SELECTIVE ANTEGRADE CEREBRAL PERFUSION IS THE TECHNIQUE OF CHOICE

MARKO TURINA
University of Zurich
Zurich, Switzerland
What is so special about the operation on the aortic arch?

- Disease process is usually well defined: degenerative, dissecting or spurious aneurysm; or a ruptured aortic plaque.
- Standard methods of cardiopulmonary bypass (with avoidance of aortic cannulation) and myocardial protection can be utilized.
- Classic aneurysm repair with graft replacement is usually possible.
- It is the necessity for interrupting the normal brain circulation which makes this operation challenging.
How to protect the brain during procedures on the aortic arch?

Historically, several different methods were utilized for brain protection when operating on the aortic arch:

- Antegrade perfusion of the cerebral vessels.
- Deep hypothermic circulatory arrest.
- Retrograde perfusion of superior vena cava (or even total body retrograde perfusion)
- Perfusion via subclavian artery, or combined subclavian and left carotid perfusion.
- Nowadays, only the last two are routinely used.
ARTICLES

Determinants and clinical significance of jugular venous valve competence

J Fisher, F Vaghaiwalla, J Tsidlik, H Levin, J Brinker, M Weisfeldt and F Yin

SUMMARY We studied the function of right internal jugular vein valves during cardiac catheterization in 32 patients and external jugular vein valves in vitro from 13 dogs. Patients with normal central venous pressure had competent valves during cough-induced transvalvular pressure gradients of 52.4 ± 8.6 mm Hg. Ten of 15 patients with elevated central venous pressure had either incompetent or absent internal jugular valves, the latter occurring only in patients with long-standing, severe tricuspid regurgitation. During coughing, competent valves were also demonstrated in the left internal jugular and in the right and left subclavian veins. The excised canine valves were competent at a static transvalvular pressure of 81.8 ± 3.7 mm Hg. Five of six excised valves remained competent during pulsatile transvalvular pressure of 64.8 ± 1.9 mm Hg. Thus, thoracic inlet venous valves are usually competent during sudden increases in intrathoracic pressure. These valves may play an important role in establishing the extrathoracic arteriovenous pressure gradient necessary for forward blood flow during cardiopulmonary resuscitation and other states with high intrathoracic pressure.
Venogram of the SVC during cough: tight vein valves in internal jugular and subclavian vein

From Fisher et al., Circulation 1982
<table>
<thead>
<tr>
<th>Vein (n = 13)</th>
<th>Forward ΔP (mm Hg)</th>
<th>Forward flow (ml/min)</th>
<th>Retrograde ΔP (mm Hg)</th>
<th>Retrograde flow (ml/min)</th>
<th>Competency index (%)</th>
<th>Classification</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>72</td>
<td>940</td>
<td>72</td>
<td>1.5</td>
<td>0.2</td>
<td>Competent</td>
</tr>
<tr>
<td>7</td>
<td>53</td>
<td>1370</td>
<td>53</td>
<td>3.5</td>
<td>0.3</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>102</td>
<td>1550</td>
<td>102</td>
<td>0.0</td>
<td>0.0</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>54</td>
<td>1380</td>
<td>54</td>
<td>1.2</td>
<td>0.1</td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>24</td>
<td>1250</td>
<td>24</td>
<td>0.0</td>
<td>0.0</td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>12</td>
<td>974</td>
<td>12</td>
<td>0.0</td>
<td>0.0</td>
<td></td>
</tr>
<tr>
<td>18</td>
<td>14</td>
<td>1010</td>
<td>14</td>
<td>0.0</td>
<td>0.0</td>
<td></td>
</tr>
<tr>
<td>19</td>
<td>20</td>
<td>590</td>
<td>20</td>
<td>0.0</td>
<td>0.0</td>
<td></td>
</tr>
<tr>
<td><strong>Mean ± SEM</strong></td>
<td><strong>43.9 ± 11.3</strong></td>
<td><strong>1133.0 ± 110</strong></td>
<td><strong>43.9 ± 11.3</strong></td>
<td><strong>0.9 ± 0.5</strong></td>
<td><strong>0.1 ± 0.04%</strong></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>12</td>
<td>1104</td>
<td>12</td>
<td>78</td>
<td>7.0</td>
<td>Partially competent</td>
</tr>
<tr>
<td>11</td>
<td>68</td>
<td>912</td>
<td>68</td>
<td>56</td>
<td>6.1</td>
<td></td>
</tr>
<tr>
<td>17</td>
<td>20</td>
<td>308</td>
<td>20</td>
<td>32</td>
<td>10.4</td>
<td></td>
</tr>
<tr>
<td><strong>Mean ± SEM</strong></td>
<td><strong>33.3 ± 17.5</strong></td>
<td><strong>774.4 ± 239.8</strong></td>
<td><strong>33.3 ± 17.5</strong></td>
<td><strong>55.3 ± 13.3</strong></td>
<td><strong>7.8 ± 1.3%</strong></td>
<td></td>
</tr>
<tr>
<td>8*</td>
<td>86</td>
<td>210</td>
<td>86</td>
<td>90</td>
<td>43.0</td>
<td>Incompetent</td>
</tr>
<tr>
<td>14</td>
<td>68</td>
<td>1570</td>
<td>68</td>
<td>360</td>
<td>22.9</td>
<td></td>
</tr>
<tr>
<td><strong>Mean ± SEM</strong></td>
<td><strong>77.0 ± 9.0</strong></td>
<td><strong>890 ± 680</strong></td>
<td><strong>77.0 ± 9.0</strong></td>
<td><strong>225 ± 135</strong></td>
<td><strong>33.0 ± 10.0%</strong></td>
<td></td>
</tr>
</tbody>
</table>

