Totally normothermic aortic arch replacement without circulatory arrest

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Abstract

Background: Various techniques have been proposed for cerebral protection during the surgical treatment of complex aortic disease. The authors propose a revisited strategy of normothermic replacement of the aortic arch to avoid limitations and complications of profound hypothermic circulatory arrest. Materials and methods: From April 2000 to May 2006, 19 patients with an aneurysm of the aortic arch and 10 patients with an acute (7) or a chronic (3) aortic dissection underwent a totally normothermic, complete replacement of the aortic arch using three pumps: One pump ensured antegrade cerebral perfusion, at a flow rate adapted to obtain a pressure of 70 mmHg in the right radial artery, and required a selective cannulation of the supra-aortic vessels. A second pump ensured body perfusion at a flow rate adapted to obtain a pressure of 55 mmHg in the left femoral artery and was situated between the right femoral artery and the right atrium. A special balloon aortic occlusion catheter was placed in the descending thoracic aorta. A third pump ensured intermittent normothermic myocardial perfusion via the coronary venous sinus. The arch reconstruction was performed with no time limit. Results: There were two operative, in-hospital (6.8%) mortalities. All others patients were rapidly extubated, except one, with no neurological sequelae, and postoperative course was uneventful, without coagulopathy or hepato-renal impairment.

Conclusions: In the light of these results, a normothermic procedure is possible for arch surgery and may ensure a more physiological autoregulation of cerebral blood flow while maintaining body perfusion without high vascular resistances.

Keywords: Aortic arch; Normothermia; Selective antegrade cerebral perfusion

1. Introduction

Since the first case of arch replacement under normothermic conditions published by De Bakey in 1957 [1], operative techniques have shifted to hypothermic (deep or moderate) body perfusion with or without selective brain perfusion. Progressive refinements of these hypothermic techniques have allowed aortic arch repair to achieve increasingly encouraging results. Nevertheless, it remains a difficult procedure dependent on maintenance of cerebral integrity and therefore on the method of cerebral protection used.

Three essential elements of this protection are the subject of numerous papers in the international literature, reflecting the importance of this surgical challenge:

- maintenance or arrest of cerebral perfusion,
- anterograde or retrograde direction of perfusion,
- recommended temperature: profound or moderate hypothermia or normothermia.

The fact that deep hypothermic circulatory arrest of 25 min or more and advanced age are associated with neuropsychological deficits [2], the morbidity induced by hypothermia and especially the impossibility of reliably establishing an optimal cerebral blood flow (CBF) indexed to perfusion temperature have encouraged the search for a new operative strategy.

In the light of 29 cases, we propose a revisited normothermic approach to aortic arch replacement. This simple and reproducible technique has enabled us to perform the surgical procedure more 'calmly', thereby allowing a more radical and more distal procedure on the isthmic aorta, and avoiding any 'hasty surgery', which could interfere with the quality of complete repair.

2. Patients and methods

2.1. Description of clinical cases

From April 2000 to May 2006, 29 patients underwent normothermic aortic arch replacement.
Inclusion criteria were:
- any arch lesion extending proximally on the ascending aorta and/or distally to the descending/isthmic aorta;
- elective, urgent or emergent operations.

Exclusion criteria were:
- presence of major carotid lesions, including extensive atherosclerosis contraindicating anterograde cannulation, either tight stenoses or dissection;
- presence of major preoperative neurological disorders.

The mean age of the patients was 59.6 ± 11 years (range: 40—82 years).

In addition to the standard assessment, the preoperative assessment included thoracic CT, multidimensional transoesophageal echocardiography and duplex ultrasound study of the supra-aortic vessels.

2.2. Monitoring

In addition to the standard monitoring, a specific monitoring to this type of surgery comprised of:
- monitoring of rectal and oesophageal temperature to maintain body temperature between 36 and 37 °C during cardiopulmonary bypass (CPB);
- double intra-arterial blood pressure monitoring:
  - right radial artery, reflecting brachiocephalic artery perfusion,
  - left femoral artery, reflecting right femoral artery perfusion;
- monitoring of cerebral protection by a bispectral index, corresponding to integration of three EEG leads.

