Operative techniques in patients with type A dissection complicated by cerebral malperfusion

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INTRODUCTION

Early mortality and morbidity after surgical treatment for acute type A aortic dissection (AAAD) has remained high over the last decades despite technical improvements and is still in the range of 10–30% [1–6]. The most important risk factor for this still high early mortality is the preoperative status of the patients [4, 7]. Especially end-organ malperfusion contributes significantly to perioperative death and is present in approximately one-third of all patients with acute aortic dissection [3, 7–9]. Coronary, cerebral, visceral and lower extremity malperfusion syndromes are most often associated with type A dissection.

A significant surgical dilemma is the treatment of AAAD patients with preoperative cerebral malperfusion [7]. Intimal tears in the proximal aorta often up to 37% [10] result in the involvement of the supra-aortic branches. Consequently, the impaired flow in the brain-supplying arteries is, besides coronary arteries, the most frequent form of malperfusion [7]. The reported incidence of neurological deficit before surgery in AAAD varies between 14% [7] and 20% [11]. The general surgical strategy in AAAD patients is directed towards (i) cannulation and perfusion of the true lumen, (ii) perfusion of all body regions intraoperatively, (iii) a certain degree of hypothermia, (iv) avoiding aortic cross-clamp during distal repair (open distal anastomosis), (v) avoiding changing arterial cannulation site and uncertain de-airing manoeuvres when resuming total body perfusion after distal aortic repair and (vi) unrestricted global perfusion postoperatively.

To develop an individual surgical plan for those patients with supra-aortic malperfusion, preoperative assessment of the extent of dissection and type of malperfusion is of utmost importance. This assessment is usually done with computed tomography angiography (CTA) preoperatively, which translates to only a few minutes of delay on the way to the operating theatre and is just as important for the surgical outcome as surgical experience [6, 12].

Matperlusion can be further validated intraoperatively by using transoesophageal echocardiography (TEE), orbital Doppler and near-infrared spectroscopy (NIRS) [9]. One has to keep in mind, however, that NIRS does not provide information in the basilar artery region [9].

There is an ongoing debate about the best surgical strategy for AAAD in general and even more for the high-risk subgroup of patients with cerebral malperfusion [9]. Despite a consensus that the true lumen of the arterial system should be cannulated [13], the approaches vary considerably. This lack of evidence to enable any recommendations for the choice of surgical methods is related to the fact that randomized studies in AAAD (with wide variations of pathologies) are very unlikely to be performed. Even though a meta-analysis of 14 papers between axillary artery and femoral artery perfusion has shown that axillary arterial perfusion had a significantly lower complication rate [14], routes that are currently advocated for AAAD include subclavian (right and left) cannulation, common carotid artery (right and left) cannulation [15, 16], cannulation of the innominate artery, peripheral cannulation of a non-dissected artery (femoral), ascending aortic cannulation (Fig. 1) [17] or apex of the left ventricle (transapical).

There is also no agreement about optimal protection (e.g. temperature) during circulatory arrest; however, even the best method of protection would be useless if the cerebral perfusion and other end-organ perfusion have not been restored during cardiopulmonary bypass (CPB) and aortic repair.

In this ‘Great Debate’, different approaches are being described and the rationale for doing so is explained by world-known experts in this field. Special emphasis will be placed on common carotid, subclavian and innominate artery cannulation for anastomotic cerebral perfusion (ACP). The rationale of retrograde cerebral perfusion (RCP) during selective cerebral perfusion is also described.
Supra-aortic cannulation offers several advantages in aortic arch surgery, among them, the possibility of easy establishment of cerebral perfusion without the need of any interruption, even during circulatory arrest of the lower body. This appears to be the reason for its increasing use, also in emergency [18, 19]. With supra-aortic cannulation, any manipulations on dissected and fragile arch arteries for the placement of perfusion cannulas can be avoided without abandonment of cerebral perfusion, at least, on the side being cannulated.

The usefulness of the innominate artery or axillary artery for cannulation can be considerably limited. The innominate artery is frequently involved in dissection and then not suitable for cannulation. The usefulness of the axillary artery is, taking cerebral perfusion into account, limited to the right side only, while the carotid artery can be used for cannulation and unilateral cerebral perfusion on both sides, according to the vascular pathology [15, 16].

