Original Article

Deep Hypothermic Circulatory Arrest in Adults Undergoing Aortic Surgery: Local Experience

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Abstract

Introduction: The aim of our study was to evaluate the efficacy and safety of deep hypothermic circulatory arrest (DHCA) as a method of cerebral protection during aortic surgery. Materials and Methods: We carried out a retrospective review of 59 consecutive patients (48 men, 11 women) undergoing elective or emergency aortic surgery requiring DHCA from January 1999 to April 2002 in 2 tertiary care hospitals. Data regarding demographics, clinical characteristics, operation type, duration of circulatory arrest, nasopharyngeal temperatures, use of retrograde cerebral perfusion and central nervous system (CNS) morbidity and perioperative mortality were collected and analysed. Results: There were 47 (79.7%) operations for aortic dissections and 12 (20.3%) for aortic aneurysms. The mean duration of circulatory arrest was 42 ± 23 minutes. The lowest nasopharyngeal temperature at the time of arrest was 16.5° ± 1.9°C. Eight (13.6%) patients had a new irreversible neurologic deficit postoperatively. These patients had a mean circulatory arrest time of 50 ± 28 minutes. Temporary neurologic dysfunction occurred in 8 (13.6%) patients. Intra-hospital mortality was 22%. The mean circulatory arrest time for patients who died was 54 ± 24 minutes. Conclusion: DHCA is a simple and effective method of CNS protection in aortic surgery with satisfactory outcomes. With increased surgical and anaesthetic experience, as well as selective use of adjuncts of cerebral protection, reductions in mortality and neurological morbidity will likely be achieved in the future.

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Key words: Aorta surgery, Induced hypothermia, Mortality, Neurologic deficits

Introduction

The use of deep hypothermic circulatory arrest (DHCA) as a method of cerebral protection during aortic surgery was first described in 1975.[1] Its use is based on 2 fundamental concepts. First, interruption of cerebral circulation with full recovery of neurologic function is possible and, secondly, brain metabolic rate decreases with temperature. This technique allows the surgeon to work in a quiet, bloodless field uncluttered by proximal clamps and perfusion cannulae. Its relative safety may be enhanced by the use of various adjuncts, such as surface cooling of the head with ice packs, retrograde cerebral perfusion (RCP) and selective antegrade cerebral perfusion,[2-4] particularly if DHCA is prolonged. Nevertheless, concerns about the increased incidence of neurologic sequelae and increased mortality rate associated with its use remain.

DHCA was first used for adult aortic surgery in Singapore in 1985. Since then, it has been employed in >100 operations for aortic dissections/aneurysms locally. We carried out a retrospective review to evaluate the efficacy and safety of DHCA in adults undergoing aortic surgery in 2 tertiary hospitals in Singapore. We report our findings and compare our local experience with that reported in other cardiothoracic units elsewhere.

Materials and Methods

A retrospective review of the case records of 59 consecutive patients who underwent DHCA for both elective

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and emergency surgeries on the aorta from January 1999 to April 2002 was undertaken.

After induction of general anaesthesia, the patients were cleaned and draped in the usual sterile fashion. Temperature probes were inserted to monitor the nasopharyngeal temperature (NPT) and rectal temperature (RT). All patients were catheterised to monitor urine output. In most patients, a median sternotomy incision was made. A posterolateral thoracotomy was performed in patients who had dissections or aneurysms involving the descending aorta. Heparin 3 mg/kg was administered and the femoral artery or distal aorta was cannulated; however, in acute dissection the femoral vein was cannulated initially.

All patients were placed on full cardiopulmonary bypass (CPB) using a membrane oxygenator, arterial line filter, non-pulsatile flow, 1.8 L prime volume (0.5 L gelatin, 1 L lactated Ringer's solution or blood prime if their starting haematocrit was <20%). Mannitol 50 g and sodium bicarbonate 8.4% 50 mL made up the rest of the pump prime. Patients who had cardioplegia received either cold blood or crystalloid cardioplegia.

