Internal Carotid Artery Stenosis: Accuracy of Subjective Visual Impression for Evaluation with Digital Subtraction Angiography and Contrast-enhanced MR Angiography

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Purpose:
To prospectively determine, for both digital subtraction angiography (DSA) and contrast material–enhanced magnetic resonance (MR) angiography, the accuracy of subjective visual impression (SVI) in the evaluation of internal carotid artery (ICA) stenosis, with objective caliper measurements serving as the reference standard.

Materials and Methods:
Local ethics committee approval and written informed patient consent were obtained. A total of 142 symptomatic patients (41 women, 101 men; mean age, 70 years; age range, 44–89 years) suspected of having ICA stenosis on the basis of Doppler ultrasonographic findings underwent both DSA and contrast-enhanced MR angiography. With each modality, three independent neuroradiologists who were blinded to other test results first visually estimated and subsequently objectively measured stenoses. Diagnostic accuracy and percentage misclassification for correct categorization of 70%–99% stenosis were calculated for SVI, with objective measurements serving as the reference standard. Interobserver variability was determined with κ statistics.

Results:
After exclusion of arteries that were unsuitable for measurement, 180 vessels remained for analysis with DSA and 159 vessels remained for analysis with contrast-enhanced MR angiography. With respect to 70%–99% stenosis, SVI was associated with average misclassification of 8.9% for DSA (8.9%, 7.8%, and 10.0% for readers A, B, and C, respectively) and of 11.7% for contrast-enhanced MR angiography (11.3%, 8.8%, and 15.1% for readers A, B, and C, respectively). Negative predictive values were excellent (92.3%–100%). Interobserver variability was higher for SVI (DSA, κ = 0.62–0.71; contrast-enhanced MR angiography, κ = 0.57–0.69) than for objective measurements (DSA, κ = 0.75–0.80; contrast-enhanced MR angiography, κ = 0.66–0.72).

Conclusion:
SVI alone is not recommended for evaluation of ICA stenosis with both DSA and contrast-enhanced MR angiography. SVI may be acceptable as an initial screening tool to exclude the presence of 70%–99% stenosis, but caliper measurements are warranted to confirm the presence of such stenosis.

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The results of large randomized controlled trials, such as the North American Symptomatic Carotid Endarterectomy Trial (NASCET) and the European Carotid Surgery Trial (ECST), have clearly demonstrated the benefits of carotid endarterectomy over medical therapy in recently symptomatic patients with severe (70%–99%) internal carotid artery (ICA) stenosis, as measured with the NASCET method (1,2). More recently, carotid artery stent placement has emerged as an effective and less invasive alternative to carotid endarterectomy (3). For symptomatic patients, eligibility criteria for both the Carotid Revascularization Endarterectomy versus Stenting Trial (CREST), and the Carotid Revascularization Using Endarterectomy or Stenting Systems, or CaRESS, trial included a NASCET stenosis of 50%–99% (4,5). Similar stenosis criteria apply for reimbursement eligibility by the Center for Medicare Services in symptomatic patients at high risk for surgery, although 50%–69% stenosis is only covered under the clinical trials policy (6).

Several measurement techniques, such as the NASCET, ECST, and common carotid methods, are used worldwide to assess the severity of stenosis (7). Regardless of the measurement method used, in the context of the original NASCET and ECST trials the degree of stenosis was calculated from objective and precise measurements of arterial diameter obtained with calipers. In the clinical setting, however, the use of subjective visual impression (SVI) of stenosis may be more widespread than is generally acknowledged (8–11). Although SVI data are rather scarce, a survey of U.S. teaching hospitals conducted by Chaturvedi et al (12) revealed that although the NASCET measurement method was unsurprisingly and overwhelmingly favored, 22.7% of centers acknowledged use of SVI alone or in combination with NASCET or ECST methods. Although use of SVI has been reported with conventional digital subtraction angiography (DSA) (13,14), less attention has been focused on non-invasive modalities, such as contrast material–enhanced magnetic resonance (MR) angiography, which is rapidly increasing in popularity (13–17). Thus, the purpose of our study was to prospectively determine, for both DSA and contrast-enhanced MR angiography, the accuracy of SVI in the evaluation of ICA stenosis, with objective caliper measurements serving as the reference standard.

