The normal internal carotid artery: a CTA study

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Aims and objectives

CT angiography (CTA) of the carotid arteries is the most common imaging technique used to evaluate carotid stenosis. The quantification of carotid stenosis still relies on the two major trials originally conducted with digital subtraction angiography (DSA); The North American Symptomatic Carotid Endarterectomy Trial (NASCET) and the European Carotid Surgery Trial (ECST), the former being the most commonly used stenosis grading standard in Finland [1,2].

NASCET-style reference standard for carotid stenosis is calculated by comparing the diameter of the residual lumen at the site of the maximal stenosis to the diameter of the ipsilateral distal internal carotid artery (ICA), with the latter as the denominator b in the formula presented in Figure 1 [1]. The stenosis is reported as the percentage of the assumed normal ICA diameter occluded by an atherosclerotic plaque, and is therefore dependent of the luminal diameter of the distal ICA. Figure 1 presents a sketch of the stenosis degree measurement according to the NASCET-style standard, and Figure 2 illustrates the actual CTA measurement of the reference diameter, that is, the distal ICA diameter.

Systematic CTA studies investigating intraindividual (side-to-side) normal variation of the ICA luminal diameters (LDs) of the carotid arteries are scarce, yet the ICA diameter is used as a reference to calculate the degree of stenosis according to the NASCET-style reference standard. CTA shows the distal parts of the ICA more reliably than, for example, Doppler and, therefore, provides a useful tool to observe the whole course of the ICA. Moreover, CTA allows the visualization of both ICAs simultaneously in contrast to DSA.

Our goal was to investigate if normal intraindividual variation in the LDs of the carotid arteries, most importantly in the ICAs, exists, as for example in the vertebral arteries. The results could be useful in the identification of the stenosis degree in cases of critical stenosis characterized as a collapse of the poststenotic ICA when the determination of the stenosis degree by means of the NASCET reference standard is impossible [3,4].

Images for this section:
**Fig. 1:** A drawing of the common carotid artery and the internal carotid artery (ICA) featuring the NASCET-style reference standard calculation of the stenosis degree; a = the most stenotic part of the ICA, usually immediately cranial to the bifurcation, and b = the ipsilateral ICA when the vessel diameter has stabilized distal to the stenosis. The yellow area depicts the atherosclerotic plaque. The stenosis degree is given as percentages.

**Fig. 2:** a) An axial source image from the 3D reformatting workstation showing the luminal diameter of the right internal carotid artery. b) A sagittal image shows the actual plane of the measurement.
Methods and materials

Patients

We searched the radiology image archive of our hospital retrospectively and collected 104 CTAs (52 women and 52 men) of the carotid arteries performed during 16.6.2011 - 18.3.2013. CTA of the carotid arteries is most often used to exclude carotid stenosis and dissection, the latter being more common in younger populations.

The inclusion criteria were:

- patient under 40 years at the time of the imaging
- no known pathology affecting the systemic vascular status and/or the carotid arteries
- no visible atherosclerotic changes in the carotid arteries

We made the selection blind to the patient register information, that is, we used the CTA referral in the radiology archive system as the only anamnestic information. Ethnic differences affect the vascular structure and function, and, therefore, we selected only patients with Finnish last names (Caucasians by default). Our aim was to examine intraindividual side-to-side carotid artery LD differences, and, hence, we did not obtain patient height, weight, neck-area diameters or other information that could have affected the absolute diameters of the carotid arteries.

We based our study on the assumption that the collected data would not contain patients with visible atherosclerotic changes affecting the carotid artery LDs. The first atherosclerotic changes, such as increased intima-media thickness, appear relatively early in life, however, visible or symptom-presenting plaques are uncommon before the fifth life decade [5,6]. Thus, the age limit was set to 40 years. We extracted the birth date, as well as the gender (given by the Finnish social security number) from the CTA referral in the radiology archive system. The youngest woman was 18 years and the youngest man 17 years, at the time of the imaging.

The retrospective archive-based study was approved by the head of the radiology department in Helsinki and Uusimaa Hospital District. Separate ethical approval was not necessary, because we did not use the patient registry.

The imaging protocol
CTA was performed with a Siemens SOMATOM Definition As+ (Siemens Healthcare, Erlangen, Germany). Patients were placed in a supine position with head tilted back as far as possible to avoid dental filling artefacts, and instructed to breathe quietly without swallowing during the imaging.