Once the patient was placed on full CPB and systemic core cooling was started, ice packs (made from crushed ice placed in plastic bags) were placed around the patient's head to cover the entire head, except for the base. When the NPT had reached 15°C to 18°C, the pump was turned off and the patient was exsanguinated into the cardiotomy reservoir. Various adjuncts were employed for cerebral protection. Patients either received thiopentone, methylprednisolone or both prior to initiation of DHCA. RCP was used at the discretion of the surgeon and cardioplegia was used in all operations involving the heart, ascending aorta and arch of aorta. When the CPB pump was restarted, the ice packs were removed and the patient slowly rewarmed keeping the temperature difference between the CPB circuit arterial blood and patient NPT <10°C at all times. After surgery, the patient was weaned from CPB in the usual fashion once the RT was ≥36.5°C. All patients were transferred to the cardiothoracic surgical intensive care unit postoperatively. A gross neurologic assessment was performed daily. If any neurologic deficit was found, the patient was examined by a neurologist and had a computed tomographic (CT) scan or magnetic resonance (MR) imaging scan as indicated. Upon discharge from hospital, all patients were followed up for 6 months by the cardiac surgeons and cardiologists.

Data regarding central nervous system (CNS) morbidity and perioperative mortality (death occurring <30 days postoperatively) were collected and examined. Statistical analysis of differences between means was done by *t* test and between proportions by χ^2 test.

Results

Of the 59 patients studied, 48 (81%) were men and 11 (19%) were women. Their mean age, weight and height were 61 ± 10 years, 67 ± 12 kg and 164 ± 8 cm, respectively. 40.7% of patients were >60 years old. Table 1 shows the patients' medical conditions preoperatively.

There were 20 (33.9%) elective and 39 (66.1%) emergency operations requiring DHCA. The majority, 47 (79.7%) were for aortic dissection and 12 (20.3%) were for aortic aneurysms. These are detailed in Table 2.

The mean CPB time was 227.5 ± 73 minutes (range, 125 to 527 minutes). Five patients received blood prime, 40 received blood cardioplegia, 11 had crystalloid cardioplegia and 8 had none. The mean NPT at circulatory arrest was 16.5°C ± 1.9°C. The mean duration of hypothermic circulatory arrest was 42 ± 23 minutes (range, 4 to 134 minutes); 44 patients had circulatory arrest times >30 minutes, of which 7 had DHCA times >1 hour. RCP was used in 44 patients (74.6%). Twenty-three (39%) patients received methylprednisolone only, 3 (5.1%) patients were given thiopentone, only while 17 (28.8%) patients had both drugs prior to circulatory arrest. The mean duration of rewarming was 81.2 ± 25.9 minutes (range, 32 to 139 minutes) with a mean NPT of 35.8°C ± 0.4°C (range, 35.8°C to 37.5°C) at termination of CPB.

Twenty patients (33.8%) developed varying degrees of CNS deficit; 10 had a cerebral infarct, 2 suffered from intracerebral haemorrhage, 3 had hypoxic encephalopathy and 5 had delirium or transient cognitive impairment. Three of these 20 patients had a preexisting neurologic deficit consequent to aortic dissection or severe hypotension prior to surgery. One patient had a right middle cerebral artery infarct 3 days prior to surgery. Therefore, the rate of neurologic morbidity was 27.1% in patients who had no preexisting neurologic deficit before surgery. The rate of new permanent neurologic deficit was 13.6%. The rate of permanent neurologic disability among those who survived to discharge (with no preexisting neurologic impairment)

Table 1. Demographic and Clinical Characteristics of Patients (n = 59)

Characteristic	Incidence (%)
Smoking	25 (42.4)
Age >60 years	24 (40.7)
Hypertension	43 (72.9)
Diabetes mellitus	4 (6.8)
Renal impairment	16 (27.1)
Prior cerebrovascular accident	9 (15.3)
Peripheral vascular disease	2 (3.4)
Prior myocardial infarction	10 (16.9)
Prior cardiac surgery	3 (5.1)
Congestive cardiac failure	4 (6.8)
Chronic obstructive pulmonary disease	3 (5.1)
Obesity (Body mass index >25)	24 (40.7)

Table 2. Type of Aortic Surgery Requiring DHCA

Type of operation	Elective patients	Emergency patients	Total
Type A aortic dissection repair	10	31	41
Type B aortic dissection repair	2	4	6
Ascending aortic aneurysm repair	2	3	5
Arch of aorta aneurysm repair	1	1	2
Descending aortic aneurysm repair	5	0	5
Total	20	39	59

CPB: cardiopulmonary bypass; DHCA: deep hypothermic circulatory arrest
Numbers represent number of patients

was 6.7%. Temporary neurologic dysfunction was observed in 13.6% of patients. When RCP was used, the rate of neurological morbidity was 27.3% versus 33.3% when RCP was not used. However, this difference did not reach statistical significance (P >0.05).

