Cerebral blood flow after hybrid distal hemiarch repair

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Abstract

OBJECTIVES: Aortic arch disease can be treated with hybrid repair (extra-anatomic bypass plus placement of aortic endoprostheses), but there is controversy about whether a bypass from one relatively small vessel will provide adequate blood flow to the entire brachiocephalic system. We, therefore, compared flow volumes before and after hybrid repair.

METHODS: We reviewed the records of 16 patients who underwent a hybrid distal hemiarch repair between October 2010 and May 2012. The procedure consisted of debranching of the left subclavian and left common carotid arteries, creation of a bypass to these vessels from the right subclavian artery by using a T-shaped synthetic graft, and placement of a stent graft. Preoperative and postoperative measurements of blood flow volume in the carotid and vertebral arteries and of regional cerebral blood flow were performed in ~70% of the patients.

RESULTS: Perioperative complications were one new-onset, fatal acute aortic dissection and two minor strokes. No major endoleaks occurred. Postoperatively, mean flow volumes in the right and left common carotid arteries, right and left internal carotid arteries, and right and left vertebral arteries were 423 and 393, 271 and 189, and 87 and 80 ml/min, respectively. Regional cerebral blood flow in the territories of the anterior, middle and posterior cerebral arteries was not significantly different from preoperative levels, as assessed both with and without administration of acetazolamide.

CONCLUSIONS: Hybrid distal hemiarch repair preserved regional cerebral blood flow and vasoreactivity, although flow in the common and internal carotid arteries was right-side dominant postoperatively.

Keywords: Aortic arch • Brain • Hybrid repair • Cerebral blood flow

INTRODUCTION

Open repair of aortic arch disease remains a challenge, particularly in patients at high risk of operative complications. The endovascular approach is useful for treating complex aortic disease, but its application is limited when the arch is affected because adequate landing zones cannot be obtained without interrupting the supra-arch vessels. Hybrid repair, which includes endovascular aortic repair plus debranching and reconstruction of the supra-arch vessels, may be an option when standard endovascular procedures are not possible for anatomical reasons [1]. Several different hybrid repairs have been described [2]. To treat disease in the distal aortic arch, we preferentially perform debranching of the left subclavian artery (SA) and left common carotid artery (CCA) and creation of a bypass to these vessels from the right SA by using a T-shaped synthetic graft. This method is less invasive and simpler than other hybrid procedures, but concerns have been raised about the adequacy of blood flow to the entire brachiocephalic system provided by one relatively small vessel. We, therefore, measured global cerebral blood flow and blood flow in the carotid and vertebral arteries before and after hybrid repair in patients with distal aortic arch disease.

METHODS

We retrospectively reviewed the records of all 16 patients (14 men; mean age, 75.4 years [range 64–86 years]; 5 octogenarians) with aortic disease who underwent a distal hemiarch hybrid repair between October 2010 and May 2012. The repair was elective in 13 cases, urgent in 2, and emergency in 1. Aside from aortic disease, patients in the series had shock due to rupture of an aneurysm (n = 1), hemosputum (n = 1), congestive heart failure (n = 1), chronic obstructive pulmonary disease (COPD) (n = 2), cerebral infarction (n = 2), dementia (n = 2), cancer (n = 2), previous aortic surgery (n = 7), previous coronary artery bypass surgery (n = 2) and previous percutaneous coronary intervention (n = 5). Patients in whom preoperative Doppler echocardiography and magnetic resonance imaging assessments showed abnormal findings, such as the occlusion of the right SA and the right carotid artery and poor communication in the Circle of
Willis, were excluded from undergoing the procedure. The Institutional Review Board of Keio University Hospital approved the study, and written informed consent to undergo all procedures associated with the study was obtained from each patient.

The repair procedure was performed with the patient under general anaesthesia. The patient was placed supine, and the left CCA and both SAs were exposed. A ringed, 8-mm diameter, expanded polytetrafluoroethylene (ePTFE) prosthesis (W.L. Gore & Associates, Flagstaff, AZ, USA) with one branch (T-shaped device) was used as the conduit for a subcutaneous bypass (Fig. 1). Each end of the graft was anastomosed to an SA in an end-to-side fashion, and the end of the branch was anastomosed to the left CCA in an end-to-end fashion under simple clamping. The proximal stump of the left CCA was ligated. Neither extracorporeal circulation nor a shunt tube was used. After creation of the bypass, a stent graft (either a GORE TAG Thoracic Endoprosthesis, W.L. Gore & Associates; a Zenith TX2 TAA Endovascular Graft, Cook Medical, Bloomington, IN, USA; a Talent Thoracic Stent Graft, Medtronic, Santa Rosa, CA, USA or a Najuta Endograft, Kawasumi Laboratories, Tokyo, Japan) was deployed through the femoral artery and positioned so that the proximal end of the covered stent graft was in the aortic arch between the brachiocephalic artery and left CCA. All procedures were performed during the same operation.