In cases without malperfusion, our surgical team in Bad Neustadt uses a common carotid artery as a single approach for arterial return and chooses the suitable side on the basis of CTA. A common carotid artery is wider than an axillary artery, and the arterial wall is stronger. The arterial return via the common carotid artery is therefore sufficient enough even for very voluminous CPB flow in obese patients. In all our experience, we have never had to switch to another cannulation site for any reason, nor were any local alterations of the cannulated artery observed. There were 117 patients heavier than 100 kg with the heaviest presenting with a weight of 137 kg.

The CTA is of utmost importance for selecting the operative strategy and the choice of the proper side for cannulation of a carotid artery. Accordingly, the anaesthetist can use the jugular on the contralateral side for the placement of venous catheters. If there is no pathology demanding a choice of particular side, we prefer the right carotid artery for cannulation because the perfusion pressure is lower and the right-sided unilateral cerebral perfusion seems to have an advantage (even if only in theory) by supplying the right carotid and right vertebral arteries [15, 16, 20].

The approach to the carotid artery on the neck is simple and very fast, and this is very important in an emergency, especially in obese patients. With experienced hands, only about 15 min are needed from the initial skin incision to the completion of arterial cannulation. The skin incision of about 3–4 cm is made along the medial margin of the sternocleidomastoid muscle, beginning approximately 3 cm above its sternal insertion and continuing towards the earlap. The common carotid artery is isolated medial to the jugular vein and, after double cross-clamping, a longitudinal incision of about 1–1.5 cm is made between the clamps and an 8- or 10-mm vascular prosthesis is anastomosed end-to-side to the artery with a continuous 5.0 Prolene suture. Cross-clamping of the common carotid artery enables a clear view and safe anastomosing for general cases and in cases of dissected arterial wall in particular (Figs 2 and 3). Among more than 900 consecutive carotid cannulations performed up to date in our institution, we have never used tangential clamping, and the average cross-clamping time has been 8 ± 2 min.

During cross-clamping of the carotid artery, we do not use a shunt, but we do monitor the regional cerebral oxygen saturation with NIRS. This offers reliable information about the efficacy of cross-perfusion during the complete clamping of the carotid artery and, in turn, is crucial when unilateral cerebral perfusion is used for protection.

The dissection of the innominate artery and common carotid arteries is especially critical from a clinical as well as a surgical point of view. In such cases with malperfusion resulting from involvement of the aforementioned arteries, a combination of two arterial lines is of utmost importance and should be considered carefully on the basis of computed tomography imaging, even if clinical symptoms of malperfusion are missing. Any single cannulation below the origin of an affected artery can result in a worsening of cerebral perfusion before the aortic arch has been repaired. In turn, CPB with arterial return performed by cannulation of a supra-aortic artery distal to its obliterated true lumen can lead to impaired perfusion of the lower body (Fig. 4). Moreover, high resistance towards the aortic arch can lead to increased flow and pressure in the brain-supplying arteries and cause over-perfusion and neurological damage [21].

In such cases, arterial inflow through two arterial lines ensures sufficient perfusion of the head and lower body during extracorporeal circulation and simple and adequate cerebral protection during arch repair without the need of deep hypothermia with all its negative side effects [22, 23]. The use of two pumps is not necessary because the arterial resistance regulates the flow in particular lines automatically and, therefore, a bifurcated line from one pump offers adequate flow in both arms (Fig. 4). In some pathologies, the improved perfusion can, for sure, be achieved by a combination of subclavian-femoral inflow [24]; however, this approach would not ensure an adequate cerebral perfusion if the bifurcation of the innominate artery or carotid arteries were...
involved in the pathology (Fig. 4). In contrast, cannulation of a common carotid artery can be performed on the right or left side and enables, consequently, improved cerebral perfusion in accordance with vascular pathology (Fig. 5). After aortic repair and anastomosing of supra-aortic arteries with an arch prosthesis, it can happen that the normal flow in the true lumen of the affected artery cannot be restored. In such cases, or even in cases where the normal flow is uncertain, the side graft anastomosed with the carotid artery can be, after disconnecting the arterial line, easily used as an additional aorto-carotid bypass [23]. The same goes for cases in which multiple tears or extensive damage of supra-aortic arteries (mostly in the innominate artery) make a sure anastomosis with the arch graft impossible. In such infrequent situations, the proximal ligation of the respective artery (innominate or left carotid) and use of the cannulation side graft as an aorto-carotid bypass is a safe surgical option [23].