Advances in Knowledge

- Subjective visual impression (SVI) of 70%–99% internal carotid artery stenosis may result in average misclassification of 8.9% with digital subtraction angiography (DSA) and of 11.7% with contrast material–enhanced MR angiography when compared with objective caliper measurements.
- Interobserver variability was higher for SVI (DSA, $\kappa = 0.62–0.71$; contrast-enhanced MR angiography, $\kappa = 0.57–0.69$) than for objective measurements (DSA, $\kappa = 0.75–0.80$; contrast-enhanced MR angiography, $\kappa = 0.66–0.72$).
- SVI generally performed worse with contrast-enhanced MR angiography than with DSA; categorical agreement between SVI and objective measurements was moderate for DSA ($\kappa = 0.71–0.78$) but lower for contrast-enhanced MR angiography ($\kappa = 0.62–0.71$).
- SVI may be acceptable as a screening tool to exclude 70%–99% stenosis, but objective measurements are recommended to confirm the presence of such stenosis.

Materials and Methods

Patients

Between August 2000 and January 2003, 167 consecutive symptomatic patients suspected of having ICA stenosis on the basis of screening Doppler ultrasonographic (US) images that depicted at least 50% stenosis in one or more arteries were initially prospectively recruited to undergo both DSA and contrast-enhanced MR angiography. Patients with contraindications to MR imaging, such as claustrophobia or metallic implants, were excluded. This study and data release were approved by the local ethics committee, and all patients gave informed written consent. Twenty-five patients did not undergo complete DSA or contrast-enhanced MR angiography for various reasons; thus, 142 patients (41 women, 101 men; mean age, 70 years; age range, 44–89 years) underwent both DSA and contrast-enhanced MR angiography.

Diagnostic Tests

One of four attending neuroradiologists (J.H.G., J.J.C., N.J.H., or N.M.A.; 2, 2, 10, and 18 years of experience, respectively, with DSA at the start of the study) performed DSA with bilateral selective common carotid artery catheterization by using a single-plane digital angiographic unit (Angioskop; Siemens, Erlangen, Germany). Images of each bifurcation were acquired in four projections (anteroposterior, lateral, and bilateral 45° oblique) with a 33-em field of view, a $1024 \times 1024$ matrix, and a $0.32 \times 0.32$-mm spatial resolution and were recorded on film hard copy.

Contrast-enhanced MR angiography was performed with a 1.5-T machine...
(Signa CV/i; GE Medical Systems, Milwaukee, Wis) with use of a transmit-receive neurovascular coil (Medrad, Indianola, Pa). A bolus-timed three-dimensional breath-hold fast spoiled gradient-echo acquisition (repetition time msec/fractional echo time msec, 5.3/1.6; 44° flip angle; 62.5-kHz bandwidth; 23 × 16-cm field of view; 0.8-mm section thickness; 256 × 256 matrix; 0.5 signal acquired) with an elliptic centric phase-encode ordering scheme was performed after administration of 30 mL of gadolinium-based contrast material (gadopentetate dimeglumine, Magnevist; Schering, Berlin, Germany) at a flow rate of 2 mL/sec with a power injector. Zero-filling interpolation was used and resulted in a final in-plane resolution of 0.60 ÷ 0.80 mm. Each contrast-enhanced MR angiographic data set was transferred to a dedicated workstation (Advantage 4.0; GE Medical Systems) to be processed by an experienced technologist with use of a maximum intensity projection algorithm. After exclusion of the vertebral arteries, each carotid bifurcation was recorded on film hard copy in the same four projections used for DSA.

