Carotid artery stenosis grading using CT angiography: Evaluation Based on Carotid Area Stenosis Index

Poster No.: C-0407
Congress: ECR 2012
Type: Scientific Exhibit
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Keywords: Obstruction / Occlusion, Decision analysis, CT-Angiography, Neuroradiology brain, Head and neck
DOI: 10.1594/ecr2012/C-0407

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Purpose

- Carotid artery stenosis is a risk factor for ischemic cerebrovascular disease, and approximately 10%-20% patients with cerebral infarction have narrowed carotid arteries. Until date, most clinical research has focused on determining whether CEA is more effective than pharmacological management for control of blood vessel ischemia. In particular, both NASCET\cite{1} and ECST\cite{2} reported that CEA is more effective in treating cases of ischemic cerebrovascular disease with high-grade carotid artery stenosis when compared with pharmacological therapy. In recent years, cases that are considered at high risk for CEA are frequently treated with CAS as an alternative procedure, and several randomized clinical trials comparing CAS with CEA have been performed\cite{3-7}. The use of CAS has increased rapidly since the SAPPHIRE\cite{7} trial, which reported that CAS is not inferior to CEA for treating cases of ischemic cerebrovascular disease with carotid artery stenosis.

- The degree of stenosis is an important factor in determining the appropriate treatment strategy for carotid artery stenosis\cite{8}. While digital subtraction angiography remains the gold standard for grading stenosis, many physicians use less invasive modalities especially since the results with less invasive carotid CT angiography have improved with the use of multi-slice CT. Despite this, recent studies have proposed that for accurate determination of a preferred imaging modality for grading stenosis, the relationship between CT angiography, US, and digital subtraction angiography should be further investigated\cite{9-11}. Moreover, there is currently no clear standard criterion for the calculation of the degree of stenosis using multi-slice CT on the basis of the relationship between geometry and US.

- The purpose of this study was to investigate the effectiveness of four methods for calculating the degree of stenosis using cross-sectional area measurements obtained using semiautomated CT angiography analysis. We also investigated the relationship between various degrees of stenosis on the basis of cross-sectional area and US measurements. In particular, we aimed to evaluate the effectiveness of CASI for the accurate determination of the degree of stenosis. This method determines the degree of stenosis on the basis of cross-sectional area measurements, which are obtained via CT angiography, and PSV, which is determined by US. Furthermore, we investigated the validity of the degree of stenosis estimations that were analyzed using the geometry of the carotid artery.
Methods and Materials

- Between June 2006 and November 2008, 137 consecutive patients (100 men, 37 women; mean age, 71.9 years; range, 54-87 years) with cerebrovascular disease underwent carotid CT angiography within one or two months before or after ultrasonography. A total of 243 carotid arteries were studied, and cases of complete occlusion and cases that had undergone CAS or CEA were excluded. During the period of this study, 22 (25 vessels) of 137 patients (19 men, 3 women; mean age, 69.1 years; range, 59-84 years) underwent CAS (Fig. 1 on page 8). This study was approved by the local Institutional Review Board and written informed consent was obtained from all subjects.

Fig. 1

References: S. Kayano; Section of Radiology, Department of Medical Technology, Sendai, JAPAN

- During carotid CT angiography, contrast media was injected into the basilic vein or median cubital vein of the right arm using a 20-G indwelling needle.
A dual-head power injector (Dual Shot GX; Nemoto Kyorindo, Tokyo, Japan) was used to inject 240 mgI/kg of a nonionic contrast medium (iohexol, Omnigaque 240; Daiichi-Sankyo, Tokyo, Japan) for 12.5 s, followed by a 30-mL saline flush with contrast medium at the same rate. All carotid CT angiographies were performed with an Aquilion 16-detector multi-slice CT scanner (Toshiba Medical Systems, Otawara, Japan) with the following parameters: 120 kV, auto exposure control (set values: SD-7), 0.5 mm thickness*16 slices, 0.5-s rotation time, 15 helical pitch, reconstructed slice thickness of 0.5 mm with 0.3 mm interval, and a reconstruction kernel of FC04. Optimal scan delay was determined using the bolus tracking method. Serial scans were performed at 20 mm cranial to the scanning start position. Scanning was started when contrast media was visually observed to have reached the bilateral carotid arteries. The scanning range was set to 120 mm assuming the foramen magnum as an upper limit, and the scanning was performed in a caudocranial direction (Fig. 2 on page 8).