*From Fisher et al., Circulation 1982*
<table>
<thead>
<tr>
<th>Vein (n = 6)</th>
<th>Forward ΔP (mm Hg)</th>
<th>Forward flow (ml/min)</th>
<th>Retrograde ΔP (mm Hg)</th>
<th>Retrograde flow (ml/min)</th>
<th>Classification</th>
</tr>
</thead>
<tbody>
<tr>
<td>14</td>
<td>26</td>
<td>101.5</td>
<td>58</td>
<td>30.9</td>
<td>Incompetent</td>
</tr>
<tr>
<td>15</td>
<td>24</td>
<td>40.8</td>
<td>60</td>
<td>1.4</td>
<td>Competent</td>
</tr>
<tr>
<td>16</td>
<td>20</td>
<td>65.8</td>
<td>64</td>
<td>0.0</td>
<td></td>
</tr>
<tr>
<td>17†</td>
<td>20</td>
<td>73</td>
<td>68</td>
<td>0.0</td>
<td></td>
</tr>
<tr>
<td>18</td>
<td>18</td>
<td>95.3</td>
<td>70</td>
<td>6.2</td>
<td></td>
</tr>
<tr>
<td>19</td>
<td>22</td>
<td>29</td>
<td>62</td>
<td>0.0</td>
<td></td>
</tr>
<tr>
<td>Mean ± SEM (veins 15–19)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>20.8 ± 1.0</td>
<td>60.8 ± 11.8</td>
<td>64.8 ± 1.9</td>
<td>1.5 ± 1.2</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*The regurgitant fraction was not calculated because equal forward and retrograde transvalvular gradients could not be imposed.
†Valve was incompetent under static conditions.
Abbreviation: ΔP = transvalvular pressure.

From Fisher et al., Circulation 1982
Does retrograde cerebral perfusion via superior vena cava cannulation protect the brain?

Andreas Künzli*, Patrick O. Zingg, Gregor Zünd, Boris Leskosek, Ludwig K. von Segesser

Table 1. In vitro assessment showed no evidence of reliable and sufficient blood flow to the brain via the internal jugular veins

<table>
<thead>
<tr>
<th></th>
<th>14 preparations of 8 females and 6 males</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Right internal jugular vein</td>
</tr>
<tr>
<td></td>
<td>14 valves (100%)</td>
</tr>
<tr>
<td></td>
<td>Left internal jugular vein</td>
</tr>
<tr>
<td></td>
<td>13 valves (92%)</td>
</tr>
</tbody>
</table>

Selective flow measurement through the internal jugular veins of seven patients (max. inlet pressure 29 mmHg)

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Four</td>
<td>0 ml/min</td>
</tr>
<tr>
<td>One</td>
<td>2500 ml/min</td>
</tr>
<tr>
<td>One</td>
<td>340 ml/min</td>
</tr>
<tr>
<td>One</td>
<td>6 ml/min</td>
</tr>
</tbody>
</table>
Retrograde cerebral perfusion can be severely impaired by competent jugular vein valves.
Anatomic and physiologic arguments for antegrade cerebral perfusion

- **Antegrade perfusion** through carotid and vertebral arteries reaches the brain in a normal flow pattern and is distributed along established arterial channels.
- **Vein valves** exist in jugular veins, which in **retrograde perfusion** can prevent the nutritive flow to reach the brain tissue.
- **Retrograde perfusion** must be administered in **deep hypothermia**; otherwise, it is not reliable.
Percent changes in middle cerebral artery blood flow velocities measured by transcranial Doppler technique in humans

Brain flow during hypothermia with antegrade (ante) and retrograde cerebral perfusion (RCP) in primates. During RCP, extremely low flow values were found in all areas examined. Those flow values differed significantly from the pre-arrest values at 18°C (p < 0.05).