2.3. Technique

Anaesthetic induction was performed with Propofol and Sufentanyl and was maintained with Propofol.

The first step of surgery consisted of dissection of the right groin to expose the right common femoral artery.

Dissection of the supra-aortic vessels was always performed via a midline sternotomy without the need for a complementary neck incision.

In only one case, presenting a type I aortic dissection, the brachiocephalic vein was ligated and sectioned to obtain better exposure of the horizontal aorta.

The brachiocephalic artery, the left common carotid artery and the left subclavian artery were identified and isolated. Cannulation sites clinically free from atheromatous plaque were identified by digital palpation of these vessels.

After heparinization (300 IU/kg), CPB was established between the right femoral artery and the right atrium.

The cardiopulmonary bypass diagram was as follows (Fig. 1).

Two arterial lines were derived from the oxygenator:
- The main arterial line: passing through pump A and ensuring right femoral (body) perfusion.
- An accessory arterial line (cardioplegia exit) ending in a Y division:
  - One arterial line passing through a second pump (pump B) supplying the two cerebral perfusion cannulas introduced into the brachiocephalic artery (3.5 mm cannula) and left common carotid artery (2.5 mm cannula); these two angled cannulas presented a bevelled distal orifice and lateral orifices (Foch Carotid Cannula Ref. 470035 and 470025 Polystan®) to avoid any risk of poor cerebral perfusion. During selective brain perfusion, the left subclavian artery was clamped.
  - One arterial line passing through a third pump (pump C) supplying the retrograde perfusion cannula in the coronary sinus (Ref. RC014T Edwards Lifesciences®) ensuring normothermic blood myocardial protection; this cardioplegia was repeated every 7—10 min to prevent any delay in restoration of high-energy reserves.

Perfusion presented the following features:
- normothermic perfusion of the lower half of the body to obtain a left femoral pressure greater than or equal to 55 mmHg;
- normothermic cerebral perfusion to obtain a right radial pressure of 70 mmHg;
- intermittent normothermic retrograde coronary perfusion to obtain a coronary venous sinus pressure between 30 and 40 mmHg.

The specific features of surgery were as follows:
- Cerebral perfusion cannulas were introduced by the classical cannulation technique into the base of the vessels, 1—2 cm distal to their origin, leaving room for clamping.
The descending thoracic aorta was occluded either by direct clamping (one case) or, more often, by insertion, on the isthmic part of the aorta, of a Robiscek Pruitt aortic occlusion catheter after opening the horizontal aorta (Ref. 12F-RPK Ideas for Medicine®) (Fig. 2), or the unique size in diameter balloon of the Djumbodis system (Saint-Come Chirurgie®) (Fig. 3). In case of aortic dissection, the occlusion device was inserted in the true lumen and inflated on so to obtain a sufficient haemostasis while perfusing the right femoral artery, as summarized above.

- The surgical procedure varied according to the disease and the extent of the lesions.

All 29 patients had complete aortic arch replacement with totally normothermic technique

- nineteen patients with an aneurysm of the aortic arch,
- ten patients with acute (7) or chronic (3) aortic dissection, associated with
- twelve Bentall procedures and four Tirone David procedures,
- fifteen patients with implantation of twenty-three Djumbodis stents,
- one reimplantation of a graft between arch prosthesis and right common carotid artery,
- one mitral valvuloplasty.

2.4. Follow-up

Clinical, echocardiographic and neurological examinations were performed immediately postoperatively, after extubation, on discharge from the department, at the second postoperative month, and 6–12 months after the operation.

3. Results

3.1. Surgical results

The surgical procedure was performed with no time limit; the mean CPB time was 157 ± 14 min and the mean clamping time was 121 ± 18 min.

Mean duration of cerebral perfusion was 49 ± 17 min.

In order to maintain a perfusion pressure greater than or equal to 70 mmHg in the right radial artery, cerebral circulation pump flow rates varied from 680 to 1100 ml/min, indicating variable degrees of vasoplegia from one patient to another.