**Image Analysis**

Three independent readers (J.J.C., N.J.H., and N.M.A., with 3, 7, and 19 years of experience, respectively, as attending neuroradiologists at the start of image analysis in 2003) who were blinded to clinical history and results of other diagnostic tests reviewed all DSA images and contrast-enhanced MR angiograms. However, the readers were aware that screening Doppler US had depicted at least 50% stenosis in at least one ICA. Patient identifiers on film hard copies were masked. Image analysis was performed in batches after patient recruitment was finished. The DSA images were randomized and evaluated over a 4-month period. The contrast-enhanced MR angiograms were then subsequently evaluated over the following 4 months in a different randomized order. Each left and right ICA was evaluated as an independent unit.

For each study, each neuroradiologist first chose the projection that demonstrated the most severe stenosis and then assigned an SVI by estimating the percentage of stenosis; an independent observer (J.M.U.) who was present during all readings immediately recorded this finding in a database. Thereafter, each neuroradiologist obtained two objective measurements with a digital Vernier caliper calibrated to the nearest 0.1 mm: Measurement A was the luminal diameter at the site of maximal narrowing, and measurement B was the luminal diameter of the normal distal ICA. In strict accordance with NASCET guidelines, care was taken to ensure that measurement B was obtained in the distal ICA, which was well beyond the bulb and where the artery walls became parallel (Fig 1a) (18–21). SVI and caliper measurements were obtained during the same session to eliminate the effects of intraobserver variability that otherwise may have occurred if reading had been performed during different sessions (22). The neuroradiologist was not permitted to revise his SVI reading after objective measurements were obtained. The independent observer recorded only the actual diameter measurements in the database at the time of image interpretation. The percentage of stenosis was calculated at a later stage by the independent observer in the absence of the neuroradiologist according to the formula $S = \frac{(B - A)}{B} \times 100$, where $A$ refers to measurement A, $B$ refers to measurement B, and $S$ refers to NASCET stenosis.

**Data Analysis**

The purpose of this study was not to compare DSA with contrast-enhanced MR angiography but rather to compare SVI with objective caliper measurements obtained independently on DSA images and contrast-enhanced MR angiograms. Thus, for each SVI interpretation performed by a neuroradiologist using a given modality, the reference standard was the percentage of stenosis, as determined with objective caliper measurements obtained by the same neuroradiologist using the same modality.

There are several scenarios, includ-
ing normal arteries, occluded arteries, and nearly occluded arteries, in which objective caliper measurements cannot be obtained. Near occlusion of the ICA refers to the appearance of partial lumenal diameter decrease (lumen diameter similar to or less than that of the ipsilateral external carotid artery and less than that of the contralateral ICA) of the nondiseased distal ICA beyond a proximal critical carotid bulb stenosis (Fig 1b) (23,24). Because of the apparent decrease in ICA diameter as a result of slow contrast medium flow, caliper measurements tend to lead to underestimation of the degree of stenosis. Thus, in clinical practice, these studies are arbitrarily classified as showing near occlusions without measurements (23). Moreover, for contrast-enhanced MR angiographic studies only, an ICA can show a flow void or signal gap, both of which have been shown to be equivalent to 70%–99% stenosis (17,25). For such studies, caliper measurements are again impossible to obtain, as there is no residual lumen. After exclusion of such studies from data analysis, stenosis was classified as 0%–49% (mild), 50%–69% (moderate), or 70%–99% (severe).

