Extradural Internal Carotid Artery Caliber Dysregulation Associated with Intradural Cerebral Aneurysms

Supplemental content

Focal Dilatations of the Extradural ICA

During diagnostic cerebral angiography, it was subjectively noted by the senior author (AMM) that patients with IAs also presented with unexpected focal dilations of the extradural internal carotid artery (Supplemental Figure 1). Invariably, these dilations were noticed upstream to the location of the aneurysms and at considerable distance of what might be considered the vicinity of the lesions. In the region immediately after this focal expansion the arterial diameter returned to normal. This study attempts to quantify these differences in the caliber along the cervical and extradural ICA, as seen on cerebral angiography, between patients with aneurysms and control subjects.

Patient Demographics

Ninety-six cerebral angiograms (from 51 patients) were included in this study. A total of thirty-eight were aneurysmal angiograms (from 33 patients). Twenty-five contralateral angiograms were also available. Thirty-three angiograms represented control data (from 18 patients). Details about the age and gender of patients in each group are available in Supplementary Table I.

Measurement Validation using Laplacian Edge Detection

To evaluate the potential confounding effect of windowing variability, a test subset of twenty angiograms was measured following application of the Laplacian edge detection filter. This algorithm highlights vessel edges independent of other visualization settings such as
window center or width. The measurements showed excellent correlation with corresponding data obtained without Laplacian edge detection with an ICC of 0.95.

While two-dimensional measurements may potentially offer room for observation error, the excellent ICC indicates that the measurements are both reliable and reproducible. Furthermore, 2-dimensional DSA is still the standard for diagnosing aneurysms and our results demonstrate that caliber changes along the ICA can be easily and reliably assessed by blinded medical operators in a clinical setting.

**Continuous ICA Caliber Measurements in a Subset of Angiograms**

Out of the 97 angiograms available, fourteen angiograms (7 aneurysms, 7 controls) were randomly chosen for a series of fifteen sequential 2D measurements carried out at equidistance along the ICA from the end of the carotid bulb ($D_{Prox}$) to the end of the cavernous segment. The measurements were performed using the line measurement tool in OsiriX software (Version 4.1.2, Pixmeo, Bernex, Switzerland) at default visualization settings (Window Level: 128; Window Width: 256). For each angiogram, a series of distal to proximal ratios were obtained by dividing each of the fifteen measurements by $D_{Prox}$.

The continuous measurements along the extradural ICA in a subset of 14 angiograms displayed a marked trend whereby the arterial caliber in the control group gradually decreased distally, as expected. In stark contrast, the ICA diameter in the aneurysmal group revealed a non-characteristic pattern with regional increases and an overall less pronounced downward trend. Despite the small number of data used for these initial measurements, statistical significance between the two groups was observed by paired t-test analysis (Supplemental Figure I).
The angiographic diameter of the 7 control non-aneurysmal ICA measured at 15 equidistant steps from the cervical origin to the cavernous segment displayed a steady downward trend in the consecutive distal to proximal ratios as expected with the normal ICA caliber decreasing distally (Supplemental Figure II). In stark contrast, similar measurements from the 7 ICA leading to an intradural IA not only failed to demonstrate the expected gentle taper but instead showed a relative increase in width progressing distally with a prominent widening of the ICA in the region of the carotid canal. Paired t-test of the two sets of average measurements (p = .001) confirmed a statistically significant difference between the ICA leading to IA and non-IA controls.
**Supplemental Table I:** Sample size and patient demographics by subgroup. Age is presented as mean ± Standard Deviation.

<table>
<thead>
<tr>
<th>Number of patients</th>
<th>Age (years)</th>
<th>Gender (female %)</th>
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<tbody>
<tr>
<td>Aneurysm (n = 33)</td>
<td>56.2 ± 10.9</td>
<td>68.4</td>
</tr>
<tr>
<td>Contralateral (n = 25)</td>
<td>56.7 ± 11.9</td>
<td>72.0</td>
</tr>
<tr>
<td>Controls (n = 18)</td>
<td>51.3 ± 15.9</td>
<td>60.6</td>
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Supplemental Figure I: Cervical carotid digital subtracted angiography (DSA) in three patients harboring intracranial aneurysms. White arrows indicate the proximal and distal extents of the observed high cervical dilations not seen in control patients.
**Supplemental Figure II:** Graph showing the average of 15 consecutive measurements of the internal carotid artery distal-to-proximal ratio ($R_{dp}$) in 7 ICA leading to intracranial aneurysms (red line) and 7 control non-aneurysm harboring controls (black line). Equidistant measurements progress from the end of the carotid bulb to the location of the petrolingual ligament.