An Integrated Automated Analysis Method for Quantifying Vessel Stenosis and Plaque Burden From Carotid MRI Images

Combined Postprocessing of MRA and Vessel Wall MR

Isabel M. Adame, MSc; Patrick J.H. de Koning, MSc; Boudewijn P.F. Lelieveldt, PhD; Bruce A. Wasserman, MD; Johan H.C. Reiber, PhD; Rob J. van der Geest, MSc

Background and Purpose—We report the evaluation of a semiautomated method for in vivo assessment of the severity of carotid atherosclerosis with minimal user interaction that combines 3-dimensional contrast-enhanced magnetic resonance angiography (CE-MRA) and vessel wall magnetic resonance imaging (MRI).

Methods—Lumen and outer-wall contours were automatically detected, and stenosis and plaque burden were estimated.

The method was tested on 22 subjects (352 postcontrast, T1-weighted cross sections and 3-dimensional CE-MRA).

Results—we observed good correlation with expert contours: lumen and outer-wall area (r = 0.96) and the degree of stenosis (r = 0.97).

Conclusions—the fusion of MRA and MRI reduces user interaction and improves contour detection, providing reproducible parameters to assess the severity of atherosclerosis. (Stroke. 2006;37:2162-2164.)

Key Words: atherosclerosis • carotid artery • magnetic resonance angiography • magnetic resonance imaging

Contrast-enhanced magnetic resonance angiography (CE-MRA) determines the location and severity of stenotic lesions, whereas vessel wall magnetic resonance imaging (MRI) can depict outward remodeling and distinguish among plaque components.

The purpose of this work was to develop an automated method for quantitative assessment of atherosclerosis from the combined data of CE-MRA and postcontrast T1-weighted MRI images (PC-T1W MRI) of the vessel wall. Automated detection of luminal contours is performed in both datasets (2 initialization points are needed), followed by automated detection of the outer-wall contours on the PC-T1W MRI images. The degree of stenosis is derived from the luminal dimensions, whereas plaque burden is quantified from wall thickness and area measurements on the PC-T1W MRI images.

Subjects and Methods

Data for this analysis was part of the Atherosclerosis Risk in Communities study. The study was approved by the institutional review board. Twenty-two participants (aged 55 to 74 years) were randomly selected for this study. Three-dimensional (3D) CE-MRA (pixel size, 0.94 mm) and 16 axial PC-T1W MRI slices per subject (pixel size, 0.54 mm) of the carotid arteries were acquired on a 1.5-T whole-body scanner (EXCITE, GE Medical Systems) equipped with a 4-element phased-array carotid coil. Gadodiamide was administered intravenously (0.1 mmol/kg) at a rate of 2 mL/s.

Description of the Algorithm

MRA Segmentation

The user needs to place 2 points to define the vessel segment of interest. A 3D pathline is then automatically detected connecting these points and follows the center line of the vessel. The threshold-based vessel segmentation is based on the detected pathline. The threshold is derived from the maximum intensity at a particular cross section with a full-width 30% maximum criterion.

Lumen and Outer-Wall Contour Detection

The algorithm works on 2-dimensional (2D) images on a slice-by-slice basis. After automated registration, a minimum-cost approach (dynamic programming) is performed on the vessel wall image to refine the lumen contour, which was obtained from MRA. A geometrical model (ellipse) is used to automatically trace the outer boundary of the vessel, as previously described. This contour is also refined by using dynamic programming. To assess accuracy, all automatically detected contours were compared with manual contours drawn by radiologists blinded to the results of the algorithm.

Stenosis Estimation

The North American Symptomatic Carotid Endarterectomy Trial (NASCET) and the European Carotid Surgery Trial (ECST) criteria were used to measure the degree of stenosis.

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TABLE 1. Stenosis and Plaque Burden Measurements

<table>
<thead>
<tr>
<th>Type</th>
<th>AHA Class</th>
<th>No. of Subjects</th>
<th>Stenosis, %</th>
<th>Stenosis, %</th>
<th>Plaque Index, %</th>
<th>Maximum-Minimum Wall Thickness, mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>a</td>
<td>0–I</td>
<td>4</td>
<td>2.13±1.61</td>
<td>1.51±1.30</td>
<td>1.05±0.23</td>
<td>42.69±2.79</td>
</tr>
<tr>
<td>b</td>
<td>I–II</td>
<td>6</td>
<td>7.41±4.01</td>
<td>5.09±1.57</td>
<td>5.20±4.31</td>
<td>44.17±6.69</td>
</tr>
<tr>
<td>c</td>
<td>III</td>
<td>5</td>
<td>15.70±7.16</td>
<td>9.40±5.94</td>
<td>10.65±7.63</td>
<td>45.00±5.97</td>
</tr>
<tr>
<td>d</td>
<td>IV–VI</td>
<td>7</td>
<td>50.03±26.04</td>
<td>31.35±31.49</td>
<td>35.56±21.14</td>
<td>58.37±7.05</td>
</tr>
</tbody>
</table>

Data are mean±SD. a indicates minimal plaque; b, moderate plaque distributed along the circumference of the vessel; c, moderate plaque localized in a small region of the vessel wall; d, prominent plaque.