**Statistical Analysis**

All data were analyzed with SPSS statistical software for Windows (version 10.1; SPSS, Chicago, Ill). Overall diagnostic misclassification was defined as the percentage of studies in which SVI and objective caliper measurements disagreed as to the correct assessment of stenosis into the 0%–49%, 50%–69%, or 70%–99% category. Sensitivity, specificity, and predictive values with 95% confidence intervals were calculated for the accuracy of SVI in the correct classification of 70%–99% stenosis and 50%–99% stenosis. These two groups (ie, 70%–99% stenosis and 50%–99% stenosis) represent generally accepted stenosis criteria for intervention in the form of carotid endarterectomy and carotid artery stent placement, respectively (4,24,26). Misclassification for correct categorization into the 70%–99% or 50%–99% group was defined as the percentage of studies in which there was disagreement as to the presence or absence of these stenosis groups. Moreover, among all cases of misclassification for categorization as 70%–99% stenosis, instances in which SVI and caliper readings were within 4% of each other were identified. We arbitrarily chose 4% because typical measurement errors for inter- and intraobserver variability for the reference standard (DSA) have been shown to be of the order of ±5% (9,27).

Agreement between the two readings was assessed with the Bland-Altman method for continuous agreement and Cohen κ statistics for categorical agreement regarding 0%–49%, 50%–69%, and 70%–99% stenosis (28). κ values of 0.80–1.00 were taken to represent good agreement; κ values of 0.60–0.79, moderate agreement; and κ values of 0.00–0.59, poor agreement. Finally, interobserver agreement was determined for both contrast-enhanced MR angiography and DSA with κ statistics and Bland-Altman methods. The Fisher exact test and χ² tests were used to determine statistical significance, and P ≤ .05 indicated a statistically significant difference.

**Results**

**Study Population**

The 142 patients who underwent both DSA and contrast-enhanced MR angiography...
Radiology were initially included, yielding 284 arteries for initial analysis. An intention-to-image approach was adopted, and no study was excluded on the basis of poor technical quality. However, after exclusion of 37 occluded arteries in 33 patients, 58 normal arteries in 51 patients, and nine nearly occluded arteries in nine patients, 180 arteries in 124 patients remained for analysis of DSA findings. Moreover, for contrast-enhanced MR angiography only, 21 additional studies in 20 patients with flow voids were excluded, yielding 159 arteries in 118 patients for analysis. The patient flow diagram constructed according to the STARD (Standard for Reporting of Diagnostic Accuracy) criteria is shown in Figure 2 (29).

**Agreement between SVI and Caliper Measurements**

Categorical agreement between SVI and caliper measurements was moderate.
for DSA, with $\kappa$ values of 0.78, 0.74, and 0.71 for readers A, B, and C, respectively. Categorical agreement for contrast-enhanced MR angiography was also moderate, although it was not as good as that between SVI and caliper measurements for DSA, with corresponding $\kappa$ values of 0.71, 0.66, and 0.62. These differences between DSA and contrast-enhanced MR angiography were significant for readers A, B, and C ($P = .03, P = .03,$ and $P = .02$, respectively).

Bland-Altman plots were used to assess differences between SVI and caliper measurements at DSA and contrast-enhanced MR angiography for each reader (Fig 3) and showed different patterns that ranged from underestimation to overestimation with SVI among the different readers, with mean biases (ie, the mean difference between the two readings) that ranged from $-4.9\%$ (reader A using DSA) to $3.7\%$ (reader B using DSA). For contrast-enhanced MR angiography, mean biases ranged from $-1.3\%$ to $2.5\%$. The limits of agreement, within which 95% of the differences between the two measurement methods (SVI vs caliper) were expected to lie, ranged from $\pm 14.1\%$ to $\pm 22.7\%$ for DSA and from $\pm 14.7\%$ to $\pm 20.9\%$ for contrast-enhanced MR angiography, with no definite trend that emerged.

### Overall Diagnostic Misclassification

For readers A, B, and C, respectively, overall diagnostic misclassifications were $14.4\%$, $17.2\%$, and $18.9\%$ for DSA and $18.9\%$, $22.0\%$, and $23.9\%$ for contrast-enhanced MR angiography (Table 1). Although there was a tendency for misclassification to be higher for contrast-enhanced MR angiography than for DSA for each reader, this difference was not significant for any reader ($P = .30, P = .27,$ and $P = .24$ for readers A, B, and C, respectively; Fisher exact test).