The neurologic outcome and mortality in relation to the duration of DHCA and CPB are described in Tables 3 and 4, respectively. The mean DHCA time and mean CPB time of patients who developed postoperative (both permanent and temporary) neurologic deficits were significantly longer than those who did not [(54.4 ± 33.1 versus 37.5 ± 16.1 minutes) (P = 0.01) and (261 ± 107.8 versus 214 ± 49.1 minutes) (P = 0.024) respectively].

There were 13 perioperative deaths. Five were related to severe neurologic impairment, of which 3 had associated sepsis and multi-organ failure and 1 had acute renal failure and disseminated intravascular coagulation. They remained in the intensive care unit for more than 14 days before they died. Six patients died within 48 hours of the operation: 4 died from cardiogenic shock, 1 from uncontrolled haemorrhage and 1 from ischaemic bowel. Two patients died from unknown cardiopulmonary complications more than 20 days after their operations. The mean DHCA and mean CPB times of the patients who died were longer than that of patients who survived to discharge (54.1 ± 23.5 versus 39 ± 22.5 minutes and 271.9 ± 73.1 versus 215 ± 69.1 minutes, respectively). These differences were statistically significant (P <0.05).

Discussion

Although DHCA has become a widely practised and accepted technique for thoracic aortic surgery worldwide, this is the first review of its use and outcomes in our local population.

Circulatory arrest allows a bloodless inspection and repair of intimal tears, while avoiding clamp injury to fragile dissected aortic tissue.[5] Profound hypothermia affords organ protection during circulatory arrest by reducing tissue metabolic rate and oxygen consumption. However, there is a time limit for the use of DHCA. Experimental studies in gerbils[6] have shown that the risk of neurologic dysfunction increased markedly after 45 minutes of circulatory arrest. In humans, the 'safe' period for strokes not developing appears to be limited to between 40 minutes[7] and 60 minutes[8] of circulatory arrest (in the absence of selective cerebral perfusion). More recently, McCullough et al[9] measured cerebral oxygen consumption in 37 adults undergoing DHCA and calculated a human cerebral temperature coefficient Q10 (ratio of metabolic rate at temperatures 10°C apart) of 2.3, and predicted that the safe duration of DHCA at 15°C was only 29 minutes. The incidence of temporary neurologic dysfunction has also been shown to rise linearly in relation to the duration of hypothermic circulatory arrest.[8]

Table 3. Neurologic Outcome and Mortality in Relation to Duration of DHCA

DHCA time (min)	No deficit (n)	Temporary neurologic deficit (n)	Permanent neurologic deficit (n)	Death with severe neurological deficit (n)	Death due to other causes (n)	Total (n)
<30	12	2	1	0	0	15
30-59	17	4	5	3	6	35
60-89	2	1	1	1	2	7
>90	0	1	0	1	0	2

DHCA: deep hypothermic circulatory arrest; n: number of patients

Table 4. Neurologic Outcome and Mortality in Relation to Duration of CPB

CPB time (min)	No deficit (n)	Temporary neurologic deficit (n)	Permanent neurologic deficit (n)	Death with severe neurological deficit (n)	Death unrelated to neurological deficit (n)	Total (n)
<180	10	3	2	0	0	15
180-239	15	2	2	2	2	23
240-299	5	2	1	2	5	15
>300	1	1	2	1	1	6

CPB: cardiopulmonary bypass; n: number of patients

In their landmark study of 656 adult patients who had undergone aortic surgery using DHCA, Svensson et al[7] reported a stroke rate of 7%. Ergin et al[8] who studied 200 patients reported an embolic stroke rate of 11% and temporary neurologic dysfunction occurred in 19% of their patients. In comparison, the postoperative stroke rate resulting in permanent deficit of 13.6% in our study may appear rather high. This is most likely due to our longer duration of DHCA and CPB. The median DHCA and CPB times in Svenson's[7] series were 31 and 126 minutes, respectively, versus our median DHCA and CPB times of 39 and 176 minutes, respectively. In particular, the median DHCA (48 minutes) and CPB (201 minutes) times were considerably longer in patients who suffered permanent neurological deficit.

Our overall mortality rate was 22%. This was higher than the mortality rate of 10% to 15% in well-known studies.[7,8] One of the reasons was probably because a high proportion (66.1%) of the operations in our study was done on an emergency basis. Patients requiring emergency surgery would not have been properly evaluated preoperatively and would have had greater perioperative haemodynamic instability. As expected, the mortality rate for emergency procedures would be higher. Sinatra et al[5] observed a mortality rate of 25.9% for acute type A aortic dissections, while Ergin et al[8] reported an operative mortality rate of 26.4% for emergency operations. The other reason is perhaps due to our longer DHCA times. The mortality rate has been shown to increase markedly after 65 minutes of circulatory arrest.[7] Indeed, we have found that both the mortality rate and rate of neurologic dysfunction increased with the length of DHCA time.