Measurements of blood flow volume in the CCAs, internal carotid arteries (ICAs) and vertebral arteries (VAs) were done ~1 month postoperatively in 13 patients and preoperatively in 11 of those 13. Blood flow volume was determined by using Doppler sonography. Measurements of regional cerebral blood flow were done postoperatively in 13 patients and preoperatively in 12. Regional cerebral blood flow was determined by means of the graph-plot method employing N-isopropyl-p-[I-123] iodoamphetamine (I-123 IMP) single-photon emission computed...
tomography (SPECT). This technique permits quantitative assessment of cerebral blood flow without arterial blood sampling [3, 4]. Two SPECT investigations were performed: a baseline study that did not include administration of acetazolamide and, ~10 days later, a study of the response to intravenous acetazolamide (1 g). The I-123 IMP SPECT method measures regional cerebral blood flow as accurately as does positron emission tomography using oxygen 15-labelled water [4], even in areas of hyper-perfusion; therefore, it can be employed for quantitative assessment of cerebral vasoreactivity to acetazolamide.

Statistical analyses of the blood flow assessments were performed by using SPSS software (Version 17.0, SPSS, Inc., Chicago, IL, USA). Results are expressed as the mean ± SD. Student’s paired t-test was used to compare parametric variables. A P-value of <0.05 was considered to represent a significant difference between groups.

Table 1: Mean blood flow volumes in individual arteries and calculated total cerebral blood flow before and after hybrid aortic repair

<table>
<thead>
<tr>
<th>Artery</th>
<th>Volume before repair (ml/min)</th>
<th>Volume after repair (ml/min)</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rt CCA</td>
<td>443 ± 91</td>
<td>482 ± 117</td>
<td>0.24</td>
</tr>
<tr>
<td>Lf CCA</td>
<td>465 ± 99</td>
<td>406 ± 93</td>
<td>0.11</td>
</tr>
<tr>
<td>Rt ICA</td>
<td>234 ± 69</td>
<td>271 ± 94</td>
<td>0.17</td>
</tr>
<tr>
<td>Lf ICA</td>
<td>213 ± 56</td>
<td>189 ± 55</td>
<td>0.18</td>
</tr>
<tr>
<td>Rt VA</td>
<td>66 ± 27</td>
<td>88 ± 62</td>
<td>0.18</td>
</tr>
<tr>
<td>Lf VA</td>
<td>89 ± 32</td>
<td>81 ± 32</td>
<td>0.46</td>
</tr>
<tr>
<td>ICA + VA</td>
<td>601 ± 117</td>
<td>629 ± 144</td>
<td>0.36</td>
</tr>
</tbody>
</table>

Rt: right; CCA: common carotid artery; Lf: left; ICA: internal carotid artery; VA: vertebral artery.

RESULTS

One of the 16 patients who underwent a hybrid distal hemiarch repair died perioperatively of a new-onset acute aortic dissection. Two patients had a minor stroke postoperatively. No major endoleaks were observed on computed tomographic scanning performed before hospital discharge in the 15 surviving patients. The mean age of the 13 patients (12 men) in whom cerebral blood flow was studied was 74.1 ± 6.0 years (range 64–82 years), with 3 of those patients being octogenarians. Two of the 13 patients had an urgent operation and 11 had an elective procedure.

Figure 2 shows the preoperative and postoperative blood flow volumes in the CCAs and VAs, as well as the calculated total cerebral blood flow, for each of the 13 patients assessed. The mean preoperative and postoperative flow volumes in the right CCA, left CCA, right ICA, left ICA, right VA and left VA in the 12 patients for whom both preoperative and postoperative data were obtained are given in Table 1. Preoperatively, the mean flow volume values for the left and right CCAs were similar (P = 0.403), as were those for the left and right ICAs (P = 0.327). Postoperatively, mean flow volume was significantly greater in the right CCA compared with the left CCA (P = 0.025) and in the right ICA compared with the left ICA (P = 0.002). The mean total cerebral blood flow, calculated as the sum of flow volumes in both ICAs and both VAs, was 601 ± 117 ml/min preoperatively and 629 ± 144 ml/min postoperatively. There was no significant difference between preoperative and postoperative total cerebral blood flow (P = 0.362).