All the US scans were performed by three medical technologists with more than two years of experience in carotid artery US. The examination used Logiq 500 or Logiq e (GE Healthcare, Tokyo, Japan) and linear type probes of 9 or 10 MHz (Fig. 2 on page 8). Special care was taken to maintain the incidence angle between the vascular wall and the Doppler beam at less than 60 degrees to minimize measurement errors\textsuperscript{[12, 13]}. In cases with no stenosis, we measured the PSV of that part of ICA where good image quality with a suitable incidence angle was obtained. Where stenosis was present, we measured PSV values at three points; i.e., the point of maximal stenosis and points proximal and distal to the stenosis, and adopted the highest PSV value. Carotid CT angiography and US measurements were collected as part of routine clinical examinations.
Methods and Materials
US & CT Acquisition, Data Analysis

**US:** Logiq 500 (9MHz Linear probe) (GE Healthcare)
Logiq e (10MHz Linear probe) (GE Healthcare)

**CT:** Aquilion16 (TOSHIBA)
120kV, SD10, 0.5s/r, 0.5mm×16, HP15, FC04, Th0.5mm/Sp0.3mm
DFOV 75mm

**Contrast Media:** iohexol 240mg/L/mL (Omnipaque® 240),
240mg/kg @ 12.5sec Injection

**Work Station:** Advantage Workstation VS2 (GE Healthcare)

**Fig. 2**

References: S. Kayano; Section of Radiology, Department of Medical Technology, Sendai, JAPAN

- Volume data of carotid CT angiography were analyzed using the Advanced Vessel Analysis application (GE Healthcare, Tokyo, Japan). Using this program, the vessel was stretched along a straight line and the following four parameters were automatically obtained at any cross-sectional area perpendicular to the vessel course: 1) the mean diameter $D_{\text{mean}}$ (mm); 2) the maximum diameter $D_{\text{max}}$ (mm); 3) the minimum diameter $D_{\text{min}}$ (mm); and 4) the cross-sectional area (mm$^2$). From these parameters, we calculated the degree of stenosis (%) using four different methods: 1) $D_{\text{mean}}$-NASCET; 2) $D_{\text{max}}$-NASCET; 3) $D_{\text{min}}$-NASCET; and 4) CASI (Fig. 3 on page 9). We also examined the relationship between the results obtained with these four methods and PSV.
Fig. 3: Four methods for calculating the degree of stenosis using CT angiography.

**References:** S. Kayano; Section of Radiology, Department of Medical Technology, Sendai, JAPAN

**D\text{mean}-NASCET**

D\text{mean}-NASCET (%) was calculated as \[ 1 - \left( \frac{D_{\text{mean}} b}{D_{\text{mean}} a} \right) \times 100 \], where D\text{mean} b is the mean diameter of a cross section b, which is a point of maximal stenosis (in normal vessels, the carotid sinus portion was adopted), and D\text{mean} a is the mean diameter of a cross section a, which is a point in the distal portion of ICA that acts as a reference diameter. Because the NASCET method considers the distal portion of ICA with normal diameter as a reference, we used the mean diameter (D\text{mean}) at this reference point.

**D\text{max}-NASCET**
D_{\text{max}}\text{-NASCET} (%) was calculated as \([1-(D_{\text{max}} b / D_{\text{mean}} a)] \times 100\), where \(D_{\text{max}} b\) is the maximum diameter of a cross section \(b\), which is a point of maximal stenosis in ICA.

\[D_{\text{min}}\text{-NASCET}\]

\(D_{\text{min}}\text{-NASCET} (%)\) was calculated as \([1-(D_{\text{min}} b / D_{\text{mean}} a)] \times 100\), where \(D_{\text{min}} b\) is the minimum diameter at a cross section \(b\), which is a point in the proximal portion of ICA, including those with stenosis.

