Grading of internal carotid artery stenosis with multidetector-row CT angiography: comparison between manual and semiautomatic measurements.

Poster No.: C-1525
Congress: ECR 2014
Type: Scientific Exhibit
Authors: R. Berletti¹, G. Casagranda¹, L. Bailoni¹, G. Giannelli¹, M. Barbieri¹, O. Caffo¹, F. Paganelli¹, M. Recla¹, M. Centonze²; ¹Trento (TN), IT/IT, ²Borgo Valsugana (Trento)/IT
Keywords: Obstruction / Occlusion, Haemodynamics / Flow dynamics, Arteriosclerosis, Technical aspects, Computer Applications-General, Comparative studies, CT-Angiography, CT, Catheter arteriography, Vascular, Computer applications, Arteries / Aorta
DOI: 10.1594/ecr2014/C-1525

Any information contained in this pdf file is automatically generated from digital material submitted to EPOS by third parties in the form of scientific presentations. References to any names, marks, products, or services of third parties or hypertext links to third-party sites or information are provided solely as a convenience to you and do not in any way constitute or imply ECR’s endorsement, sponsorship or recommendation of the third party, information, product or service. ECR is not responsible for the content of these pages and does not make any representations regarding the content or accuracy of material in this file.
As per copyright regulations, any unauthorised use of the material or parts thereof as well as commercial reproduction or multiple distribution by any traditional or electronically based reproduction/publication method ist strictly prohibited.
You agree to defend, indemnify, and hold ECR harmless from and against any and all claims, damages, costs, and expenses, including attorneys’ fees, arising from or related to your use of these pages.
Please note: Links to movies, ppt slideshows and any other multimedia files are not
available in the pdf version of presentations.
www.myESR.org
Aims and objectives

Stroke is the third leading cause of death, behind coronary artery disease and cancer, and is the most common cause of disability in developed countries. Roughly half are caused by atherothromboembolism and most of these by extracranial atheromatous lesions, most often involving narrowing of the internal carotid arteries (ICAs) [1,2]. Since the publication of large-scale randomized carotid endarterectomy trials during the 1990s, such as the European Carotid Surgery Trial (ECST), the North American Symptomatic Carotid Endarterectomy Trial (NASCET), and the Endarterectomy for Asymptomatic Carotid Artery Stenosis (ACAS) study, there has been increasing interest in the method of grading internal carotid artery stenosis. The results of these trials indicate that the degree of stenosis, expressed as a percentage reduction in vessel diameter, is a major factor in determining whether a patient is likely to benefit from endarterectomy [3]. The available data showed that carotid endarterectomy is highly beneficial in symptomatic patients with 70% or greater stenosis, but without near-occlusion. Endarterectomy confers some benefit for those with symptomatic 50%-69% stenosis, moderately reducing the risk of ipsilateral stroke [4,5].

While stenosis grading was primarily based on intra-arterial digital subtraction angiography (DSA), this technique has gradually been replaced by less invasive techniques such as duplex ultrasound (DUS), magnetic resonance angiography (MRA) and computed tomographic angiography (CTA) [6]. With the introduction of multidetector-row scanning, CTA has become faster, easier to use and has further gained in spatial resolution [7]. In addition, CTA of the carotid and intracerebral arteries has been advocated as part of the work-up of patients with acute stroke [8].

