Magnetic Resonance Perfusion Tracks $^{133}$Xe Cerebral Blood Flow Changes After Carotid Stenting

Nerissa U. Ko, MD; Achal S. Achrol, BSc; Alastair J. Martin, PhD; Manju Chopra, MD; David A. Saloner, PhD; Randall T. Higashida, MD; William L. Young, MD

**Background and Purpose**—To compare magnetic resonance (MR) perfusion to gold-standard cerebral blood flow (CBF) determined by intra-arterial $^{133}$Xe washout method.

**Methods**—Eight patients with high-grade carotid stenoses underwent bolus-tracking MR perfusion and intra-arterial $^{133}$Xe washout before and after carotid stenting. MR perfusion was compared with $^{133}$Xe-CBF values using Pearson linear correlation analysis.

**Results**—We observed a mean 37±38% increase in $^{133}$Xe-CBF and a mean 19±27% increase in relative CBF (rCBF) by MR perfusion immediately after stent placement. Relative (percent) changes in MR-rCBF showed a close and linear correlation to those seen in $^{133}$Xe-CBF ($r=0.91; R^2=0.84; P=0.002$). There was a trend for MR perfusion to underestimate change in CBF at higher relative changes in flow.

**Conclusion**—Bolus-tracking MR perfusion correlates with $^{133}$Xe-CBF in estimating postprocedural increases in blood flow but may underestimate the magnitude of the change with higher relative changes. *(Stroke. 2005;36:676-678.)*

**Key Words:** cerebral blood flow ■ magnetic resonance imaging ■ xenon

---

Hemodynamic changes associated with interventional procedures such as stenting are poorly understood. MRI perfusion techniques have the ability to show acute changes in cerebral blood flow (CBF) within 3 hours after carotid stenting, but more studies are needed to validate these data. The purpose of this study was to compare bolus-tracking magnetic resonance (MR) perfusion to the well-validated quantitative $^{133}$Xe washout method to assess CBF in patients treated with carotid stenting.

**Methods**

After institutional approval and informed consent, 8 patients undergoing stenting for carotid stenosis were enrolled in the study. Degree of stenosis was determined from cerebral angiogram using North American Symptomatic Carotid Endarterectomy Trial (NASCET) criteria.

All procedures were performed in a combined “XMR” suite consisting of a 1.5T MR scanner (Philips Integra) and an integrated catheterization laboratory (Philips Integris V5000) connected via a floating tabletop, permitting rapid patient transfer between the 2 systems.

**Endovascular Technique**

A transfemoral approach under intravenous sedation was used in all cases with selective catheterization of the target artery as described previously. Systemic anticoagulation using intravenous heparin (70 U/kg) was continued for 12 hours. The stent device (Smart Stent, Precise Stent, or Mednova Carotid Stent; Abbott Laboratories) was selected on the basis of the anatomical location and diameter of the artery. No distal protection devices were used. Percutaneous suture ligation of the arteriotomy site was performed using the Perclose device (Abbott Laboratories). Each patient was closely monitored for 24 hours after the procedure. In general, intravenous labetalol or nicardipine was used to maintain systolic blood pressures $\leq 160$ mm Hg and diastolic blood pressure $\leq 100$ mm Hg. Each patient was treated with daily aspirin (325 mg) and clopidogrel (75 mg; Plavix; Bristol-Myers Squibb/Sanofi Pharmaceuticals) starting 3 days before the procedure.

**CBF Measurements**

$^{133}$Xe-CBF

These data were taken from a larger study of the physiological effects of endovascular stenting in intracranial and extracranial vessels. CBF was determined by the intra-arterial $^{133}$Xe injection initial slope method as described previously.

**MR Indices of Perfusion**

These data were taken from a larger study of the diagnostic accuracy of MR perfusion. MR acquisitions included angiography, phase-contrast quantitative flow, and single-shot $T_2^*$ perfusion as described previously. $T_2^*$-shortening gadolinium-based contrast (Omniscan; Amersham Health) was administered intravenously. Perfusion data were fit to a standard gamma variate function, and relative CBF (rCBF) and relative cerebral blood volume (rCBV) parameters were extracted. MRI regions of interest were selected to best approximate the field of view of the external $^{133}$Xe detectors, providing a more direct comparison between the 2 modalities (Figure 1).
Data Analysis

Descriptive statistics are expressed as mean±SD. Results were analyzed by Pearson linear correlation, linear regression, and ANOVA. In addition, we subjected the data for relative changes in CBF to analysis described by Bland and Altman9 and previously reported when comparing perfusion indices against the 133Xe gold standard.5

Results

Of 8 patients studied, 1 had visual loss from stroke and 1 had transient ischemic deficits. The 6 asymptomatic patients underwent elective stenting for restenosis after carotid endarterectomy, surgical risk, or patient preference. Average age was 74±4 years, with average stenosis of 72±8%. Hematocrit was 41±3%. Physiological parameters were obtained concurrent with each blood flow measurement (Table).