Individual results of baseline (no administration of acetazolamide) SPECT assessments of regional cerebral blood flow performed preoperatively (11 patients) and postoperatively (13 patients) are shown in Fig. 3. The mean preoperative and postoperative blood flow values (ml/100 g/min) in the territories of the right anterior cerebral artery (ACA), left ACA, right middle...
cerebral artery (MCA), left MCA, right posterior cerebral artery (PCA) and left PCA are given in Table 2.

Values obtained for regional cerebral blood flow on SPECT analysis after administration of acetazolamide in individual patients are shown in Fig. 4. The mean preoperative (11 patients) and postoperative (13 patients) blood flow values (ml/100 g/min) in the territories of the right ACA, left ACA, right MCA, left MCA, right PCA and left PCA are given in Table 3.

So far, none of the patients in the series have had a procedure-related complication, although the patient with COPD died 10 months postoperatively, after progression of the disease. The 2-year actuarial survival rate in the series, calculated with use of Kaplan–Meier analysis by including this patient and the patient who died during initial hospitalization, was 85.2% ± 9.8% (Fig. 5).

**DISCUSSION**

Recent advances have improved the outcomes of open repair of aortic arch disease, but the procedure remains a challenge, particularly in patients at high risk of complications [5]. Several innovative methods for treating aortic arch disease have been described. With respect to minimally invasive repair, procedures using fenestrated or branched stent grafts have yielded some promising results, but experience with these new endovascular devices is still limited. Hybrid repair is another alternative. In our previous experience with hybrid repair (33 patients), the source of the blood flow for the bypasses was the aorta. However, avoiding sternotomy and cardiopulmonary bypass has several potential advantages for high-risk patients [6, 7]. Because the greatest advantage of a hybrid procedure is its decreased invasiveness compared with open repair, sternotomy should be avoided if possible. In this study, we found evidence that the blood flow provided to the brachiocephalic system via the relatively small SA after a specific hybrid repair is adequate. In our patients who underwent this repair, postoperative total cerebral blood flow was similar to preoperative flow, although postoperative flow volume was significantly greater in the right compared with the left CCA (P = 0.025) and the right compared with the left ICA (P = 0.002). Moreover, there were no significant differences between preoperative and postoperative cerebral flow volumes (i.e., flow in the ACAs, MCAs and PCAs), with or without acetazolamide administration.

Using colour duplex sonography, Schöning et al. [8] measured blood flow volumes in the CCAs, ICAs and VAs in healthy adults and reported mean values of 470, 265 and 85 ml/min (either side), respectively. The mean value for total cerebral blood flow in their investigation was 701 ml/min (corresponding to 54 ± 8 ml/100 g/min), and no variations according to age or sex were

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**Table 2:** Baseline mean preoperative and postoperative regional cerebral blood flow values, as detected with SPECT.

<table>
<thead>
<tr>
<th>Artery</th>
<th>Preoperative flow (ml/100 g/min)</th>
<th>Postoperative flow (ml/100 g/min)</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rt ACA</td>
<td>37.2 ± 5.1</td>
<td>37.6 ± 4.6</td>
<td>0.64</td>
</tr>
<tr>
<td>Lf ACA</td>
<td>37.2 ± 5.3</td>
<td>37.1 ± 5.3</td>
<td>0.91</td>
</tr>
<tr>
<td>Rt MCA</td>
<td>38.9 ± 5.4</td>
<td>39.4 ± 4.9</td>
<td>0.29</td>
</tr>
<tr>
<td>Lf MCA</td>
<td>38.0 ± 5.0</td>
<td>37.8 ± 4.8</td>
<td>0.86</td>
</tr>
<tr>
<td>Rt PCA</td>
<td>40.6 ± 5.5</td>
<td>40.8 ± 4.9</td>
<td>0.84</td>
</tr>
<tr>
<td>Lf PCA</td>
<td>40.5 ± 4.9</td>
<td>40.4 ± 4.8</td>
<td>0.96</td>
</tr>
</tbody>
</table>

Rt: right; ACA: anterior cerebral artery territory; Lf: left; MCA: middle cerebral artery territory; PCA: posterior cerebral artery territory.