Stenosis grading on DSA is most commonly based on NASCET criteria [9]. Current clinical practice in North America continues to relay upon the guidelines from NASCET; carotid artery stenosis quantification uses percent diameter ratios from conventional angiography [10]. Direct millimeter measurements of the carotid stenosis diameter on CTA were shown to correlate with NASCET-style ratios and with luminal cross-sectional area [11]. Stenosis diameter and NASCET-style ratios can be measured on the axial source images, oblique axial multiplanar reformats (MPR), or maximum intensity projections (MIP) of CTA data. Axial source images, MIP or other 3D images, and MPR images have all been advocated for measuring carotid stenosis [11,12]. Axial source images allow confident distinction of luminal enhancement form adjacent calcification, are easiest to obtain with the least operator intervention, and are expected to yield the most reproducible measurements. Theoretically, source images may underestimate the severity of stenosis if the lumen at the tightest area of narrowing passes obliquely through the axial plane. An axial oblique MPR perpendicular to the stenosis, therefore, is preferred by several investigators; however, the extra steps required may introduce measurement variability and decrease reliability. MIP images provide the closest analog to DSA images and are useful for quick stenosis visualization but are limited by vessel calcification [13].
The aim of our study was to test the performance of manual measurements on axial source images against semiautomatic estimations on MPR images using a vessel analysis software for grading of internal carotid artery stenosis with multidetector CTA. We compared manual and semiautomatic CTA measurements with DSA calculations based on NASCET method as the reference standard.
Methods and materials

Study population.

This retrospective cohort study included 35 patients (24 men and 11 women; mean age 74±7 years, range 55-85) with evidence of an ICA stenosis more than 50% on DUS or a stenosis that was difficult to grade because of extensive calcifications, who underwent CTA and DSA in our institution within a maximum period of 28 days. All DSA examinations were performed after CTA studies and during carotid artery stenting procedures. Examinations were collected from our PACS data base (Synapase, Fujifilm Medical Systems, Milan, Italy). Exclusion criteria included inadequate coverage and/or technical errors precluding full evaluation of the cervical carotid arteries by CTA or DSA. The final analysis comprised 35 carotid arteries.

CTA.

CTA was performed using a Brilliance CT 64-channel scanner (Philips Medical Systems, Best, the Netherlands) or a Somatom Definition AS 128-slice scanner (Siemens, Erlangen, Germany). Patients were placed in a supine position with the head tilted back to avoid dental filling artifacts. Patients were instructed to breathe quietly without swallowing during the imaging. After unenhanced CT of the head, nonionic contrast medium (50-60 mL of iopromide, Ultravist 370 mgI/mL, Bayer Healthcare, Berlin, Germany) was injected with a power injector into an antecubital vein at a rate of 4 mL/s followed by a saline chaser bolus of 30-40 mL injected at the same flow rate. The scan range started just below the aortic arch and ended 3 cm under the vertex after an initial injection delay depending on an attenuation of 100 HU in the aortic arch. We used 64x0,625 mm or 128x0,6 mm collimation with reconstructed overlapping sections of 1 mm slice thickness at a reconstruction interval of 0,5 mm. Exposure settings were respectively 120 kV and 180 mAs (effective) or 120 kV and 140 mAs (effective).

DSA.

Intra-arterial DSA was performed on a Xper FD/20 single plane angiographic unit (Philips Medical Systems, Best, the Netherlands). A 5-F catheter was introduced using the Seldinger technique and was selectively positioned in the common carotid artery of interest. At least two projections (postero-anterior and lateral) were acquired from each carotid artery. All examinations were performed during stenting procedures. For each projection, 8 ml of contrast material (Ultravist 300, Bayer Healthcare, Berlin, Germany) was injected at a flow rate of 3 ml/s. Flat detector system was characterized by a maximum field of view of 30x38 cm, an image matrix of 2480x1920 pixels and a pixel pitch of 154 µm.

Image analysis.
Both CTA and DSA were interpreted by 2 experienced radiologists, unaware of the clinical information, each other’s findings, and the results of other modalities. The degree of ICA stenosis was analyzed according to NASCET criteria (fig. 1): degree of stenosis = (1 - minimal residual lumen diameter / distal lumen diameter) x 100%. If the degree of stenosis could not be measured due to near-occlusion, i.e. severe collapse of the distal lumen, the observers assigned a 95% degree of stenosis. Differences in readings were resolved by consensus.