The aorto-carotid bypass can be easily routed below the brachiocephalic vein to avoid its potential constriction.

In conclusion, our operative strategy in AAAD, regardless whether complicated by cerebral perfusion or not, is based on CTA, which is only abandoned in very exceptional clinical situations. On the basis of this imaging that demonstrates the particular anatomopathology of the aorta and its branches, the patient-adapted perfusion strategy and cannulation site or sites are chosen, which consist of one, two or even, in exceptional cases, three arterial lines (perfusion of carotid arteries on both sides plus aortic perfusion, e.g. through a femoral artery). Our perfusion strategy includes at least one carotid artery in order to

Figure 2: Operative view of the common carotid artery isolated by typical approach along the medial edge of the sternocleidomastoid muscle. Longitudinal border between the dissected and non-dissected arterial wall is well visible and marked with arrows (A). The artery is cannulated by anastomosing the graft to its non-dissected wall (B).

Figure 3: Operative view of common carotid artery and its bifurcation isolated by typical approach along the medial edge of the sternocleidomastoid muscle. The transverse border between the dissected common carotid artery and non-dissected bifurcation is well visible and marked with arrows (A). The artery is cannulated by anastomosing the graft to its bifurcation above the dissected wall (B).
ensure sufficient cerebral perfusion even before aortic repair and to allow easy and safe cerebral protection during this procedure.

CANNULATION OF THE AXILLARY ARTERY

Jean Bachet, Paris, France

Among various cannulation techniques, cannulation of the right axillary artery, reintroduced in the mid-90s by Sabik et al. [25], appears as the method that associates the largest and most important advantages with the most reduced technical and physiological drawbacks. It has therefore become more and more popular.

The artery may be approached in the deltopectoral sulcus or immediately under the right clavicle. At this level, the artery is very seldom the site of atheromatous lesions or dissection.

The artery can be cannulated directly according to the same techniques as for the femoral artery. The skin incision is either vertical in the deltopectoral sulcus or horizontal following the inferior ridge of the clavicle. After partial division of the major and minor pectoralis muscles, the artery is dissected free at a distance of about 4–5 cm. The artery is often covered by the axillary vein and its many small tributaries. Those small vessels should be carefully ligated or cauterized in order to avoid further bleeding.

Direct cannulation

The artery is controlled upstream of and downstream from the cannulation site by means of snares and proximally and distally cross-clamped after proper heparinization. A 5/0 polypropylene purse-string suture is carried out on the anterior wall of the vessel and put on a tourniquet. A transverse or longitudinal (according to the surgeon’s habits and preference) small incision (about 5 mm) is made through which a 14- to 18-French arterial cannula can be carefully placed into the arterial lumen at a distance of 3–4 cm. It may be harmful to place a larger arterial cannula because of the increasing risk of injuring the artery and because, in most patients, the flow admitted through a 14- to 18-French cannula (4–5 l/min) is largely enough to allow a proper perfusion during CPB.

Figure 4: Schematic illustration demonstrating aortic dissection with obliteration of the true lumen (light-coloured) of the innominate artery and its bifurcation caused by flap and false lumen (dark-coloured). To restore cerebral perfusion and ensure sufficient perfusion of the lower body during cardio-pulmonary bypass, a combination of two arterial lines (above and below the obliteration) is necessary. To achieve this goal in the demonstrated sample, the right common carotid artery and the femoral artery were cannulated using a Y-shaped arterial line. See text for further details.