**Figure 4:** Preoperative and postoperative regional cerebral blood flow in arteries in individual patients after administration of acetazolamide, as detected with SPECT. Rt: right; ACA: anterior cerebral artery territory; MCA: middle cerebral artery territory; PCA: posterior cerebral artery territory; Lf: left.
our patients had a lower regional flow volume because of their age. Our patient population was relatively old because the hybrid procedure was used primarily in those at high risk of complications from conventional surgery. Postoperative values for regional cerebral blood flow in our study were very similar to preoperative values.

SPECT studies using acetazolamide to assess regional cerebral perfusion showed that our patients had good cerebral vasoreactivity, even after distal hybrid repair. Remarkably, cerebral blood flow hyporeactivity to acetazolamide was not observed in any territory, either preoperatively or postoperatively. These findings indicate that both the right and left hemispheres of the brain had sufficient perfusion reserve both before and after aortic arch repair.

The limitations of our study include the small number of patients, its retrospective nature, and the lack of long-term follow-up. So far, none of our patients have had a late complication from their repair. However, data on the long-term safety of the procedure and the durability of the patency of the implanted bypass grafts and endovascular devices are not yet available, although extra-anatomic bypass grafting using an ePTFE prosthesis in carotid and subclavian reconstruction has previously been found to provide excellent patency rates [9, 10]. Moreover, use of the hybrid procedure in young, active patients requires specific investigation. We conclude, however, that our study provides good preliminary evidence that efficient regional cerebral blood flow and vasoreactivity are preserved in patients who undergo hybrid distal hemiarch repair for aortic arch disease.

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Conflict of interest: none declared.

REFERENCES


Table 3: Mean preoperative and postoperative regional cerebral blood flow values, as detected with SPECT after administration of acetazolamide

<table>
<thead>
<tr>
<th>Artery</th>
<th>Preoperative flow (ml/100 g/min)</th>
<th>Postoperative flow (ml/100 g/min)</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rt ACA</td>
<td>46.7 ± 9.5</td>
<td>51.8 ± 10.2</td>
<td>0.09</td>
</tr>
<tr>
<td>Lf ACA</td>
<td>46.7 ± 9.4</td>
<td>51.7 ± 9.8</td>
<td>0.09</td>
</tr>
<tr>
<td>Rt MCA</td>
<td>48.5 ± 9.4</td>
<td>53.3 ± 10.2</td>
<td>0.09</td>
</tr>
<tr>
<td>Lf MCA</td>
<td>47.5 ± 9.1</td>
<td>51.9 ± 9.5</td>
<td>0.10</td>
</tr>
<tr>
<td>Rt PCA</td>
<td>50.3 ± 8.9</td>
<td>55.5 ± 9.9</td>
<td>0.08</td>
</tr>
<tr>
<td>Lf PCA</td>
<td>50.4 ± 8.9</td>
<td>54.7 ± 9.5</td>
<td>0.12</td>
</tr>
</tbody>
</table>

Rt: right; ACA: anterior cerebral artery territory; Lf: left; MCA: middle cerebral artery territory; PCA: posterior cerebral artery territory.

Figure 5: Two-year actuarial survival rate in the series. One patient died during initial hospitalization and another died 10 months postoperatively from chronic obstructive pulmonary disease.

observed. In our series, the mean preoperative values for the CCAs, ICAs and VAs were 454, 223 and 77 ml/min, respectively, and the calculated total cerebral blood flow was 601 ml/min. The postoperative values were 444, 230 and 84 ml/min, respectively, for the CCAs, ICAs and VAs and 629 ml/min for the calculated total cerebral blood flow. Thus, all the mean postoperative values in our study were consistent with the preoperative values, as well as with the values reported by Schöning et al., although we did observe that blood flow volumes in the right CCA and right ICA were significantly greater than those in the left CCA and left ICA after the hybrid procedure. Because the diameter of the left CCA and left ICA is smaller than that of the prosthetic grafts we used (8 mm), the grafts could not increase flow in the vessel. However, the greater flow volume on the right side compensated for the lower volume on the left.

Preoperatively, the mean values for regional cerebral blood flow volume (without administration of acetazolamide) in the territories of the right and left ACA, MCA and PCA in our patients ranged from 37 to 41 ml/100 g/min. These values were slightly lower than the mean value of 45.4 ml/100 g/min observed by Ishii et al. [4] in healthy volunteers (mean age 63.5 years). Perhaps...