CTA examinations were transferred to PACS and dedicated workstations for analysis. Manual measurements were performed using axial source images on PACS stations. All millimeter measurements were made on magnified images by using the PACS station submillimeter measurement tool. Carotid stenosis measurements were made by manually placing measurement calipers at the contrast interfaces that defined the narrowest portion of residual lumen at the carotid bulb. Window and level settings were meticulously adjusted for calcified stenoses to best demonstrate the contrast interfaces. All distal ICA diameters were measured well beyond the bulb, where the walls are parallel and no longer tapering from the bulb, as per NASCET methodology (fig. 2). Semiautomatic measurements were performed on a dedicated workstation (Brilliance Workspace, Philips Medical Systems, Best, the Netherlands) using its "advanced vessel analysis" program. In the vessel of interest, a seed point was placed within the ICA. The starting point was placed at the distal common carotid artery and the ending point at the ICA to the level where the caliber of the vessel had normalized. One or more intermediate points could be added if required. The software automatically detected the vessel centerline on a curved planar reformat (CPR) and computed cross-sectional area and minimum, maximum, and mean diameters at each point. The user defined the key anatomic points of interest, which were the maximal stenosis and the reference point according to NASCET. The software calculated the percentage of stenosis. In case the software presented an incorrect centerline, the observer was able to adjust it. Particular care was taken to manually adapt the contours of the lumen area whenever necessary so that it avoided crossing calcified plaques. All measurements were determined in a plane perpendicular to the center lumen line of the vessel (axial oblique reformats). The software evaluated the degree of stenosis in terms of effective diameter and cross-sectional area (fig. 3).

The DSA images were analyzed on PACS stations using calipers. The 2 readers could choose image enlargement according their personal preference. They chose the projection with maximum stenosis and determined the degree of stenosis using the NASCET criteria (fig. 4).

**Statistical methods.**

Proximal and distal carotid diameters and NASCET style ratios were measured by 2 radiologists on separate occasions. Diameter measurements of normal and stenosed carotid arteries on CTA were performed on cross-sectional images from PACS (manual method) and on oblique multiplanar reformats using a vessel analysis software.
(semiautomatic method). The stenosis percentage was calculated by using longitudinal projection imaging on DSA. All differences in readings were resolved by consensus. The estimated stenosis by the 2 observers in DSA was considered the "gold standard" reference. Pearson product-moment correlation coefficients were calculated to evaluate the performance of manual and semiautomatic methods to identify >70% stenosis against NASCET-style reference on DSA. The closer the value of the correlation coefficient gets to zero, the greater the variation the data points are around the line of best fit. Values of 0.7-1.0 mean high correlation. Manual method was also compared with semiautomatic vessel analysis. Sensitivity, specificity, positive predictive values (PPVs) and negative predictive value (NPVs) were calculated for both CTA methods with a carotid stenosis threshold of >70%. All raw data were analyzed by using the statistical software package SPSS for Windows, version 12.0.0 (SPSS Inc., Chicago, IL).
Fig. 1: Quantification of the degree of carotid stenosis: the NASCET method. Degree of stenosis = \( B - A / B \times 100 \). ICA (Internal Carotid Artery); ECA (External Carotid Artery); CCA (Common Carotid Artery).

© Radiologia, APSS Trento, Ospedale Santa Chiara - Trento (TN)/IT
Fig. 2: Manual measurements on CTA. Carotid stenosis measurements are obtained from axial source data at the narrowest portion of the carotid bulb and well beyond the bulb where the walls are parallel.

© Radiologia, APSS Trento, Ospedale Santa Chiara - Trento (TN)/IT
Fig. 3: Semiautomatic measurements on CTA. Vessel analysis software allows semiautomatic measurements of vessel diameter and percent stenosis: the program displays the vessel centerline on a curved planar reformat and computes cross-sectional area and effective diameter at each point.

© Radiologia, APSS Trento, Ospedale Santa Chiara - Trento (TN)/IT
**Fig. 4:** DSA: NASCET-style ratios. The minimum perfused diameter of the ICA and the diameter at the first normal appearing distal ICA are measured.

© Radiologia, APSS Trento, Ospedale Santa Chiara - Trento (TN)/IT
Results

Pearson product-moment correlation coefficients were calculated to evaluate the performance of manual and semiautomatic methods to identify #70% stenosis against NASCET-style reference on DSA. The closer the value of the correlation coefficient gets to zero, the greater the variation the data points are around the line of best fit. Values of 0,7-1,0 mean high correlation.