Most cases of misclassification for either modality stemmed from overestimation with SVI, although there were some important interobserver differences (Tables 1, 2). The proportion of cases of overestimation that accounted for overall misclassification was high for readers B (DSA, $93.5\%$; contrast-enhanced MR angiography, $91.4\%$) and C (DSA, $94.1\%$; contrast-enhanced MR angiography, $73.7\%$). However, the SVI assigned by reader A was more balanced, with overestimation accounting for only $53.8\%$ of errors for DSA and $60.0\%$ of errors for contrast-enhanced MR angiography.

### Table 1

**Summary of Diagnostic Performance of SVI with Caliper Measurements as the Reference Standard for DSA and Contrast-enhanced MR Angiography on a Per-Reader Basis**

<table>
<thead>
<tr>
<th>Statistic</th>
<th>Reader A</th>
<th>Reader B</th>
<th>Reader C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overall diagnostic misclassification</td>
<td>$14.4 (26/180)$</td>
<td>$17.2 (31/180)$</td>
<td>$18.9 (34/180)$</td>
</tr>
<tr>
<td>$95%$ CI</td>
<td>$10.1, 20.3$</td>
<td>$12.4, 23.4$</td>
<td>$12.9, 24.0$</td>
</tr>
<tr>
<td>Detection of $70%$–$99%$ stenosis</td>
<td>$87.3 (55/63)$</td>
<td>$88.1 (104/118)$</td>
<td>$96.7 (58/60)$</td>
</tr>
<tr>
<td>$95%$ CI</td>
<td>$76.8, 93.4$</td>
<td>$81.0, 92.8$</td>
<td>$86.7, 99.0$</td>
</tr>
<tr>
<td>Specificity</td>
<td>$93.2 (109/117)$</td>
<td>$100 (62/62)$</td>
<td>$86.7 (104/120)$</td>
</tr>
<tr>
<td>$95%$ CI</td>
<td>$87.1, 96.5$</td>
<td>$95.4, 100$</td>
<td>$79.4, 91.6$</td>
</tr>
<tr>
<td>Negative predictive value</td>
<td>$93.2 (109/117)$</td>
<td>$100 (104/104)$</td>
<td>$98.1 (104/106)$</td>
</tr>
<tr>
<td>$95%$ CI</td>
<td>$87.1, 96.5$</td>
<td>$97.2, 100$</td>
<td>$93.4, 99.4$</td>
</tr>
<tr>
<td>Positive predictive value</td>
<td>$87.3 (55/63)$</td>
<td>$81.6 (62/76)$</td>
<td>$78.4 (58/74)$</td>
</tr>
<tr>
<td>$95%$ CI</td>
<td>$76.8, 93.4$</td>
<td>$71.4, 88.7$</td>
<td>$67.7, 86.2$</td>
</tr>
<tr>
<td>Misclassification</td>
<td>$8.9 (16/180)$</td>
<td>$7.8 (14/180)$</td>
<td>$10.0 (18/180)$</td>
</tr>
<tr>
<td>$95%$ CI</td>
<td>$5.6, 14.0$</td>
<td>$4.7, 12.6$</td>
<td>$6.4, 15.2$</td>
</tr>
</tbody>
</table>

**Note.**—Overall diagnostic misclassification refers to the percentage of studies whereby SVI and caliper measurements disagreed as to correct classification into $0\%$–$49\%$, $50\%$–$69\%$, or $70\%$–$99\%$ stenosis group. Misclassification regarding the presence or absence of $70\%$–$99\%$ and $50\%$–$99\%$ stenosis group are provided. Data in parentheses were used to calculate percentages. CI = confidence interval.
Misclassification of Categorization into 70%–99% and 50%–99% Stenosis Groups

With regard to the presence or absence of 70%–99% stenosis (Table 1), there was a spectrum of values for sensitivity (87.3%–96.7%) and specificity (83.1%–100%) that ranged from moderate to excellent for each reader. However, the consistently excellent negative predictive values ranged from 92.3% to 100%.