\textbf{Carotid Area Stenosis Index}

We investigated CASI, a stenosis calculation method that uses volume data obtained by carotid CT angiography. CASI (%) was calculated as \([1-(\text{Area } b / \text{Area } a)] \times 100\), where \(\text{Area } b\) is the area of an orthogonal cross section \(b\), which is a point in the proximal portion of ICA, and \(\text{Area } a\) is the area of an orthogonal cross section \(a\), which is a point in the distal portion of ICA with a normal diameter. We examined the relationship between CASI and PSV.

\textbf{Measurement and Analysis of the Carotid Artery}

In fluid dynamics, there is a close relationship between flow velocity and volume. In this study, we evaluated the relationship between the area measurements and PSV at point \(b\), which is an orthogonal cross section in the proximal ICA (243 vessels).

Furthermore, to investigate the variety of shapes seen in cross sections of stenosed carotid arteries, we investigated the ratio between the minimum diameter \(D_{\text{min}}\) and the maximum diameter \(D_{\text{max}}\) of an orthogonal cross section \(b\), which is in the proximal ICA (243 vessels), and the relationship of these results with PSV.

\textbf{Statistical Analysis}

All analyses were performed using JMP Pro 9.0.2 for Macintosh (SAS Institute, Cary, NC, USA) statistical package. A \(p\) value of < 0.01 indicated a statistically significant difference.
The sensitivity, specificity, accuracy, PPV and NPV, and Kappa scores for each method of calculating the degree of stenosis were obtained. Cut-off values were set at 70% stenosis and a PSV exceeding 200 cm/s. As references for CASI, the sensitivity and specificity of $D_{\text{mean}}$-NASCET, $D_{\text{max}}$-NASCET, and $D_{\text{min}}$-NASCET were statistically compared using the McNemar test with 95% CIs. The difference in sensitivity and specificity were calculated.

The accuracy of each calculation method for predicting the degree of stenosis was summarized using ROC curves and compared using a nonparametric test for comparing areas under correlated ROC curves. The optimal cut-off values for each of the calculation methods were determined by the Youden index\(^{[14]}\).

**Images for this section:**

![Patient Background](image)

**Methods and Materials**

**Patient Background**

<table>
<thead>
<tr>
<th></th>
<th>Male</th>
<th>Female</th>
<th>Mean Age</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>243 vessels</strong>*</td>
<td>100 cases</td>
<td>37 cases</td>
<td>71.9 years (range 54 - 87)</td>
</tr>
<tr>
<td>(Total 137 cases)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Underwent CAS</strong></td>
<td>19 cases</td>
<td>3 cases</td>
<td>69.1 years (range 59 - 84)</td>
</tr>
<tr>
<td><strong>25 vessels</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(Total 22 cases)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* except complete occlusion cases and a follow-up study of CAS and CEA cases

**Fig. 1**
Methods and Materials
US & CT Acquisition, Data Analysis

**US**: Logiq 500 (9MHz Linear probe) (GE Healthcare)
Logiq e (10MHz Linear probe) (GE Healthcare)

**CT**: Aquilion16 (TOSHIBA)
120kV, SD10, 0.5s/r, 0.5mm×16, HP15, FC04, Th0.5mm/Sp0.3mm,
DFOV 75mm

**Contrast Media**: iohexol 240mg/l/mL (Omnipaque® 240),
240mg/l/kg @ 12.5sec Injection

**Work Station**: Advantage Workstation VS2 (GE Healthcare)

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Fig. 2
Methods and Materials