No elephant trunk technique was performed.

The operative procedure was considered to be complete in all cases. No problem of haemostasis of the distal aortic suture line was observed.

After de-airing the heart and aortic unclamping, defibrillation occurred spontaneously in all patients. Cardiopulmonary bypass was stopped without using inotropic drugs in all patients.

Mean serum lactate during CPB, at the start of CPB and 6 h after stopping CPB were 1.8, 2.1 and 1.7 mmol/l, respectively.

- Operative mortality: 6.8% (two patients).
- All patients were extubated between the 4th and the 16th postoperative hour, except one, and mean blood loss in the drains was 545 ± 105 ml on the first day.
No transient or permanent neurological deficit suggestive of poor perfusion was observed, except in one patient, with partial clinical recovery.

No coagulopathy, hepatic or renal impairment was observed.

Mean blood loss drainage was 545 ± 105 ml on the first day.

Postoperative mean ejection fraction was similar to preoperative values (52% vs 56.6%).

Follow-up was complete for all patients, ranging from 4 to 70 months (mean: 21.6 ± 9 months).

For all survivors, follow-up was free from cardiac or neurologic events. Besides no echocardiographic or CT abnormalities could be observed during routine imaging follow-up. No alteration of cognitive function and no disorders of orientation, attention or memory were detected on neurological examination (Mini Mental Scoring).

Among the 13 patients who had a Djumbodis Stenting of the descending aorta, 12 had a good RMI result (Fig. 4); in 1 patient, the false lumen of the dissection was only partially occluded.

### 4. Discussion

In view of the limitations of circulatory arrest with profound hypothermia, and anterograde or retrograde selective perfusion, and considering the absence of any proven additional neurological protective effect of hypothermic CPB compared to normothermic CPB [3], it seemed logical to evaluate a completely normothermic approach to aortic arch surgery.

This strategy is supported by two elements: the superiority of anterograde cerebral perfusion over retrograde perfusion [4] and the superiority of normothermic CPB over hypothermic CPB, as demonstrated by several published randomized studies [3,5].

As hypothermia decreases but does not eliminate cerebral metabolism [6], maintenance of cerebral perfusion appears to be essential. Cannulation of supra-aortic vessels was popularized by Bachet et al. [7] and appears, for our team, like a true revolution in aortic surgery. Their original technique was based on the principle of maintaining cerebral perfusion with cold blood (6—12 °C) combined with circulatory arrest of the lower half of the body with moderate hypothermia (25—28 °C). This technique clearly provided better results than those of isolated profound hypothermia, and was adopted as the technique of choice in our centre from 1991 to 2000, with satisfactory results, identical to those reported by the original team.

However, determination of the cerebral perfusion pump flow rate remained arbitrary with a number of unknowns. CBF represents about 15% of cardiac output, i.e. 50 ml/min/100 g of cerebral tissue. This flow rate is distributed heterogeneously in the various regions of the brain: 20 ml/min/100 g of white matter and 80 ml/min/100 g of grey matter. A 30% reduction of the theoretical cerebral blood flow also induces loss of autoregulation properties [8]. Autoregulation of cerebral blood flow rate is partially maintained at a temperature of 20 °C but is altered and is largely compromised at temperatures less than 20 °C because of an increase in the cerebral vascular resistances (339 ± 48%) [6]. Anterograde cerebral perfusion between 6 and 12 °C therefore appears to be potentially harmful with a risk of excessive or insufficient cerebral perfusion.

The advantage of retrograde cerebral perfusion technique, popularized by Japanese teams [9], is its simplicity and it appears to give better results than the use of profound hypothermia and circulatory arrest. However, many clinical studies have confirmed the useless or insufficient effects of retrograde cerebral perfusion (RCP), leading Griep to think that RCP should be abandoned, as it increases the number of transient postoperative neurological disorders and could transform small strokes to large strokes [10—14].