For readers A, B, and C, respectively, misclassifications in the categorization of 70%–99% stenosis were 8.9%, 7.8%, and 10.0% for DSA and 11.3%, 8.8%, and 15.1% for contrast-enhanced MR angiography (Table 1). Again, there was a tendency for these misclassification rates to be higher for contrast-enhanced MR angiography than for DSA within each reader; this difference was not significant for readers A or B (P = .11 and P = .14, respectively) but was significant for reader C (P = .049). Individual review of such cases of misclassification showed that the mean number of studies where SVI and caliper measurements were within 4% of each other was three (range, two to five studies) for each data set.

Regarding the sensitivity, specificity, and predictive values for correct categorization of 50%–99% stenosis with SVI (Table 1), negative predictive values were excellent and ranged from 90.0% to 98.1%. There was a tendency for misclassification with SVI to be slightly higher for contrast-enhanced MR angiography than for DSA within each reader; this difference was not significant for readers A or B (P = .11 and P = .14, respectively) but was significant for reader C (P = .049). Individual review of such cases of misclassification showed that the mean number of studies where SVI and caliper measurements were within 4% of each other was three (range, two to five studies) for each data set.

Interobserver Agreement

For both DSA and contrast-enhanced MR angiography (Table 3), interobserver variability was greater for SVI measurements than for caliper measurements. Thus, for DSA, k values ranged from 0.75 to 0.80 for caliper measurements and from 0.62 to 0.71 for SVI measurements. Similarly, for contrast-enhanced MR angiography, k values were better for caliper measurements (0.66–0.72) than for SVI measurements (0.57–0.69). Consistent with this pattern, Bland-Altman analysis revealed undeniably wider limits of agreement for SVI (range, ±19.1 to ±23.6%) than for objective caliper measurements (range, ±13.7% to ±20.8%), reflecting the poorer interobserver variability of SVI.

Discussion

There are several reasons why radiologists and clinicians tend to use SVI rather than obtain objective measurements. Miller (30) argued that as radiologists, we are often taught to train our eyes to identify and characterize abnormalities without the need for objective quantification. Frequently, a ruler or caliper may not be available at the time of reporting. Also, the more confident the radiologist is, the more he or she may believe that objective quantification will add little to the careful qualitative evaluation based on his or her unique expertise acquired during many years of practice. Moreover, for ICA stenosis, it is arguable whether SVI can enable one to integrate information from different viewing angles into one result and thereby eliminate some variability due to disagreement over which projection to assess.
vant to clinical practice probably relate to the presence or absence of 70%–99% stenosis for surgery and of 50%–99% stenosis for stent placement.

For 70%–99% stenosis, misclassification with SVI ranged from 8.9% to 10.0% for DSA and from 11.3% to 15.1% for contrast-enhanced MR angiography in our study. Similarly, for 50%–99% stenosis, misclassification with SVI ranged from 6.1% to 9.4% for DSA and from 7.5% to 13.2% for contrast-enhanced MR angiography. SVI performed well for all three readers with 99% stenosis was concerned, SVI performed substantially worse than it did in our study. Misclassification was high, ranging from 40% to 56% for the 16%–49% stenosis group, from 30% to 44% for the 50%–79% stenosis group, and from 27% to 51% for the 80%–99% stenosis group. In the Schmittling et al study, all errors were due to overestimation (ie, SVI never resulted in underestimation of ICA stenosis).