Methods for calculating the degree of stenosis

1. \( D_{\text{mean NASCET}} \); 
   \[ 1 - \frac{D_{\text{mean}} b}{D_{\text{mean}} a} \times 100 = \% \text{ stenosis} \]

2. \( D_{\text{max NASCET}} \); 
   \[ 1 - \frac{D_{\text{max}} b}{D_{\text{mean}} a} \times 100 = \% \text{ stenosis} \]

3. \( D_{\text{min NASCET}} \); 
   \[ 1 - \frac{D_{\text{min}} b}{D_{\text{mean}} a} \times 100 = \% \text{ stenosis} \]

4. CASI*; 
   \[ 1 - \frac{\text{Area}_b}{\text{Area}_a} \times 100 = \% \text{ stenosis} \]

*aCASII: Carotid Area Stenosis INDEX

Fig. 3: Four methods for calculating the degree of stenosis using CT angiography.
Results

\(D_{\text{mean}}\)-NASCET and PSV

In most cases in which PSV exceeded 200 cm/s, \(D_{\text{mean}}\)-NASCET was greater than 40%, such that this indication is similar to the 25 vessels with underwent CAS. The moderate correlation between \(D_{\text{mean}}\)-NASCET and PSV \((r = 0.687, p < 0.001)\) is shown in Fig. 4 on page 19.

![Fig. 4: Relationship between Dmean-NASCET and PSV \((r = 0.687, p < 0.001)\).](image)

References: S. Kayano; Section of Radiology, Department of Medical Technology, Sendai, JAPAN

\(D_{\text{max}}\)-NASCET and PSV

In most cases in which PSV exceeded 200 cm/s, \(D_{\text{max}}\)-NASCET was greater than 20%, such that this indication is similar to the 25 vessels with underwent CAS. The moderate correlation between \(D_{\text{max}}\)-NASCET and PSV \((r = 0.596, p < 0.001)\) is shown in Fig. 5 on page 19.
D\textsubscript{min}-NASCET and PSV

In most cases where PSV exceeded 200 cm/s, D\textsubscript{min}-NASCET was greater than 50%, such this indication is similar to the 25 vessels with underwent CAS. The moderate correlation between D\textsubscript{min}-NASCET and PSV ($r = 0.674$, $p < 0.001$) is shown in Fig. 6 on page 20. Because the NASCET method traditionally uses the minimum linear dimension at the point of maximal stenosis, this result indicated that D\textsubscript{min}-NASCET was the only method that actually represents NASCET on the basis of digital subtraction angiography.
**Fig. 6**: Relationship between Dmin-NASCET and PSV ($r = 0.674$, $p < 0.001$).

**References**: S. Kayano; Section of Radiology, Department of Medical Technology, Sendai, JAPAN

**Carotid Area Stenosis Index and PSV**

In most cases where PSV exceeded 200 cm/s, CASI was greater than 60%, such this indication is similar to the 25 vessels with underwent CAS. The moderate correlation between CASI and PSV ($r = 0.692$, $p < 0.001$) is shown in **Fig. 7 on page 20**.
Fig. 7: Relationship between carotid area stenosis index (CASI) and PSV ($r = 0.692$, $p < 0.001$).

**References:** S. Kayano; Section of Radiology, Department of Medical Technology, Sendai, JAPAN

**Measurement and Analysis of the Carotid Artery**

A strong inverse correlation was observed between the cross-sectional area $b$ and PSV in the proximal portion of ICA ($b$) ($r = 0.699$, $p < 0.001$) ([Fig. 8 on page 21](#)); i.e., PSV values increased rapidly for vessels measuring 5 mm$^2$ or less.
Fig. 8: Relationship between the cross-sectional area at a point in the proximal portion of ICA and PSV (243 vessels). Scatter plot demonstrates a strong inverse correlation ($r = 0.699, p < 0.001$).