**Plaque Burden Estimation**

Plaque index (percentage of wall volume relative to the volume of the whole vessel lumen and vessel wall inclusively) and vessel wall thickness were measured on the PC-T1W images. Wall volume was estimated in the segment covered by the PC-T1W slices by multiplying the average wall area by the slice thickness.

**Results**

**Lumen and Outer-Wall Contour Detection**

The descriptive statistics yielded by the automated method were 36.53±22.58 mm² for lumen area and 75.71±31.24 mm² for outer-wall area. Those measurements derived from manually traced contours were 40.90±23.45 mm² for lumen area and 73.57±31.09 mm² for outer-wall area. Those expert contours were used as a standard to assess the accuracy of the automated detection method.

A high correlation between automated and manual area measurements was observed for both the lumen and outer wall ($r=0.96$). The average paired difference between the automatic-manual measurement pairs was 4.35±5.59 mm² (11.74±15.08%; $P=0.0002$) for lumen area and −2.13±10.62 mm² (−2.97±14.80%; $P=0.0001$) for outer-wall area. The automated vessel wall contour detection (both on CE-MRA and PC-T1W-MRI) takes less than 20 seconds per subject.

**Stenosis and Plaque Burden Measurements**

Table 1 presents estimates of the severity of stenosis. The average paired difference between the ECST/NASCET combination measurement pairs was 7.42±8.71% ($P=NS$) and between the ECST/NASCET MRA, it was 7.58±11.14% ($P=NS$). Table 1 also shows values for plaque index and vessel wall thickness. In 6 cases (I–II, American Heart Association classification) where CE-MRA found almost no stenosis, analysis of the PC-T1W MRI images showed that there was an abnormal vessel wall, corresponding to the early stages of atherosclerosis: low plaque burden and marginal luminal reduction (Figure, B). The rest of the subjects, who had higher degrees of stenosis (c, d; III–VI), had a high plaque index and increased vessel wall thickness. Table 2 presents statistics for interobserver and intraobserver reproducibility. The measurements from different analyses were also compared with Student’s 2-sided paired $t$ test and showed no statistically significant difference ($P>0.05$).

**Discussion**

Only a few studies have been reported that combine different MRI sequences to characterize plaque composition. In the present study, CE-MRA and PC-T1W MRI are combined to delineate the contours of the vessel wall. Reproducibility was higher for the combined approach (Table 2), which demonstrates that the combination of CE-MRA and vessel wall PC-T1W images reduces subjectivity from the process of stenosis estimation. Table 1 demonstrates that with the combined approach, the effect of outward remodeling can be observed, as different subjects showed a low stenosis percentage by CE-MRA (type c in Table 1 and panel B of the Figure), despite a large amount of plaque detected by PC-T1W MRI.

Although the average paired difference between automatic/manual measurement pairs was statistically significant ($P<0.05$), this is not assumed to be clinically relevant, as the differences are very small (lumen, $<2$ mm²; outer-wall, $<4$ mm²) in comparison with the average values (lumen, $<37$ mm²; outer-wall, $<76$ mm²).

In conclusion, the fusion of MRA and MRI reduces user interaction and improves contour detection, providing reproducible parameters to assess the severity of atherosclerosis. Nevertheless, further work needs to be done including more patients (multicenter study) and comparing the reported algorithm with ultrasound data.
Source of Funding

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Disclosures

None.

References


### TABLE 2. Reproducibility

<table>
<thead>
<tr>
<th></th>
<th>Intraobserver</th>
<th>Interobserver</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>SD, mm</td>
<td>COV, %</td>
</tr>
<tr>
<td>A (from CE-MRA)</td>
<td>0.37</td>
<td>7.95</td>
</tr>
<tr>
<td>B (from CE-MRA)</td>
<td>0.29</td>
<td>5.59</td>
</tr>
<tr>
<td>A (from T1W MR)</td>
<td>0.23</td>
<td>5.12</td>
</tr>
<tr>
<td>B (from T1W MR)</td>
<td>0.12</td>
<td>2.43</td>
</tr>
</tbody>
</table>

COV indicates coefficient of variation; A, minimum diameter; B, reference diameter.
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