Figure 5: (A) Preoperative computed tomography (CT) angiography showing extension of the dissection membrane into the right subclavian and axillary artery (arrows) and subtotal occlusion of the left common carotid artery with cerebral malperfusion (arrowhead). (B) Postoperative CT angiography after complete arch replacement. To restore cerebral perfusion and ensure sufficient perfusion of the lower body, the left common artery and the femoral artery were cannulated using a Y-shaped arterial line. Supra-aortic arteries were anastomosed end-to-end with respective branches of a quadrifurcated vascular prosthesis after a careful squeezing of clots out of the false lumen in the left common carotid artery (no use of Fogarty catheter). Arrow marks the completely open true lumen of the left common carotid artery. In case of any doubts in respect to unhindered flow after anastomosing, the cannulation side graft can be easily used as additional aorto-carotid bypass.
The arterial cannula is then tightly attached to the tourniquet or directly to the artery by the upstream snare (Fig. 6A). Some surgeons prefer to use a sort of Seldinger technique to cannulate the artery. After dissecting it free and controlling the vessel as described above, they puncture the artery and place a guide into it. Then, using increasing dilators, they place a proper arterial cannula and fix it to the vessel. However, because of the cannula design and mode of placement, it might be pushed too far and beyond the carotid-subclavian arteries bifurcation; thus, in our opinion, the disadvantage of this technique is that the cerebral flow during CPB and selective cerebral perfusion is jeopardized.

The main criticism of this direct method of cannulation is that the artery may be too small to accept a cannula of adequate diameter to achieve proper arterial inflow during CPB.

Therefore, many groups cannulate the axillary artery by means of a small Dacron® tube (8 or 10 mm in diameter) implanted end-to-side on the artery.

**Cannulation through a side graft**

The approach, dissection and control of the axillary artery are similar to those for direct cannulation. After snaring and clamping the artery upstream and downstream, a 1.5-cm longitudinal incision is carried out on the anterior wall of the vessel. Then, an 8- to 10-mm Dacron or polytetrafluoroethylene (PTFE) short graft is sutured in an end-to-side manner on the artery by means of a continuous 5/0 polypropylene suture. After careful de-airing, the graft is connected to the main arterial line (Fig. 6B).

In any case, whatever technique is used, at the end of the cannulation process, appropriate care should be given to checking that the cannula and the arterial line are properly placed and fixed on the operating field in order to avoid any dangerous kinking during CPB.

The dissecting process rarely involves the right axillary artery; we never observed such a pathological condition. The innominate artery and the common carotid artery may be implied into the dissection process. If the axillary artery is not dissected, it can still be cannulated. The arterial perfusion flow would go mainly through the true lumen or equally through both true and false channels into the innominate artery and aorta.

However, in the rare cases in which the axillary artery is compromised, it must not be used as a cannulation site. The risk of injuring the artery beyond any possible repair and, moreover, the risk of implementing a severe cerebral malperfusion through the jeopardized carotid artery precludes any use of this vessel for arterial perfusion during CPB. Another arterial cannulation site must be chosen. Those are probably the cases in which femoral artery cannulation remains acceptable if a rapid use of CPB is mandated by the patient’s haemodynamic condition.

This technique has the advantage of allowing the use of a larger arterial cannula (Fig. 6B). It also permits perfusion of the whole right upper limb and control of the arterial pressure in the right radial artery. It seems that this method, although more time-consuming, provides improved results.

Many reports have emphasized the advantages of the right axillary artery cannulation during AAAD surgery. Among those, four groups have reported their experience and compared the results obtained with femoral and right axillary artery cannulation. The hospital mortality rate was reduced from a mean of 23% (19–30%) with femoral cannulation to a mean of 6.5% (5–8%) with axillary cannulation [18, 26–28]. Despite the fact that the studies were not randomized, the difference seems convincing enough.

Although it is generally less easy and takes more time than femoral cannulation, particularly in obese patients, right axillary artery cannulation is presently without any doubt the most favourable technique of arterial approach in surgery of AAAD (Table 1).

**CANNULATION OF THE INNOMINATE ARTERY**

Cannulation of the innominate artery may be considered as a good surrogate of right axillary artery cannulation as it shares most of its advantages. It is easily accessible in any circumstance, and its approach requires no other incision than sternotomy. In most adults, the artery has a diameter of 10–15 mm or even more and may easily and directly accept a cannula similar to the ones used for aortic cannulation. The length of this artery (5–7 cm) is sufficient to allow distal placement of the cannula and, thus, easy cross-clamping or division of the vessel near its origin (Fig. 7).

However, the main drawback of using this vessel for cannulation during repair of acute type A dissection is that:
the procedure cannot be carried out before the opening of the sternum;
- the vessel must be free of any dissecting process that might be difficult to assess preoperatively.