Nonionic contrast medium (Omnipaque 350 mg of iodine/mL, Amersham Health, UK) was injected (amount of 50 ml) with a power injector to an antecubital vein at a rate of 5 ml/s, followed by a saline chaser bolus of 50 ml injected at the same flow rate. The helical acquisition was initiated after bolus reached the ascending aorta using a triggering system (Bolus Tracking, Siemens Healthcare). Imaging data was acquired from the vertex to the aortic arch. The slice thickness was 0,75/0,5 mm, pitch 1,4:1, field of view large, with 120 kV tube voltage and 100 mAs as quality reference.

**Measurements and analysis**

Two experienced neuroradiologists (L.V. and H.S.) and one 4th year radiology resident (S.M.K.), trained to analyze carotid artery CT angiograms, performed the LD measurements using the axial source images at a 3D reformatting workstation (Advantage Workstation, AW 4.4; GE Medical Systems) with a built-in measurement tool of submillimetre accuracy. The examiners performed the measurements unaware of the others to allow all diameters to be determined twice; both neuroradiologists analyzed 52 CTAs and the resident all 104. We averaged the double measurements to produce the final measurement values in order to minimize the effect of inter-rater variability. In cases where a larger than 1 mm discrepancy existed between the measurements of the neuroradiologists and the resident, all three examiners together conducted a consensus measurement, which we then used as the final measurement value.

We selected the measured slice from the source images so that the axial imaging plane would be orthogonal to the course of the artery, regarding that particular slice, and used the 3D reformations at the workstation to detect the actual course of the artery on all planes. Instead of standard windowing, each examiner adjusted windowing manually to produce optimal available arterial edge detection.

Figures 2a and 3a show the actual measurement of the luminal diameters of the CCA and ICA at the 3D reformatting workstation using the axial source images and the built-in measurement tool. Sagittal reformations are presented in Figures 2b and 3b to show the levels of these measured axial slices.

We measured the luminal diameters of the common carotid arteries (CCAs) bilaterally. The measurement point was over 1 cm below the bifurcation, denoted by the arrow in Figure 3b. Moreover, we measured the bilateral luminal diameters of the ICA well beyond
the carotid bulb at a level where the artery walls were aligned, denoted by the arrow Figure 2b.

In addition, we performed measurements of the ICA at the external opening of the bony carotid canal, together with the diameter of the bony canal perpendicular to its long axis. However, measurements from this distal part of the ICA together with the bony carotid canal turned out to be inaccurate, mostly because of the slightly tortuous/curvy course of the ICA at the external opening of the canal, thus complicating the axial plane measurements. Hence, the measured values of the distal ICA and the canal were left out from the statistical analysis.

We analyzed the bilateral averaged measurements by using a paired T-test with R statistics software version 3.0.2 [7], with 0.05 significance level and a 95 % confidence interval (CI). Moreover, we correlated the right and the left CCA and ICA LDs using the squared Pearson correlation coefficient.

Images for this section:

Fig. 2: a) An axial source image from the 3D reformatting workstation showing the luminal diameter of the right internal carotid artery. b) A sagittal image shows the actual plane of the measurement.
Fig. 3: a) An axial source image from the 3D reformatting workstation showing the luminal diameter of the right common carotid artery. b) A sagittal image shows the actual plane of the measurement.
Results

The ranges and the mean values with their standard deviations (SD) of the measured carotid artery LDs are presented in Table 1. In addition, the mean side-to-side differences in LDs with their 95 % confidence intervals (CI) are depicted in Table 1.

Based on the T-tests, we observed no significant side-to-side differences in LDs regarding the ICA; for both the women's and men's groups the 95 % CIs of the mean ICA differences include zero, supporting the T-test results.

The squared Pearson correlation coefficients between the right and the left LDs for CCA and ICA were 0.54 and 0.55 in the women's group, and 0.65 and 0.58 in the men's group. The scatterplots of the right and the left CCA and ICA LDs are presented in Figure 4. In addition, we detected no ICA or carotid canal agenesis, thus supporting the statistical test results.

For women, 95 % CI for CCA LD does not include zero, and, indeed, the p equals 0.018 according to the corresponding T-test, indicating that some side-to-side difference does exist. However, Cohen's d for the CCA difference in the women's group was only 0.34, indicating a rather weak effect. Moreover, Cohen's d for the ICA difference in the women's group was 0.13. The corresponding Cohen's d-values for the men's group were 0.20 for the CCA and 0.02 for the ICA. In addition, the right CCA LD was larger in 40 (77 %) women and 34 men (65 %).

Images for this section:
**Table 1:** The ranges and the mean values of the measured luminal diameters with the standard deviations (SD), and the mean side-to-side differences with the corresponding 95% confidence intervals (CI). CCA_r = the right common carotid artery, CCA_l = the left common carotid artery, ICA_r = the right internal carotid artery, ICA_l = the left internal carotid artery.