References: S. Kayano; Section of Radiology, Department of Medical Technology, Sendai, JAPAN

Fig. 9 on page 22 A demonstrates the relationship between the minimum diameter $D_{\min}$ and maximum diameter $D_{\max}$ of a cross-section in the proximal portion of ICA (243 vessels). Two straight lines with respective slopes of 1.0 and 0.4 can be drawn on $D_{\min}$ and $D_{\max}$, and the lines indicated that the ratios between minimum and maximum diameter fell within the range of 1:1 to 2:5. Fig. 9 on page 22 B demonstrates the relationship between $D_{\min}$, $D_{\max}$, and PSV. We observed that PSV increased as vessel...
diameter decreased. However, PSVs of smaller vessels varied more when compared to PSVs of larger vessels.

**Fig. 9:** Relationship between Dmin and Dmax of the cross-sectional diameter of the proximal ICA. A: Two straight lines with respective slopes of 1.0 and 0.4, indicating that ratios of minimum diameter to maximum diameter range from 1:1 to 2:5 in the proximal ICA ($r = 0.946$, $p < 0.001$). B: B demonstrates the relationship between Dmin, Dmax, and PSV. PSV increases as the vessel diameter decreases. PSV values of smaller vessels vary more widely than PSV values of larger vessels.

**References:** S. Kayano; Section of Radiology, Department of Medical Technology, Sendai, JAPAN

**Statistical Analysis**

**Table 1** on page 24 demonstrates the diagnostic performance of $D_{\text{mean}}$-NASCET, $D_{\text{max}}$-NASCET, $D_{\text{min}}$-NASCET, and CASI in comparison with the cut-off values of 70% stenosis and PSV exceeding 200 cm/s. The sensitivity of CASI was significantly higher than that of the other methods ($D_{\text{mean}}$-NASCET, $D_{\text{max}}$-NASCET, and $D_{\text{min}}$-NASCET vs. CASI, $p < 0.01$). In contrast, the specificity of CASI was significantly lower than that of other methods ($D_{\text{mean}}$-NASCET, $D_{\text{max}}$-NASCET, and $D_{\text{min}}$-NASCET vs. CASI, $p < 0.01$). High NPV (96.6%) and good Kappa scores (0.592, 95% CI = 0.419-0.718) were obtained for CASI.
To identify the diagnostic potential of each method, ROC curves derived from the baseline values of CASI, $D_{\text{mean}}$-NASCET, $D_{\text{max}}$-NASCET, and $D_{\text{min}}$-NASCET were prepared (Fig. 10 on page 23). CASI and $D_{\text{mean}}$-NASCET were the most accurate methods overall (AUC 0.957, reference and $p = 1.000$), followed by $D_{\text{min}}$-NASCET (AUC 0.954, $p = 0.476$) and $D_{\text{max}}$-NASCET (AUC 0.943, $p = 0.047$) (Table 2). The optimal cut-off value was 57.8% for CASI, 48.2% for $D_{\text{min}}$-NASCET, 36.1% for $D_{\text{mean}}$-NASCET, and 20.0% for $D_{\text{max}}$-NASCET (Table 2 on page 25).

Table 1: The diagnostic performance of $D_{\text{mean}}$-NASCET, $D_{\text{max}}$-NASCET, $D_{\text{min}}$-NASCET, and CASI.

<table>
<thead>
<tr>
<th></th>
<th>Sensitivity (%)</th>
<th>p value (vs CASI)</th>
<th>Specificity (%)</th>
<th>Accuracy (%)</th>
<th>PPV (%)</th>
<th>NPV (%)</th>
<th>Kappa (95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$D_{\text{mean}}$-NASCET</td>
<td>25.0</td>
<td>$&lt;0.001^{**}$</td>
<td>99.5</td>
<td>90.9</td>
<td>87.5</td>
<td>91.0</td>
<td>0.356 (0.171-0.411)</td>
</tr>
<tr>
<td>$D_{\text{max}}$-NASCET</td>
<td>14.3</td>
<td>$&lt;0.001^{**}$</td>
<td>99.5</td>
<td>89.7</td>
<td>80.0</td>
<td>89.9</td>
<td>0.215 (0.060-0.274)</td>
</tr>
<tr>
<td>$D_{\text{min}}$-NASCET</td>
<td>39.3</td>
<td>0.002**</td>
<td>97.2</td>
<td>90.5</td>
<td>64.7</td>
<td>92.4</td>
<td>0.440 (0.240-0.598)</td>
</tr>
<tr>
<td>CASI</td>
<td>75.0</td>
<td>reference</td>
<td>92.5</td>
<td>90.5</td>
<td>56.8</td>
<td>96.6</td>
<td>0.592 (0.419-0.718)</td>
</tr>
</tbody>
</table>