Both Pelz et al (13) and Schmittling et al (14) investigated conventional DSA only. Given the growing acceptance of noninvasive modalities as alternatives to DSA, it is interesting that use of SVI with contrast-enhanced MR angiography generally performed worse than did use of SVI with DSA. There was a tendency for higher diagnostic and clinically relevant misclassification with SVI and contrast-enhanced MR angiograms compared to that with SVI and DSA images, although these differences were not always significant. However, a significant finding was that categorical agreement between SVI and objective measurements was worse for contrast-enhanced MR angiography than for DSA. Moreover, for both SVI and objective measurements, interobserver variability was also consistently and significantly higher for contrast-enhanced MR angiography than for DSA. The explanation for this is probably spatial resolution differences. Although we achieved submillimeter spatial resolution (0.60 × 0.80 mm) with contrast-enhanced MR angiography, this was still two or three times less than that achieved with conventional DSA (0.32 × 0.32 mm). With technical advances in MR angiographic techniques, such as the use of parallel imaging or higher field strength, such differences between DSA and MR angiography will probably decrease (32,33).

We used film hard copies because this was the current practice at our institution at the time of reporting. We acknowledge this as a limitation of our study, given the increasing use of reporting at workstations; however, we suggest that there are no convincing reasons why our conclusions regarding SVI would not also apply to soft-copy images. Thus, in our opinion, the use of electronic calipers or measuring tools that are routinely available on picture

To test the hypothesis that there are no significant differences in measurement variability between SVI and contrast-enhanced MR angiography, a Bland-Altman analysis (%)

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**Table 3**

<table>
<thead>
<tr>
<th>Interobserver Agreement of SVI and Objective Caliper Measurements for DSA and Contrast-enhanced MR Angiography</th>
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<tr>
<td><strong>DSA</strong></td>
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<tr>
<td>Bland-Altman Analysis (%)</td>
</tr>
<tr>
<td>Caliper measurements</td>
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<tr>
<td>Reader A vs reader B</td>
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<tr>
<td>Reader A vs reader C</td>
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<tr>
<td>Reader B vs reader C</td>
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<tr>
<td>SVI</td>
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<tr>
<td>Reader A vs reader B</td>
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<tr>
<td>Reader A vs reader C</td>
</tr>
<tr>
<td>Reader B vs reader C</td>
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</tbody>
</table>

Note.—For Bland-Altman analysis, data presented include mean bias between the pairs of readers, followed by the Bland-Altman 95% limits of agreement around this mean bias. κ Values refer to categorical agreement for correct classification into mild, moderate, and severe stenosis groups.
archiving and communications systems is recommended.

Another study limitation is that we used an absolute threshold of 70% to indicate severe stenosis on the basis of NASCET and ECST findings (1,2). Thus, a stenosis of 70% measured with SVI that was objectively measured and found to be 67% would be considered a misclassification, as it is likely that such small differences are not clinically important. This must be placed into context, as it is clear from our data that readers tend to assign SVIs of ICA stenosis to at least the nearest 5%. Moreover, even objective measurements of stenosis are not true reference standards, as they are subject to inter- and intraobserver variability (27). We therefore acknowledge that our misclassifications could result in an overestimation of the number of times SVI would have made an important difference in patient care. Nevertheless, we manually counted all instances in which SVI readings were within 4% of caliper measurements but were still categorized as misclassifications because they straddled the 70% threshold. Such studies were few and ranged from a minimum of two to a maximum of five studies for each data set, implying that these misclassifications were unlikely to substantially affect our overall conclusions.

In conclusion, SVI of ICA stenosis is associated with significantly higher interobserver variability compared with objective caliper measurements. Even when performed by experienced neuroradiologists, SVI alone is not recommended for evaluation of ICA stenosis with either DSA or contrast-enhanced MR angiography. SVI may be acceptable as an initial screening tool to exclude the presence of 50%–99% or 70%–99% stenosis, but confirmatory caliper measurements are warranted to confirm the presence of such categories of stenosis.

References