<table>
<thead>
<tr>
<th></th>
<th>CCA_r</th>
<th>CCA_l</th>
<th>ICA_r</th>
<th>ICA_l</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Women (n = 52)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean (mm)</td>
<td>5,9</td>
<td>5,8</td>
<td>4,0</td>
<td>4,0</td>
</tr>
<tr>
<td>SD (mm)</td>
<td>0,4</td>
<td>0,4</td>
<td>0,4</td>
<td>0,4</td>
</tr>
<tr>
<td>Range [min; max] (mm)</td>
<td>[5,2; 6,9]</td>
<td>[5,0; 7,3]</td>
<td>[3,2; 4,9]</td>
<td>[3,2; 4,8]</td>
</tr>
<tr>
<td>Mean difference and 95% CI (mm)</td>
<td>0,1 [0,02; 0,18]</td>
<td>0,03 [-0,04; 0,11]</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Men (n = 52)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean (mm)</td>
<td>6,6</td>
<td>6,5</td>
<td>4,4</td>
<td>4,4</td>
</tr>
<tr>
<td>SD (mm)</td>
<td>0,6</td>
<td>0,6</td>
<td>0,5</td>
<td>0,5</td>
</tr>
<tr>
<td>Range [min; max] (mm)</td>
<td>[5,6; 8,3]</td>
<td>[5,4; 7,8]</td>
<td>[3,5; 5,5]</td>
<td>[3,6; 5,4]</td>
</tr>
<tr>
<td>Mean difference and 95% CI (mm)</td>
<td>0,07 [-0,03; 0,17]</td>
<td>0,01 [-0,08; 0,09]</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Fig. 4: Scatterplots with regression lines showing the luminal diameters of the right and the left CCAs and ICAs separately for women and men. The corresponding squared Pearson correlation coefficients are presented above each plot. CCA_r = the right common carotid artery, CCA_l = the left common carotid artery, ICA_r = the right internal carotid artery, ICA_l = the left internal carotid artery.
Conclusion

After conducting the CTA measurements of the carotid arteries (CCA and ICA) for a total of 104 patients, we found no statistically significant intraindividual difference in the measured luminal diameters regarding the ICA. In the women's group, some intraindividual variation might exist between the right and the left CCA, and this may need further investigation. The right CCA was more often larger than the left one, as in a previous study, probably because of the dominance of the right-side CCA [8].

Among these 104 patients, we did not find any hypoplasia or agenesis/aplasia of the ICA. Hypoplasia and agenesis are known to be very rare regarding the ICA [9,10,11,12] and related to the agenesis of the bony carotid canal (narrow or absent) [13,14]. Carotid canal, with its diameters corresponding well to the LDs of the ICA at the external opening, was normal in all the patients, thus supporting normal ICA development.

Race is known to affect the diameters of the carotid arteries, even in studies conducted in the same communities adjusted for general living conditions [15,16]. In order to minimize the race bias, we excluded patients with foreign full names, and assumed that the patients with Finnish full names would be Caucasians by race. Either way, our main goal was to examine intraindividual variation.

In addition to the race-specific differences in carotid artery LDs, the carotid artery diameters are smaller among women even when body and neck size were taken into account [8,17]. Moreover, the general arterial luminal diameter is, of course, influenced by such things as the arterial wall thickness, age, gender, and even hemodynamics.

Limitations of our study:

- We did not incorporate inter-rater variability in to the analysis.
- As we do not have all the patient characteristics, this study does not assess inter-individual variation. Thus, absolute LDs are not comparable.

Implications:

- The results support our hypothesis that post-stenotic collapse is a true sign of critical carotid stenosis. A severe post-stenotic collapse of the ICA caused by atherosclerosis is depicted in Figure 5; NASCET -style stenosis grading is not possible [3,4].
- Because side-to-side variations in the LDs of the ICA are very rare, we could measure a modified NASCET -style stenosis degree by using the
contralateral ICA LD as the reference in cases, where a critical stenosis has caused the ipsilateral ICA to collapse.

- We propose this modified evaluation of critical stenosis by means of stenosis percentage, as carotid stenosis treatment guidelines still rely on the ones published in NASCET and ECST.

**Images for this section:**

![Fig. 5: a) An axial CTA slice showing a severe post-stenotic collapse of the left internal carotid artery (ICA, long arrow) as a result of atherosclerosis. NASCET-style stenosis grading is not possible. b) A sagittal slice of the same patient showing that the whole left ICA has collapsed and is very narrow along its course.](image-url)
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