References: S. Kayano; Section of Radiology, Department of Medical Technology, Sendai, JAPAN
Fig. 10: To identify the diagnostic potential of each method, ROC curves derived from the baseline CASI, Dmean-NASCET, Dmax-NASCET, and Dmin-NASCET values are compared.

References: S. Kayano; Section of Radiology, Department of Medical Technology, Sendai, JAPAN
Table 2: Diagnostic potential based on ROC.

<table>
<thead>
<tr>
<th>Metric</th>
<th>AUC (95% CI)</th>
<th>p value (vs CASI)</th>
<th>Optimal cut-off Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>D_mean NASCET</td>
<td>0.957 (0.925-0.975)</td>
<td>1.000</td>
<td>36.1%</td>
</tr>
<tr>
<td>D_max NASCET</td>
<td>0.954 (0.919-0.974)</td>
<td>0.476</td>
<td>20.0%</td>
</tr>
<tr>
<td>D_min NASCET</td>
<td>0.943 (0.906-0.967)</td>
<td>0.047</td>
<td>48.2%</td>
</tr>
<tr>
<td>CASI</td>
<td>0.957 (0.925-0.975)</td>
<td>reference</td>
<td>57.8%</td>
</tr>
</tbody>
</table>

**References:** S. Kayano; Section of Radiology, Department of Medical Technology, Sendai, JAPAN

**Images for this section:**

**Fig. 4:** Relationship between D_mean-NASCET and PSV ($r = 0.687$, $p < 0.001$).
Fig. 5: Relationship between Dmax-NASCET and PSV ($r = 0.596$, $p < 0.001$).

Fig. 6: Relationship between Dmin-NASCET and PSV ($r = 0.674$, $p < 0.001$).
Fig. 7: Relationship between carotid area stenosis index (CASI) and PSV ($r = 0.692$, $p < 0.001$).
**Fig. 8:** Relationship between the cross-sectional area at a point in the proximal portion of ICA and PSV (243 vessels). Scatter plot demonstrates a strong inverse correlation ($r = 0.699$, $p < 0.001$).

The equation for the line of best fit is $y = 206.79x^{-0.3781}$. At a cross-sectional area of $5 \text{ mm}^2$, the PSV is approximately 100 cm/s.
Fig. 9: Relationship between Dmin and Dmax of the cross-sectional diameter of the proximal ICA. A: Two straight lines with respective slopes of 1.0 and 0.4, indicating that ratios of minimum diameter to maximum diameter range from 1:1 to 2:5 in the proximal ICA ($r = 0.946$, $p < 0.001$). B: B demonstrates the relationship between Dmin, Dmax, and PSV. PSV increases as the vessel diameter decreases. PSV values of smaller vessels vary more widely than PSV values of larger vessels.
Fig. 10: To identify the diagnostic potential of each method, ROC curves derived from the baseline CASI, Dmean-NASCET, Dmax-NASCET, and Dmin-NASCET values are compared.
### Table 1: The diagnostic performance of Dmean-NASCET, Dmax-NASCET, Dmin-NASCET, and CASI.