Pearson's correlation coefficients showed high correlation between the direct measurements on CTA and the NASCET-style percent ratios calculated on DSA images.

The agreement was comparable for both stenosis grading CTA methods: 0,712 for manual method and 0,715 for semiautomatic evaluation. A high correlation was also found between the 2 methods based on CTA measurements (0,864).

Correlation scatter plots show the results (fig. 5).

For stenosis percentages # 70% the CTA values of sensitivity, specificity, positive and negative predictive values were respectively 60%, 86%, 70%, 79% for manual method and 76%, 86%, 70%, 79% for semiautomatic analysis.

The data of the study with all measurements are shown in figure 6.
Fig. 5: Correlation scatter plots. Diagrams show high correlation values between the measurement techniques used to derive percent stenosis.

© Radiologia, APSS Trento, Ospedale Santa Chiara - Trento (TN)/IT
<table>
<thead>
<tr>
<th>Patient</th>
<th>Sex</th>
<th>Age</th>
<th>ACI</th>
<th>DSA</th>
<th>CTA semiautomatic analysis</th>
<th>CTA Manual method</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>M</td>
<td>55</td>
<td>S N</td>
<td></td>
<td>45%</td>
<td>50%</td>
</tr>
<tr>
<td>2</td>
<td>M</td>
<td>72</td>
<td>S N</td>
<td></td>
<td>60%</td>
<td>64%</td>
</tr>
<tr>
<td>3</td>
<td>M</td>
<td>59</td>
<td>S N</td>
<td></td>
<td>74%</td>
<td>65%</td>
</tr>
<tr>
<td>4</td>
<td>M</td>
<td>73</td>
<td>S N</td>
<td>DX</td>
<td>55%</td>
<td>44%</td>
</tr>
<tr>
<td>5</td>
<td>F</td>
<td>71</td>
<td>DX</td>
<td></td>
<td>65%</td>
<td>66%</td>
</tr>
<tr>
<td>6</td>
<td>F</td>
<td>85</td>
<td>DX</td>
<td></td>
<td>68%</td>
<td>68%</td>
</tr>
<tr>
<td>7</td>
<td>M</td>
<td>63</td>
<td>DX</td>
<td></td>
<td>53%</td>
<td>62%</td>
</tr>
<tr>
<td>8</td>
<td>M</td>
<td>80</td>
<td>DX</td>
<td></td>
<td>37%</td>
<td>53%</td>
</tr>
<tr>
<td>9</td>
<td>M</td>
<td>77</td>
<td>DX</td>
<td></td>
<td>60%</td>
<td>66%</td>
</tr>
<tr>
<td>10</td>
<td>M</td>
<td>82</td>
<td>S N</td>
<td></td>
<td>68%</td>
<td>82%</td>
</tr>
<tr>
<td>11</td>
<td>F</td>
<td>65</td>
<td>S N</td>
<td></td>
<td>90%</td>
<td>70%</td>
</tr>
<tr>
<td>12</td>
<td>M</td>
<td>83</td>
<td>DX</td>
<td></td>