This discussion of the route of cerebral perfusion tends to indicate that anterograde selective perfusion is superior to retrograde perfusion, but perfusion temperature remain controversial.
Separate hypothermia was proposed by a Japanese team [15] and combines retrograde cerebral perfusion at 37 °C with femoral perfusion at 24–26 °C. Moderate hypothermia was then adopted by other teams, and we believe that it constitutes a logical improvement of cerebral protection. As compared to techniques using moderate hypothermia and selective antegrade cerebral perfusion as advocated by Jean Bachet, the technique hereby described offers the advantage to considerably reduce the duration of CPB while allowing the surgeon to perform arch replacement in a safe and unhaughty fashion. As a result of this improvement, the mean time of CPB was only 30 min higher than the mean of aortic clamping time in this series. Other potential benefits include a better haemostasis, indeed in the current series, drainage blood loss was minimal despite extensive aortic arch repair.

Considering brain protection, due to the dramatic evolution of CPB components since the De Bakey first case (including arterial filters), we could observe excellent neurological outcome in this series by simply adopting to normothermic selective cerebral perfusion a standard circuit.

We recently presented a preliminary clinical series of six patients operated by a totally normothermic approach [16]. We prospectively decided to reproduce conditions strictly identical to those of classical normothermic cardiopulmonary bypass. Furthermore, by eliminating the "time factor" in aortic arch repair, it allows a more radical and more distal procedure on the isthmic aorta.

Normothermic CPB and myocardial protection at 37 °C have gradually become part of standard practice in many adults or paediatric surgical teams, on the basis of the superior results obtained due to maintenance of the patient’s physiological state. Simple application of this technique to aortic arch surgery should provide the same advantages and eliminate the adverse effects of hypothermia and circulatory arrest. It therefore appeared simpler to continue normothermic antegrade cerebral perfusion, as physiological as possible, reproducing conditions strictly identical to those of classical CPB.

Furthermore, by eliminating the "time factor" in aortic arch repair, it allows a more radical and more distal procedure on the isthmic aorta. In addition, femoral artery perfusion obviates ischemic multiorgan injuries in this limited series. Further refinements of the technique including a perfusing occluding balloon should allow to obviate the risk of false channel pressurisation or deleterious malperfusion.

A parallel can be drawn between myocardial protection and cerebral protection: during 1970s, surface hypothermia (Shumway) combined with hypothermic CPB was gradually abandoned in favour of antegrade coronary perfusion at 4 °C and then retrograde perfusion (Buckberg). Normothermic myocardial protection was proposed at the end of 1980s (Lichenstein, Salerno) and is now used routinely in a large number of cardiac surgery centres in combination with normothermic CPB.

With a time lag of 12–15 years, cerebral protection has advanced along similar lines: no perfusion with profound hypothermia, followed by hypothermic antegrade perfusion and then hypothermic retrograde perfusion. Normothermia appears to be the next logical step in cerebrospinal protection, allowing more physiological autoregulation of cerebral blood flow.

References

do, and you can go very far on the isthmic ridge and the isthmic part of the aorta to do your suture line. So the clamp is taking a lot of space.

**Dr Dion:** And in case of chronic dissection, don’t you have a problem with some retrograde perfusion of the false lumen?

**Dr Touati:** No. The only problem we had in one patient of chronic dissection was when I was inflating the balloon and put the Djumbodis system, thrombi of the false lumen was like toothpaste in the aorta, and we saw that on the MRI, and anticoagulation permits the complete eliminating of that.

**Dr S. Kucuker (Ankara, Turkey):** You haven’t cooled down your patients. You have worked on 37 degrees. But you have to stop your femoral perfusion while putting the stents in. You said it takes only 5 min. But if in case it gets longer, you may have problem with the spinal cord protection. And again, at 37 degrees, your cardiopulmonary bypass times are quite long. So how did you protect the myocardium?

**Dr Touati:** Concerning the perfusion in the femoral artery, it was not completely interrupted, but the flow was around 1 l or 1.5 l, just to obtain the direct vision of the aorta when you are inflating the balloon and the Djumbodis system. So it takes, really, 2 to 5 min. And the perfusion of the heart was obtained like standard myocardial protection on the sinus, retrograde sinus, every 8 min. So we don’t have a problem with that.