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<tr>
<th></th>
<th>Sensitivity (%)</th>
<th>Sensitivity p value (vs CASI)</th>
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<th>Accuracy (%)</th>
<th>PPV (%)</th>
<th>NPV (%)</th>
<th>Kappa (95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dmean NASCET</td>
<td>25.0</td>
<td>&lt; 0.001**</td>
<td>99.5</td>
<td>&lt; 0.001**</td>
<td>90.9</td>
<td>87.5</td>
<td>91.0</td>
<td>0.356 (0.171-0.411)</td>
</tr>
<tr>
<td>Dmax NASCET</td>
<td>14.3</td>
<td>&lt; 0.001**</td>
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<td>&lt; 0.001**</td>
<td>89.7</td>
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<td>89.9</td>
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<td>90.5</td>
<td>56.8</td>
<td>96.6</td>
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</tr>
</tbody>
</table>

### Table 2: Diagnostic potential based on ROC.

<table>
<thead>
<tr>
<th></th>
<th>AUC (95% CI)</th>
<th>p value (vs CASI)</th>
<th>Optimal cut-off Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dmean NASCET</td>
<td>0.957 (0.925-0.975)</td>
<td>1.000</td>
<td>36.1%</td>
</tr>
<tr>
<td>Dmax NASCET</td>
<td>0.954 (0.919-0.974)</td>
<td>0.476</td>
<td>20.0%</td>
</tr>
<tr>
<td>Dmin NASCET</td>
<td>0.943 (0.906-0.967)</td>
<td>0.047</td>
<td>48.2%</td>
</tr>
<tr>
<td>CASI</td>
<td>0.957 (0.925-0.975)</td>
<td>reference</td>
<td>57.8%</td>
</tr>
</tbody>
</table>
Conclusion

We observed that CASI, including the factors of $D_{\min}$ and $D_{\max}$, has greater potential clinical value for the grading of severe stenosis when compared to that of the NASCET method when CT angiography is used.

CASI is directly correlated with PSV and the geometry of the maldistribution of the stenosis. Further large clinical trials are necessary to confirm the usefulness of CASI in the grading of carotid artery stenosis.

Fig. 11

References: S. Kayano; Section of Radiology, Department of Medical Technology, Sendai, JAPAN

Discussion

- Our study revealed several major findings. First, the NASCET methods using carotid CT angiography tended to underestimate the degree of stenosis, whereas CASI tended to give a more accurate estimation. In detail, the optimal cut-off value of CASI was 57.8%; this value was similar to that of the NASECT criteria (60%-70%) for grading stenosis using digital subtraction angiography. However, other NASCET methods demonstrated values of 20%-48.2%; these values were lower estimation. Moreover, we observed that the ratios for cross-sectional shapes measured in the proximal portion of ICA in cases of severe stenosis were limited to 1:1-2:5. These results suggest that CASI is an effective index for grading carotid artery
stenosis, particularly severe stenosis, on the basis of blood flow and shape of the cross-sectional area.

- Our results demonstrated that in cases where PSV exceeded 200 cm/s, \( D_{\text{mean}}^\text{NASCET} \), \( D_{\text{max}}^\text{NASCET} \), and \( D_{\text{min}}^\text{NASCET} \) demonstrated the degree of stenosis as 40%, 20%, and 50%, respectively (Fig. 4 on page , Fig. 5 on page , Fig. 6 on page ). However, Wang et al. have defined PSV exceeding 150 cm/s as stenosis of 50% or more according to the NASCET method using conventional angiography\(^{15}\), and Koga et al. have reported that PSV values exceeding 200 cm/s indicates advanced stenotic lesions of 70% stenosis or more\(^{16}\). Therefore, it appears that the NASCET methods using carotid CT angiography in our study may have underestimated the degree of stenosis. This may be due to the weak correlation between the geometry of stenosis observed on CT angiography and that observed on digital subtraction angiography as described by Wang et al\(^{15}\) and Koga et al\(^{16}\). In addition, the weak relation between the degree of stenosis observed on CT angiography and PSV will also be a reason for the underestimation. Previous studies have reported that maldistribution of the stenosis area as seen on CT angiography may strongly influence the calculation of the degree of stenosis using the NASCET method\(^{17},^{18}\). In addition, Silvennoinen et al. proposed that the thinner the stenotic residual lumen, the higher the relative error of measurement resulting from voxel size\(^{11}\). These findings justify our results.

