, 20]. Mortality rate varied from 15.3% for elective operations to 21.2% for urgent operations. Statistical analysis revealed advanced age as the only constant determinant of mortality, which is in accordance with the observations reported by Ergin
and associates [18] and Galloway and colleagues [15]. We did not find an influence of cerebral ischemia time, sex, or previous cardiac or aortic operations on mortality rate. These results led us to conclude that the physical condition of the patient and not the duration of circulatory arrest time greatly influences the patient’s outcome.

In conclusion, this study indicates that mortality rate and neurologic dysfunction are significantly related to the patient’s age. Circulatory arrest time influences neither mortality rate nor neurologic outcome. Profound hypothermia is an effective method for cerebral protection within the time limits used in this study.

References