CEREBRAL PROTECTION

It is largely demonstrated that suppression of the cerebral flow in normothermia rapidly induces two kinds of reactions through which different metabolic and enzymatic pathways lead to cell death. This ischaemic condition is reversible within certain limits but rapidly becomes permanent when the flow is reduced to very low levels.

In 1975, Griepp described the use of profound hypothermia associated to total circulatory arrest during arch replacement [29]; within a few years, this method became universally accepted. Indeed, hypothermia markedly reduces oxygen demand and cerebral metabolism in general. But contrary to what has been thought for decades, even for very low temperatures, this metabolism is never reduced to nil [30]. Therefore, besides hypothermia, cerebral protection has also to include cerebral blood flow and autoregulation of the flow.

Based on more physiological and logical concepts, the method of selective antegrade cerebral perfusion maintaining the advantages of the circulatory arrest, suppressing the drawbacks of profound hypothermia and allowing a less limited time for the aortic repair, was described in the late 80s by Guilmet et al.

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**Table 1: Advantages and drawbacks of the various arterial cannulation techniques**

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<th>Cannulation site</th>
<th>Advantages</th>
<th>Drawbacks</th>
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<tr>
<td>Femoral arteries</td>
<td>Two sites</td>
<td>Retrograde perfusion</td>
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<td>Easy and conventional</td>
<td>Dissected vessels</td>
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<td>Cannulation first</td>
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<td>Possible venous cannulation</td>
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<td>Right axillary artery (and right brachial artery)</td>
<td>Cannulation first</td>
<td>Time-consuming</td>
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<td>Antegrade aortic perfusion</td>
<td>Uneasy in obese patients</td>
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<td></td>
<td>Cerebral perfusion</td>
<td>Fragile vessel</td>
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<td></td>
<td>No cannula switch</td>
<td>Veins and nerves</td>
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<td>Vessel seldom dissected</td>
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<td>Direct or side graft</td>
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<td>Left axillary artery</td>
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<td>Vessel seldom dissected</td>
<td>Uneasy in obese patients</td>
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<td>No cannula switch</td>
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<td>Direct or side arm</td>
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<td>Carotid arteries</td>
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<td>Easy and fast</td>
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<td>Cannulation first</td>
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<td>Vessel seldom dissected</td>
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<td>No cannula switch</td>
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<td>Innominate artery</td>
<td>Easy and direct</td>
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<td>Antegrade aortic perfusion</td>
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<td>No cannula switch</td>
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<td>Ascending aorta ‘regular’</td>
<td>Antegrade flow</td>
<td>Sternotomy first</td>
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<td>Totally dissected aorta?</td>
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<td>Ascending aorta ‘true lumen’</td>
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<td>Left ventricle apex</td>
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<td>Difficult apex repair?</td>
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Of course, a certain number of issues remain for which we have incomplete or no answers [36]. For example, what is the best level of core temperature? Many experimental studies and clinical reports have addressed this issue and their conclusions are somewhat divergent. However, most authors agree that profound hypothermia (<20°C) is unnecessary, and safe protection of the visceral organs and the spinal cord is provided by core temperatures between 23 and 27°C for a circulatory arrest duration up to 90 min [37–41].

Concerning the temperature of the cerebral perfusate data are also very variable. Recently, Salazar et al. in an experimental study in pigs compared two levels of perfusate temperature: 18 and 25°C. They concluded that systemic circulatory arrest with selective cerebral perfusion (SCP) at 25°C can be safely performed while providing comparable cerebral and end-organ protection to that of 18°C with SCP [42]. Clinically, Bachet et al. [43] obtained satisfactory results by perfusing the brain at 12°C, while Kazui et al. also obtained excellent results while perfusing the brain at 23°C [44–46]. So, it seems that the method is safe and efficacious for a wide range of perfusate temperatures.

Hence, the technique is presently widely accepted and the rate of adverse events has remained particularly low [47–51]. This may not apply totally to the patients operated on for acute type A dissection, since the neurological disorders observed after the surgical procedure are not always dependent on the surgical strategy and technique but also on the preoperative condition of the patient.