<td>44%</td>
<td>67%</td>
</tr>
<tr>
<td>13</td>
<td>M</td>
<td>83</td>
<td>S N</td>
<td></td>
<td>57%</td>
<td>69%</td>
</tr>
<tr>
<td>14</td>
<td>M</td>
<td>71</td>
<td>DX</td>
<td></td>
<td>43%</td>
<td>52%</td>
</tr>
<tr>
<td>15</td>
<td>F</td>
<td>78</td>
<td>S N</td>
<td></td>
<td>70%</td>
<td>80%</td>
</tr>
<tr>
<td>16</td>
<td>F</td>
<td>83</td>
<td>S N</td>
<td></td>
<td>58%</td>
<td>60%</td>
</tr>
<tr>
<td>17</td>
<td>M</td>
<td>73</td>
<td>DX</td>
<td></td>
<td>80%</td>
<td>72%</td>
</tr>
<tr>
<td>18</td>
<td>M</td>
<td>73</td>
<td>S N</td>
<td></td>
<td>72%</td>
<td>70%</td>
</tr>
<tr>
<td>19</td>
<td>F</td>
<td>74</td>
<td>S N</td>
<td></td>
<td>64%</td>
<td>66%</td>
</tr>
<tr>
<td>20</td>
<td>F</td>
<td>74</td>
<td>DX</td>
<td></td>
<td>80%</td>
<td>81%</td>
</tr>
<tr>
<td>21</td>
<td>M</td>
<td>64</td>
<td>S N</td>
<td></td>
<td>56%</td>
<td>67%</td>
</tr>
<tr>
<td>22</td>
<td>F</td>
<td>81</td>
<td>DX</td>
<td></td>
<td>81%</td>
<td>77%</td>
</tr>
<tr>
<td>23</td>
<td>F</td>
<td>81</td>
<td>DX</td>
<td></td>
<td>62%</td>
<td>64%</td>
</tr>
<tr>
<td>24</td>
<td>M</td>
<td>72</td>
<td>DX</td>
<td></td>
<td>70%</td>
<td>65%</td>
</tr>
<tr>
<td>25</td>
<td>M</td>
<td>69</td>
<td>S N</td>
<td></td>
<td>66%</td>
<td>61%</td>
</tr>
<tr>
<td>26</td>
<td>M</td>
<td>81</td>
<td>S N</td>
<td></td>
<td>92%</td>
<td>95%</td>
</tr>
<tr>
<td>27</td>
<td>F</td>
<td>68</td>
<td>S N</td>
<td></td>
<td>67%</td>
<td>70%</td>
</tr>
<tr>
<td>28</td>
<td>M</td>
<td>73</td>
<td>DX</td>
<td></td>
<td>62%</td>
<td>73%</td>
</tr>
<tr>
<td>29</td>
<td>M</td>
<td>73</td>
<td>S N</td>
<td></td>
<td>92%</td>
<td>95%</td>
</tr>
<tr>
<td>30</td>
<td>M</td>
<td>84</td>
<td>S N</td>
<td></td>
<td>52%</td>
<td>63%</td>
</tr>
<tr>
<td>31</td>
<td>M</td>
<td>77</td>
<td>DX</td>
<td></td>
<td>86%</td>
<td>95%</td>
</tr>
<tr>
<td>32</td>
<td>F</td>
<td>68</td>
<td>S N</td>
<td></td>
<td>83%</td>
<td>58%</td>
</tr>
<tr>
<td>33</td>
<td>M</td>
<td>71</td>
<td>S N</td>
<td></td>
<td>62%</td>
<td>52%</td>
</tr>
<tr>
<td>34</td>
<td>M</td>
<td>71</td>
<td>DX</td>
<td></td>
<td>81%</td>
<td>82%</td>
</tr>
<tr>
<td>35</td>
<td>M</td>
<td>82</td>
<td>DX</td>
<td></td>
<td>52%</td>
<td>54%</td>
</tr>
</tbody>
</table>