- We believe that the influence of maldistribution of the stenosis area is the most important characteristic affecting flow conditions such as velocity. Fig. 8 on page shows just how rapidly the PSV values increase to over 200 cm/s as the proximal portion of the ICA becomes smaller. This finding is supported by Brice et al., who reported how stenosis affects hemodynamics in carotid arteries with less than 5 mm\(^2\) cross-sectional areas\(^{19}\). Furthermore, we found that if only one parameter from \( D_{\text{min}}^\text{NASCET} \) or \( D_{\text{max}}^\text{NASCET} \) is used for the grading of stenosis, particularly in cases of severe stenosis, PSV at the \( D_{\text{min}}^\text{NASCET} \) or \( D_{\text{max}}^\text{NASCET} \) can range from 1:1 to 2:5 (Fig. 9 on page \( A \) ). This range is based on the geometry of cross-sectional areas, which may take the form of a circle or an ellipse. In contrast, we observed that if both the parameters of \( D_{\text{min}}^\text{NASCET} \) and \( D_{\text{max}}^\text{NASCET} \) are used, an unambiguous PSV value appeared, as shown in Fig. 9 on page \( B \). Given this, we concluded that both factors (\( D_{\text{min}}^\text{NASCET} \) and \( D_{\text{max}}^\text{NASCET} \)) should be included in calculation indices like CASI.

- According to a report by Ward-Smith that demonstrates the relationship between the pressure loss coefficient and the percentage reduction in the area at the orifice of the throat, if the percentage reduction in this area is 70% or more, the pressure loss coefficient rapidly increases\(^{20}\). Because the
calculation method in CASI is similar to that for the percentage reduction in the area at the orifice of the throat, we hypothesized that 70% stenosis was the criterion for an advanced stenotic lesion of the carotid artery according to CASI. This hypothesis does require further examination in future; however, our study revealed that PSV exceeded 200 cm/s in as many as 60%-70% cases (Fig. 7 on page______). We must therefore consider the validity of a 70% criterion for advanced stenotic lesions according to CASI.

- Consequently, the characteristics of the CASI calculation method could be used to devise a solution for the underestimation caused by the NASCET calculation method when determining the degree of stenosis by carotid CT angiography.

- In this study, the calculations of the degree of stenosis using the NASCET method, carotid CT angiography, and $D_{\text{mean}}$, $D_{\text{max}}$, or $D_{\text{min}}$ tended to underestimate severe stenotic disease. Accordingly, it seems that there is a discrepancy between the NASCET method using digital subtraction angiography, which is the current gold standard, and the semiautomated CT angiography analysis method, which is based on vessel diameters. Considering that the shape of severe stenosis can vary widely, the CASI method based on cross-sectional area measurements will be more reliable.

- This study had limitations. Our results were not compared to those of digital subtraction angiography, which is the current gold standard, and the potential clinical value of CASI in the assessment of stenosis needs to be further evaluated in large clinical trials.

**Conclusion**

- We observed that CASI, including the factors of $D_{\text{min}}$ and $D_{\text{max}}$, has greater potential clinical value for the grading of severe stenosis when compared to that of the NASCET method when CT angiography is used.

- CASI is directly correlated with PSV and the geometry of the maldistribution of the stenosis. Further large clinical trials are necessary to confirm the usefulness of CASI in the grading of carotid artery stenosis.

**Images for this section:**
Conclusion

We observed that CASI, including the factors of $D_{\text{min}}$ and $D_{\text{max}}$, has greater potential clinical value for the grading of severe stenosis when compared to that of the NASCET method when CT angiography is used.

CASI is directly correlated with PSV and the geometry of the maldistribution of the stenosis. Further large clinical trials are necessary to confirm the usefulness of CASI in the grading of carotid artery stenosis.

Fig. 11


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