Nevertheless, as pointed out by several authors [52–54], we are convinced that right axillary artery cannulation associated with selective ACP at moderate hypothermia is presently the best possible method for treating acute type A dissection, regardless of the aortic repair itself. This recommendation is based on the facts that (i) it is technically easy enough; (ii) it can be initiated before opening the chest; (iii) it provides a safe and almost unlimited duration of brain protection and, thus, aortic repair; and (iv) it avoids unnecessary complicated manoeuvres during CPB.

CANNULATION OF THE ASCENDING AORTA AND SUPERIOR VENA CAVA FOR RETROGRADE CEREBRAL PERFUSION

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Our fundamental approach to circulation management for major aortic arch reconstruction is as follows:

The major morbidity associated with short (<35–40 min) arch reconstructive times is focal cerebrovascular accident (CVA). The major morbidity with long (>35–40 min) arch reconstructive times is global cerebral ischaemia. Therefore, based on this conceptual framework, the most advantageous and theoretically appropriate circulation management technique is RCP with hypothermic circulatory arrest (HCA) for ‘short’ (open distal and hemiarch procedures) arch reconstructive times and ACP (either cold or tepid) for ‘long’ (total arch or significant brachiocephalic procedures). RCP is superior in the prevention of embolic, focal neurological deficit and ACP is superior in global cerebral ischaemia reduction.

However, for the majority of arch reconstructions for aortic dissection, and especially with significant supra-aortic vessel
dissection, RCP offers more advantages over ACP with no reproducible difference in neurological or survival outcome between these two valuable adjunctive techniques.

Cannulation decision-making in type A dissection extending to supra-aortic vessels

Although we have developed and changed our cannulation techniques over the past 15 years, our present preference regarding cannulation in the setting of acute dissection into the supra-aortic vessels is ‘direct aortic’ with ultrasound/TEE guidance into the true lumen using the Seldinger technique (Fig. 1). This allows for easy RCP and subsequent conversion to direct cannulation of the right and/or left common carotid if more extensive total arch reconstructive time (>35–40 min) is necessary (5–10%).

RCP’s primary advantage over ACP is that it allows for a completely unencumbered arch reconstruction with no obstructive clamps or cannulae within the confined field of reconstruction. Secondly, there is no need for additional remote cannulation sites or incisions (e.g. left subclavian arterial exposure) with RCP, which add both time and morbidity potential. There is also no need to place traumatic clamps on the often extremely fragile and friable dissected innominate/carotid arteries (supra-aortic vessels) that can easily complicate reconstruction and portend distal carotid dissection and thrombosis. RCP affords a ‘no touch’ principle to the handling of the dissected supra-aortic vessel walls with better exposure than ACP. Moreover, despite a relatively sparse amount of objective data that support that RCP facilitates effective delivery and uptake of metabolic substrates at the brain cell level, RCP provides an extremely effective means of maintaining consistent hypothermic cerebral temperature and washing out of air and both micro- and macro-particle debris from the arch and supra-aortic vessels during open arch reconstruction. Target flow rates of 200–400 cc/min are delivered to an isolated superior vena cava to yield a target jugular venous pressure of 25 mmHg [55–57]. There may actually be an advantage to initiating RCP with a slightly higher perfusion pressure (30–40 mmHg) transiently to enhance uniform cerebral distribution [58], although continued higher jugular pressure at this level is not recommended because it may lead to cerebral oedema. Collectively, the use of RCP has been shown to reduce new stroke rates as low as 1–5% compared with rates of 9–12% with HCA alone [55, 59–68]. Mortality rate has also been shown to be improved using RCP with HCA, particularly in patients with longer HCA times [11]. RCP with HCA for arch reconstructive times <45 min is generally very safe, and as effective as ACP [69, 70].

Currently, during repair of acute type A dissection, we use HCA with RCP for predicted circulatory arrest times of <40 min (hemi-arch and straightforward 2-branch arch replacements), and HCA with ACP is reserved for more difficult reconstructions with arch reconstructive times of >40 min (more complex total arch replacements).