Aortic and Peripheral Vascular Surgery

Unilateral Antegrade Cerebral Perfusion Through the Right Axillary Artery Provides Uniform Flow Distribution to Both Hemispheres of the Brain

A Magnetic Resonance and Histopathological Study in Pigs

Jian Ye, MD; Guangping Dai, PhD; Lawrence N. Ryner, PhD; Piotr Kozlowski, PhD; Luojia Yang, MD; Randy Summers, MSc; Jiankang Sun, MSc; Tomás A. Salerno, MD; Rajmund L. Somorjai, PhD; Roxanne Deslauriers, PhD
Percentage changes in rCBV in right and left hemispheres during U-ACP at 15°C and at 60 minutes of reperfusion with CPB (R-CPB) at 37°C. No significant difference was observed between right and left hemispheres.

During retrograde perfusion through SVC only 1/10’000 of flow reaches brain capillaries

RCP via cerebral capillaries: microspheres recovered from brain  

Non-brain capillary perfusion 9.19 cc

Veno-arterial shunts 0.8 cc

Veno-venous shunts

SVC input 100 cc

90 cc IVC (RA) recovery

10 cc Aortic Arch recovery

Hypothermic circulatory arrest with moderate, deep or profound hypothermic selective antegrade cerebral perfusion: which temperature provides best brain protection?


Abstract

**Objective:** Selective antegrade cerebral perfusion (SACP) seems to be associated with a better outcome compared to hypothermic circulatory arrest (HCA) alone. This study was undertaken to evaluate the influence of different SACP temperatures on the neurological integrity. **Methods:** Twenty-six pigs were included in the study and assigned to 100 min HCA at 20 °C body temperature without (n = 6) or with either 10 °C (n = 6), 20 °C (n = 7) or 30 °C (n = 7) of SACP. Haemodynamics, metabolics and neurophysiology (EEG, SSEP, ICP, sagittal sinus saturation) were monitored. Animals were sacrificed 4 h after reperfusion and brains perfused for histological and molecular genetic assessment. **Results:** There were no clinically relevant differences in haemodynamics between groups. The rise in ICP during SACP was significantly more marked in the 30 °C group (p < 0.05) and remained high during the entire experiment. In the 10 °C group the rise in ICP was postponed, but increased during reperfusion. The 20 °C group showed a slight increase of ICP over time, but remained significantly lower compared to HCA (p < 0.05). Sagittal sinus saturation decreased during SACP at 30 °C (p < 0.05). EEG recovery was most complete in the 20 °C group (p < 0.05). RT-PCR analysis of brain tissue revealed a reduction for heat shock protein (HSP-72) in 20 °C (p < 0.05) and 10 °C animals (p = 0.095). Histopathological evaluation showed a reduction of edema and eosinophilic cells in the groups treated with SACP. **Conclusion:** In this model, SACP is superior to HCA alone. Regarding the optimal temperature for SACP, it seems that 20 °C provides adequate brain protection in comparison to the potential detrimental effects of moderate (30 °C) and profound (10 °C) temperatures.

© 2006 Elsevier B.V. All rights reserved.
Percent of animals (pigs) with EEG recovery after 100 minutes of circulatory arrest determined at 3 h after reperfusion

Cardiopulmonary support and physiology

Neuropsychometric outcome following aortic arch surgery: a prospective randomized trial of retrograde cerebral perfusion

D.K. Harrington, MBChB, MRCSa, M. Bonser, DBO, RGNa,*, A. Moss, BSca, M.T.E. Heafield, MB, BS, FRCPa, M.J. Ridoch, PhD, CPsychol, MCSPA, R.S. Bonser, MB, BCh, FRCP, FRCS, FRCS (C/Th)a
Figure 1. Changes in PCO2 (A) and PO2 (B) in retrograde cerebral perfusion (RCP) outflow blood specimens measured at two different time points in individual patients who had two or more serial measurements available for analysis (n = 15)

Influence of antegrade cerebral perfusion on averaged SF-36 (+/-1 SD) score for patients from group 1, group 2, and group 3.

In this prospective randomized trial, neuropsychiatry tests show less postoperative decline in the selective cerebral perfusion

Perfusion Via Axillary Artery Results In Less Cerebral Embolization (Deflection?)