Some workers, however, believe that it is the CPB time that correlates more closely with mortality and serious neurological deficit. King et al[10] observed no significant differences in hospital mortality, stroke rate or operative morbidity between patients who had thoracic aneurysms repaired on DHCA and those repaired on CPB without DHCA. Svensson et al[7] showed that the length of time on CPB was a better predictor of postoperative death and stroke than the DHCA time. Microembolisation during prolonged CPB is likely to be a greater factor in the cause of stroke than cerebrovascular ischaemia time per se.[11] In our study, we also found that the patients who died or suffered neurological deficit had significantly longer CPB times.

Administration of pharmacological agents as cerebral protectants during DHCA is widely practiced, but the body of evidence supporting their use is small. A survey conducted by Dewhurst et al[12] showed considerable variation in the dose and timing of administration of these agents among cardiothoracic anaesthetists. In our review, barbiturates (thiopentone) and methylprednisolone were the most commonly used drugs. Disadvantages of large doses of thiopentone include delayed awakening and myocardial depression. High-dose steroid use may lead to increased risk of sepsis. Recent research has focused on adjunctive methods of cerebral protection, which may augment the safety of DHCA more effectively. Two such techniques are RCP and selective antegrade cerebral perfusion (SCP).

RCP through the superior vena cava has garnered increasing support in recent literature. It has the following advantages: continuous and homogeneous cerebral cooling: flushing out of microemboli; and washing out of metabolites, thus delaying onset of acidosis in the ischaemic brain, thereby extending the "safe" period of DHCA and perhaps allowing a decrease in the extent of hypothermia required. Yagdi et al[13] observed a low stroke rate of 1.4% in 144 patients who underwent aortic surgery using DHCA with RCP. Temporary neurologic dysfunction was seen in only 6.3% of their patients. Coselli and LeMaire[14] reported that patients who had RCP during DHCA had lower mortality (7.9%) and stroke (2.4%) rates than those who had undergone DHCA without RCP (early mortality, 14.8%; stroke, 6.5%). This is probably because RCP can extend the safe DHCA period especially when DHCA times are >60 minutes.[15] Indeed, Lin et al[16] demonstrated that the safe period of DHCA could be extended to 93 minutes with the aid of RCP at higher RTs (21.7°C ± 0.8°C), thus avoiding deep hypothermia. In our review, RCP could not be shown to confer significant advantage in terms of neurological outcomes or mortality because of the small number of patients who had DHCA without RCP. However, RCP has several disadvantages. It leads to additional blood in the surgical field. The increased cerebral oedema associated with RCP may lead to increased intracranial pressure and impaired postoperative cerebral perfusion. In a prospective comparative study of DHCA with either RCP or SCP in total aortic arch replacement, Okita et al[17] reported a significantly higher prevalence of transient brain dysfunction in patients who had RCP.

SCP is an alternative method of cerebral protection during DHCA. Arterial access is achieved with 1 cannula in the right axillary or brachiocephalic artery, and another in the left common carotid artery. The most important advantage of SCP is that it provides luxury of time, thus allowing for deliberate repair of arch aneurysms. However, several criticisms have been levelled against SCP, including the longer time required for arch repair, cannulation-origin embolism and uneven distribution of intracranial blood flow. Svensson et al[18] found no neurocognitive advantage with RCP or SCP up to 6 months postoperatively when compared to DHCA alone in a prospective randomised study of RCP and SCP for aortic arch operations.

In conclusion, this review has shown that the use of DHCA in adult aortic surgery has had satisfactory outcomes in our local practice. Regrettably, the number of subjects studied is too small to allow meaningful comparison of methods of cerebral protection. With growing expertise and experience with the use of DHCA, an accurate and comprehensive assessment of neurocognitive function will be required to allow proper analysis and comparison of methods and outcomes. A systematic and blinded assessment by a neurologist/neuropsychologist in all patients undergoing DHCA may be worthwhile, to enable early detection of neurologic dysfunction and institution of rehabilitation. Our ultimate goal should not merely be the restoration of function, but to return to the patient his quality of life. The challenge for the future therefore lies in refining surgical technique and enhancing cerebral protection so that a meaningful improvement in patient outcomes can be ostensibly achieved in years to come.

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