Cannulation technique for retrograde cerebral perfusion

RCP is best orchestrated using a separate pump head to allow for optimal de-airing following arch reconstruction. Cannulation is performed using a 26-F flexible right-angled single-staged venous cannula with its tip positioned in the right internal jugular vein cephalad to its confluence with the innominate vein. This cannula is then connected into the venous outflow line joining drainage of the right atrium via another dual-staged cannula. The SVC cannula is connected to this circuit using a Y-connector that also has a side-arm Luer lock connection through which the cardiologypump circuit (the separate pump head) is connected to allow cold (16°C), oxygenated blood to be perfused into the SVC. Once HCA is initiated, the SVC is snared around the 26-F cannula and cold blood perfusate administered via the cardiologypump circuit at a rate of 200–400 ml/min to maintain a jugular venous pressure of 20–25 mmHg. Higher flow rates or pressures may lead to cerebral oedema, although there are some data to support that there may be better delivery of oxygen and nutrients with slightly higher pressures approaching 35–40 mmHg [71–74]. Pressures are monitored via a short right internal jugular venous catheter placed preoperatively. While it is generally accepted that RCP probably does not provide adequate nutritive delivery to meet cerebral metabolic demands, the technique clearly facilitates maintenance of uniform brain temperature during HCA and flushes air and debris out of the cerebral circulation, preventing embolic phenomena.

Cannulation technique for antegrade cerebral perfusion with dissected supra-aortic vessels (after direct ascending central cannulation)

When total arch replacement with brachiocephalic arterial reconstruction is required due to extensive tears within the arch or dissection of either carotid artery, we utilize ACP to allow for longer circulatory arrest periods. Several techniques to deliver ACP have been described. However, when we use central aortic cannulation, we provide ACP without direct subclavian or carotid cannulation. In order to exclude all dissected components of the supra-aortic vessels, we isolate either the right or left common carotid. We do this within the chest or via a separate neck incision during systemic cooling and after core temperature is below 30°C. If the dissection extends beyond the carotid bifurcation into the internal carotid, the dissection flap is repaired and tacked down at the level of the distal common carotid and the false lumen flow excluded at this point. Often, in this extreme situation, we will proceed to the hybrid room and place a carotid stent after appropriate imaging to define common carotid involvement. The vessel that has the worst or most extensive dissection is grafted first to establish optimal perfusion through it prior to reaching the point of HCA and arch reconstruction. Perfusion to the rest of the body is maintained throughout this time via central inflow including the other carotid that is not being isolated, and then the isolated innominate/carotid is transected and reconstructed using a custom trifurcated graft. Upon completion of this first branch vessel reconstruction, the trifurcated graft is de-aired and perfused via the proximal inflow limb of the trifurcated graft that is cannulated via an extension off the primary arterial pump inflow to establish ACP via this graft. The pressure is monitored in this portion of the circuit beyond the graft cannulation site, and resistance is calibrated by partial clamping of the inflow line to the trifurcated graft to ensure that there is not inappropriately high unilateral cerebral perfusion pressure while maintaining inflow to the rest of the body.

HCA is subsequently not initiated until reaching over 4 min of electromechanical silence (ECS) with electroencephalography monitoring (average temperature of 18–20°C) [75] but, at that point, the remaining arch and brachiocephalics are reconstructed using the
selective ACP that was just established. The second carotid arterial reconstruction is the first vessel to be completed upon initiation of HCA, and antegrade perfusion through it is begun immediately following its reconstruction in order to maximize cerebral blood flow during the remaining arch reconstruction. Use of ACP in this manner allows for extended periods of HCA with superb neurocerebral protection [76]. Flow rates to achieve a carotid mean blood pressure of 50–60 mmHg (~1–1.5 L/min) are maintained. Others have also demonstrated the efficacy of utilizing ACP with only moderate systemic hypothermia [47], although we have maintained a protocol of utilizing neurophysiological monitoring to direct arch reconstruction.