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**Editorial comment**

**Normothermic selective cerebral perfusion — how safe is it?**

I read the article by Touati and colleagues with great interest [1]. In this study, the authors analyze the surgical outcome of 29 patients who underwent total aortic arch replacement under normothermic conditions without circulatory arrest. There was one in-hospital death (3.4%). Transient neurological deficit was apparently seen in one patient. The authors compare their technique and results with those of arch replacements under profound hypothermic circulatory arrest and propose that their strategy ensures a more physiological autoregulation of cerebral blood flow and maintains body perfusion without high vascular resistance. Before we go on to discuss this work, I think it is important to remember that the authors are reporting on their experiences with the above technique in a very small series of patients — a fact that almost automatically precludes any definitive conclusions to be drawn from here.

Antegrade selective cerebral perfusion (SCP) has now established itself as the most reliable method of brain protection during aortic arch repair operations. While the technique is basically performed under profound or at least moderate hypothermic conditions, there have been attempts to raise the temperature to somewhere around 30 °C. Some surgeons have even attempted normothermic SCP as in the present study. This takes us back to Dr DeBakey, who, as early as in 1957, had performed aortic arch operations using high-flow, high-pressure perfusion under normothermic conditions [2]. However, discouraged by the high incidence of in-hospital mortality and neurological complications with this strategy, it was subsequently abandoned. Since then, there have been numerous attempts to make SCP a safer and more efficient brain protection method. The authors have correctly pointed out the role of Dr Jean Bachet in popularizing the technique. However, the important contributions by the numerous Japanese aortic surgery groups in this regard failed to get a mention, which is rather regrettable.

In the early nineties of the last century, we conducted a series of experimental studies to resolve the temperature, flow, pressure, and other related issues concerning SCP. On the basis of the results of those studies, we have settled into our present SCP strategy, which is bilateral two-vessel perfusion (innominate or right axillary artery and the left common carotid artery) with a flow rate of 10 ml/kg/min and flow pressure of 40 mmHg under moderately hypothermic condition (at a rectal temperature of 25 °C). Alpha-stat strategy is used for blood pH management. However, three-vessel perfusion that is additional left subclavian artery perfusion is performed in selected patients, who have occlusion of right vertebral artery, dominant left vertebral artery, and lack of efficient intracranial arterial communication to avoid the risk of vertebro-basilar artery insufficiency. With this strategy, we have been able to achieve results of total arch replacement operations that rank among the best in this specialty [3,4]. While the results achieved by the authors in the present study are commendable, there are a few issues that merit further evaluation. First of all, is there any specific rationale for setting the perfusion pressure at 70 mmHg? I do understand that the authors were trying to maintain the cerebral autoregulation and that this pressure would be adequate for most patients without a history of cerebral vascular accidents. However, as we know that in hypertensive elderly patients with a history of apoplexy, the cerebral autoregulation tends to shift to the right and that such a perfusion pressure might cause watershed infarction in these patients. Secondly, the two-vessel perfusion under a normothermic condition, as employed by the authors, theoretically leaves the vertebro-basilar region of the brain vulnerable to ischemic insult. Thirdly, the authors employ three separate pumps and a descending aortic occlusion balloon placed in an antegrade fashion. Such a technique has the potential of cluttering the operative field and may also be considered cumbersome. Placing an occlusion balloon in the true lumen of the descending aorta in patients with aortic dissection may also be technically difficult and risky. Moreover, the retrograde systemic perfusion through the femoral artery can be considered a suboptimal strategy in the sense that it may result in underperfusion of the abdominal viscera, particularly in patients with dissection. The cannulation technique employed by the authors can be called a blind cannulation technique as they do not transect the neck vessels and cannulate under direct vision — a technique that is practiced by many aortic surgeons nowadays. There was one patient who apparently suffered some form of neurological deficit but recovered in the postoperative period. The nature of this