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Pretreatment</th>
<th>Pretreatment</th>
<th>Post-Treatment</th>
<th>Post-Treatment</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>MR</td>
<td>133Xe</td>
<td>133Xe</td>
<td>MR</td>
</tr>
<tr>
<td>Heart rate (bpm)</td>
<td>64±13</td>
<td>65±10</td>
<td>66±11</td>
<td>63±12</td>
</tr>
<tr>
<td>Pac02 (mm Hg)</td>
<td>...</td>
<td>42±3</td>
<td>42±2</td>
<td>...</td>
</tr>
<tr>
<td>Mean arterial pressure (mm Hg)</td>
<td>93±12</td>
<td>94±11</td>
<td>90±20</td>
<td>86±13</td>
</tr>
<tr>
<td>Elapsed time, min</td>
<td>0</td>
<td>173±23</td>
<td>216±24</td>
<td>307±44</td>
</tr>
<tr>
<td>Elapsed time, h</td>
<td>0</td>
<td>2.9±0.4</td>
<td>3.6±0.4</td>
<td>5.1±0.7</td>
</tr>
<tr>
<td>133Xe-CBF (mL/100 g/min)</td>
<td>...</td>
<td>34±10</td>
<td>45±13</td>
<td>...</td>
</tr>
<tr>
<td>MR-bfICA (mL/s)</td>
<td>2.6±1.9</td>
<td>...</td>
<td>...</td>
<td>4.1±2.8</td>
</tr>
<tr>
<td>MR-rCBF*</td>
<td>0.72±0.15</td>
<td>...</td>
<td>...</td>
<td>0.84±0.18</td>
</tr>
<tr>
<td>MR-rCBV*</td>
<td>7.2±1.4</td>
<td>...</td>
<td>...</td>
<td>7.3±1.2</td>
</tr>
</tbody>
</table>

Mean±SD.
*Expressed in relative units.

133Xe-CBF measured immediately before and after stent placement (mean 48±17 minutes) showed a mean 37±38% increase. Bolus tracking MR perfusion measured within 1 hour demonstrated a mean 19±27% increase in rCBF (Table). Changes observed by the 2 modalities showed close and linear correlations (Figure 2A through 2F).

We calculated the “limits of agreement” between the relative changes determined by MR measurements and by 133Xe-CBF method (Figure 2G through 2I). There was a trend for MRI to underestimate the extent of perfusion increase at higher degrees of change.

Observed correlations were not significantly affected by adjusting for physiological parameters, type of anesthesia, time between measurements, and patient characteristics. There were no differences between symptomatic and asymptomatic patients.

Discussion

We report the first demonstration of acute changes in CBF after carotid stenting measured by bolus-tracking MR perfusion and 133Xe washout methods. Our results show a strong linear correlation between qualitative changes in MR perfusion and quantitative 133Xe-CBF. Relative changes in rCBF had the strongest correlation. However, rCBV did not show a strong correlation and may reflect different states of autoregulation that are not necessarily correlated with perfusion rates.

Because of the spatial limitation of the radioactive tracer technique, we only examined ipsilateral CBF correlations. MRI has the ability to assess perfusion changes in the contralateral hemisphere. Further studies will be necessary to compare CBF changes in other brain regions. Use of bolus-tracking MR perfusion data may improve selection of patients who may benefit from procedures such as stenting. These methods can accurately demonstrate acute hemodynamic effects of interventional revascularization techniques.

Acknowledgments

This work was supported by PHS grants K23 NS044014-01A1 (N.K.); RO1 NS27713 and K24 NS02091 (W.L.Y.). The authors gratefully acknowledge the contribution of Nancy Quinnine, RN, and Louis Juravsky, MD, for assistance in conducting these studies; John...
Huberty for assistance in preparation of the radiopharmaceuticals; Carroll Schreibman and Broderick Belenson for preparation of this manuscript; and the other members of the UCSF Brain Arteriovenous Malformation Study Project.

References


Figure 2. Comparison of changes in perfusion before and after carotid stenting. A through C, Relative (%) changes vs 133Xe-CBF: A, MR–bulk flow internal carotid artery (bfICA; r = 0.26; R² = 0.07; P = 0.528). B, MR-rCBV (r = 0.62; R² = 0.39; P = 0.099). C, MR-rCBF (r = 0.91; R² = 0.84; P = 0.002). D through F, Absolute changes versus 133Xe-CBF: D, MR bfICA (r = 0.86; R² = 0.74; P = 0.006). E, MR-rCBV (r = 0.33; R² = 0.11; P = 0.424). F, MR-rCBF (r = 0.75; R² = 0.56; P = 0.033). G through I, Limits of agreement. G, MR-bfICA (mean 54; SD 109%). H, MR-rCBV (mean 33; SD 30%). I, MR-rCBF (mean 18; SD 17%).

678 Stroke March 2005

by guest on October 22, 2017
http://stroke.ahajournals.org/ Downloaded from
Magnetic Resonance Perfusion Tracks $^{133}$Xe Cerebral Blood Flow Changes After Carotid Stenting

Nerissa U. Ko, Achal S. Achrol, Alastair J. Martin, Manju Chopra, David A. Saloner, Randall T. Higashida and William L. Young

*Stroke*. 2005;36:676-678; originally published online February 3, 2005; doi: 10.1161/01.STR.0000155743.60019.e5

*Stroke* is published by the American Heart Association, 7272 Greenville Avenue, Dallas, TX 75231
Copyright © 2005 American Heart Association, Inc. All rights reserved.
Print ISSN: 0039-2499. Online ISSN: 1524-4628

The online version of this article, along with updated information and services, is located on the World Wide Web at:
http://stroke.ahajournals.org/content/36/3/676

Permissions: Requests for permissions to reproduce figures, tables, or portions of articles originally published in *Stroke* can be obtained via RightsLink, a service of the Copyright Clearance Center, not the Editorial Office. Once the online version of the published article for which permission is being requested is located, click Request Permissions in the middle column of the Web page under Services. Further information about this process is available in the Permissions and Rights Question and Answer document.

Reprints: Information about reprints can be found online at:
http://www.lww.com/reprints

Subscriptions: Information about subscribing to *Stroke* is online at:
http://stroke.ahajournals.org/subscriptions/