Amidst thoracic aortic reconstruction, once adequate neurocerebral protection is achieved with ECS, arch reconstruction becomes the priority. The primary goals during dissected arch reconstruction are (i) optimal neurocerebral protection (which includes minimizing the extent of HCA time required), (ii) restoration of unobstructed true lumen blood flow to all supra-aortic branches and the descending aorta and (iii) exclusion of false lumen blood flow. Preservation of the left vagus and recurrent laryngeal nerves are also important and minimizing the need for clamps on either the left common carotid or left subclavian arteries during reconstruction (as with the RCP technique) alleviates potential injury. Total aortic arch replacement with or without an elephant trunk extension is indicated when an intimal tear within the arch extends into the proximal descending aorta or extends throughout the arch on the greater curve aspect, i.e. involves separation or disruption of the ostia of the brachiocephalic vessels. Circumferential dissection around the brachiocephalic vessels may also indicate the need for total arch replacement with a branched graft, particularly if there is separation of the media in each or any of the branch vessels causing the aortic wall around the brachiocephalics to fail to satisfactorily accept sutures. When these circumstances determine the need for a lengthier period of circulatory arrest (e.g. 45–60 min), use of ACP should be considered as these longer HCA times are better tolerated with the addition of ACP. However, once arch reconstruction is completed, RCP can be extremely effective in flushing out arch branch vessel air and debris. The distal graft should then be cannulated and CPB resumed centrally to optimize antegrade true lumen blood flow patterns.

RESULTS OF AUTHORS’ COMBINED SERIES

The total combined experience of the University of Pennsylvania (1993–2012) and the University of Pittsburgh (2007–2013) dissection series equals 869 procedures. A standardized approach to type A dissection was institutionalized and 566 (65%) of these procedures were completed using an isolated RCP cerebral circulation management technique. The remainder were treated using ACP and were generally more complex or total arch procedures. The overall in-hospital mortality rate for the RCP group was 8.4% (48/566) and the overall new CVA rate was 3% (17/566).

CONCLUSION

The tenets of aortic arch reconstruction in type A dissection are to protect the brain from ischaemic and embolic injury, to ensure patency of the brachiocephalic vessels with reduced trauma to these friable vessels, to obliterate false lumen blood flow during acute dissection repair and to restore descending thoracic aortic true lumen flow with a durable distal anastomosis. Optimizing neurocerebral protection with hypothermia and adjunctive cerebral perfusion allows for safe, extended periods of circulatory arrest and open arch reconstruction. In particular, RCP during open arch surgery dramatically improves our ability to extend circulatory arrest to allow for safe, precise, expeditious and unencumbered arch reconstructions.

Furthermore, in answer to ‘How do I cannulate if there is cerebral malperfusion’?

Our preferred cannulation strategy for acute type A dissection is a direct aortic approach into the true lumen under echo guidance. In 65% of our cases, we use RCP as our circulation management strategy, and 35% of cases are completed with an ACP strategy, usually in conjunction with a 3-branch total arch repair.

DISCUSSION

Several arterial cannulation techniques have been suggested to establish CPB in AAAD patients with dissection extending to supra-aortic vessels. Despite concerns over cerebral oedema during carotid cannulation for both cerebral and whole body perfusion, carotid cannulation has promising results even in obese patients requiring higher CPB flow. If the carotid artery is dissected, its cannulation should be combined with cannulation of another artery. Furthermore, the side graft anastomosed with the carotid artery can be easily used as an aorto-carotid bypass after the end of CPB, if necessary. Cannulation of the true lumen of dissected subclavian or innominate artery is feasible; however, it necessitates an additional cannulation of one or both carotid arteries for cerebral protection. Direct cannulation of the ascending aorta with RCP offers exceptional advantages over ACP. There is no need for additional remote cannulation, no need to place traumatic clamps on the dissected supra-aortic arteries and no need for canulas within the field of reconstruction. However, RCP alone should not be applied if more extensive arch reconstruction (>35–40 min) is necessary, since it may lead to global cerebral ischaemic complications.

In summary, all proposed techniques are proved to be safe and efficacious in AAAD patients with dissected supra-aortic vessels. There are no randomized trials on cannulation site in AAAD, and therefore making a definitive recommendation is not possible. However, there is a general agreement on what should be avoided in AAAD patients, such as, for instance, operating under hypothermia without cerebral perfusion, clamping of dissected arteries, dissected subclavian or carotid artery cannulation with no second arterial line, or RCP alone for arch reconstruction requiring >40 min. Outcome in AAAD patients undergoing emergency surgery is not just a matter of cannulation site; however, appropriate strategies for CPB establishment may increase in-hospital survival and freedom from neurological complications.

Conflict of interest: none declared.

REFERENCES

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