Cerebral microsphere distribution, expressed as mean {+/-} SD for aortic and axillary cannulation (n = 5), indicating fewer spheres in the cerebral circulation during axillary cannulation (canine study)

Various methods of administering the antegrade brain perfusion

- Cannulation of the right axillary artery, via graft or cannula; most common method.
- Antegrade cannulation of the innominate and right carotid artery.
- Combined axillary and femoral artery perfusion.
(A) A pursestring suture (5-0 polypropylene) is placed anteriorly in the exposed subclavian artery

Simplified technique for selective cerebral perfusion

The distal anastomosis phase in group B2 patients

From Barbeau et al, Ann Thor Surg 1999
Subclavian cannulation technique
ACUTE TYPE A DISSECTION: Cannulation

University Hospital Zurich, 1997 - 2002 (122 patients)

**Early mortality in %**

- Femoral: 24%
- Subclavian: 8%

\[ p = 0.0179 \]
Yearly number of axillary artery cannulations performed either directly or with a side graft

Table 1 Summary of the Analyzed Reports in the Literature

<table>
<thead>
<tr>
<th>Axillary cannulation</th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Direct</td>
<td>N = 691</td>
<td>Perioperative Mortality, n (%)</td>
<td>Local Complications, a n (%)</td>
<td>Neurologic Complications, b n (%)</td>
</tr>
<tr>
<td>Via side graft</td>
<td>715</td>
<td>36 (5.2)</td>
<td>27 (3.9)</td>
<td>43 (6.2)</td>
</tr>
<tr>
<td>Total c</td>
<td>1,635</td>
<td>94 (5.75)</td>
<td>32 (1.96)</td>
<td>82 (5.02)</td>
</tr>
<tr>
<td>Femoral cannulation</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>General</td>
<td>N = 4,056</td>
<td>149 (3.67)</td>
<td>18 (0.44)</td>
<td>116 (2.85)</td>
</tr>
<tr>
<td>In type A dissection</td>
<td>1,025</td>
<td>149 (13.73)</td>
<td>7 (0.65)</td>
<td>116 (10.7)</td>
</tr>
</tbody>
</table>

a Vascular or neuronal complications caused by the cannulation.

b Cerebral neurologic events.

c All reported cases with axillary cannulation are summarized. The two other axillary groups summarize those studies reporting technical aspects and results of the axillary cannulation. There is a clear trend towards an improved neurologic outcome in the axillary cannulation group (neurologic complications: 5.02% versus 10.7%). This also results in a reduced mortality (5.75% versus 13.73%). The incidence of local complications was markedly lower when the side graft technique was used (0.7% versus 3.9%).

N = number of patients reported.
Incidence of neurological damage after arch surgery increases with patient’s age

Multivariate analysis:
OR 4.5,  p < 0.001*

* (grouped data; patients ≤ 60 years of age vs patients > 60 years)

Hagl  C. et al.; J Thorac Cardiovasc Surg 2001;121:1107-1121
Brain circulation during right axillary artery perfusion

Willis circle: is it safe to perfuse only one carotid and subclavian artery?
The minimally invasive computed tomography angiogram with good illustration of the brain vascular anatomy

Willis circle: in reality not so simple as in the textbooks
RESULTS: In our material 22% of the anterior communicating arteries and 46% of the left posterior communicating arteries were missing. In this anatomic population the perfusion to the left hemisphere might have been insufficient in 14% of the patients at a threshold of 0.5 mm and in 17% at a threshold of 1 mm.

CONCLUSIONS: When the right axillary artery is used for perfusion, the circulation to the contralateral hemisphere seems to be good for most patients undergoing operations of the aortic arch, but additional means of brain protection are still needed.
A, The triple-branched stent graft is a branched 1-piece graft consisting of a self-expandable nitinol stent and polyester vascular graft fabric.

Postoperative computed tomographic scans show that all stent grafts were fully opened and not kinked; there was no space or blood flow surrounding the triple-branched stent graft.
Unresolved questions about antegrade cerebral perfusion

- **Necessary flow rate**: usually quoted as 10 ml/kg/min, but no hard data in support of this particular flow rate.
- **Perfusion pressure**: usually given as 50 – 70 mmHg, with some experimental evidence; but where to measure? The right radial is unpredictable, and left radial is obviously lower. Use cannula tip?
- **What to do about the lower body**: when innominate artery is clamped and left carotid and subclavian blocked, what is the ischemic tolerance of abdominal organs, and at what temperature?
- **Optimal method of cannulation**: axillary artery (graft or cannula?); with a single cannula or additional one in left carotid; or innominate and subclavian artery directly, after sternotomy.
Antegrade vs. retrograde cerebral perfusion

Summary

- Antegrade cerebral perfusion provides superior brain protection in arch surgery.
- Isolated subclavian artery perfusion is sufficient when only a short (15 – 20 minutes) interruption of normal flow pattern is necessary.
- Perfusion via subclavian and right carotid artery is advised for longer periods of flow interruption.
- Additional lower body perfusion might be advantageous in complex cases (redos, etc.).
- With these techniques, perfusion at 28°C is possible, greatly shortening the CPB time.