**Fig. 6:** Patients studied and relative NASCET-style derived percent stenoses.

© Radiologia, APSS Trento, Ospedale Santa Chiara - Trento (TN)/IT
Conclusion

Stroke risk is dependent on many factors, but for patients with carotid bifurcation disease, the most important are a history of neurologic symptoms, the degree of stenosis of the carotid bifurcation plaque, and to a lesser extent, plaque characteristics such as ulcerations, intraplaque hemorrhage, and lipid content. The purpose of carotid bifurcation imaging is to detect "stroke-prone" carotid bifurcation plaque and identify a high-risk patient likely to benefit from therapy designed to reduce stroke risk [2]. Accurate measurements of the degree of stenosis are important because higher grades of carotid artery stenosis are associated with an increased risk of stroke and because the degree of stenosis together with stenosis-related symptoms determine how much a patient might profit from carotid endarterectomy or stent placement [14].

Duplex ultrasonography is usually the first imaging method for carotid arteries and has many advantages as a fast, noninvasive, and easily available screening method. However, a confirmatory imaging method is necessary if an intervention is considered or if the degree of stenosis remains undetermined by DUS [15]. Digital subtraction angiography has been the "gold standard" for diagnosis of carotid artery stenosis. Noninvasive MRA and CTA have partially replaced DSA, which has up to a 1% risk of stroke, a 4% risk of transient ischemic attack (TIA), and nearly a 1% mortality rate [16,17]. Modern CTA, performed with multidetector high-speed CT hardware and evaluated with advanced reformatting software, accurately and reliability depicts carotid disease, and allows for direct quantification of carotid stenosis in millimeters [18].

Similar to other investigators, we found that carotid wall calcifications can complicate evaluation of stenosis on 2D MPR and 3D MIP images. As have other investigators, we found that the axial source images are key to CTA carotid stenosis evaluation [13]. Axial source images allow good visualization of the patent lumen apart from vessel wall plaque, even with calcium on the sides. We meticulously adjusted window and level settings for calcified stenoses to best demonstrate the contrast interfaces. Anyone familiar with measuring vessels from CTA or from other digitized systems (including MRA and DSA) is aware of the "fuzzy" edge created when images are significantly magnified. Most of our measurements were obtained with minimal - if any - magnification. Magnification was used if the residual vessel lumen was diminutive, usually <2 mm, and difficult to measure on original images. In these cases, measurements were obtained with the cursor at the midpoint of the outer "fuzzy" border, as in the middle of the perceived bell-shaped curve of the artery edge. The appropriateness of all cursor placements was verified on the unmagnified source images.

Axial source images represent the raw acquired CTA data. Theoretically, they may underestimate the severity of stenosis if the proximal stenosis passes obliquely through the axial plane. An MPR tool, therefore, can be used to create axial oblique images perpendicular to the tightest stenosis. The extra steps involved in selecting an oblique
plane are time consuming. Many commercially available software packages allow semiautomatic analysis of vessel diameter and percent stenosis on curved planar images. The semiautomated method for stenosis measurement may provide a useful approach in a clinical setting; however, as previously pointed out by other authors, manual correction is still required [18]. Furthermore, the software user should be aware of potential errors due to misinterpretation of the software, often associated with presence of calcium near the site of maximal stenosis. In our experience, particular care was taken to adjust incorrect centerlines and manually adapt the contours of the lumen area whenever necessary. Recent reports on the accuracy of semiautomatic analysis do not show a benefit relative to manual measurement [18,19].

Our study shows a high correlation between semiautomated measurements on axial oblique multiplanar reformats and manual measurements on axial source images in CTA compared with DSA as the reference standard. The manual method appears faster and easier, and can rapidly confirm visual stenosis estimation and other modalities results.
Personal information

Riccardo Berletti M.D. - Department of Radiology - Santa Chiara Hospital - Trento - Italy
riccardo.berletti@apss.tn.it

Giulia Casagranda M.D. - Department of Radiology - Santa Chiara Hospital - Trento - Italy
giulia.casagranda@apss.tn.it

Lorenzo Bailoni R.T. (resident) - Department of Radiology - Santa Chiara Hospital - Trento - Italy
lorenzo.bailoni@hotmail.it

Giovanni Giannelli M.D. - Department of Radiology - Santa Chiara Hospital - Trento - Italy
giovanni.giannelli@apss.tn.it

Michele Barbieri M.D. - Department of Radiology - Santa Chiara Hospital - Trento - Italy
michele.barbieri@apss.tn.it

Orazio Caffo M.D. - Department of Medical Oncology - Santa Chiara Hospital - Trento - Italy
orazio.caffo@apss.tn.it

Francesca Paganelli M.D. - Department of Radiology - Santa Chiara Hospital - Trento - Italy
francesca.paganelli@apss.tn.it

Mauro Recla M.D. - Department of Radiology - Santa Chiara Hospital - Trento - Italy
mauro.recla@apss.tn.it

Maurizio Centonze M.D. - Department of Radiology - San Lorenzo Hospital - Borgo Valsugana - Trento - Italy
References


