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## **Simplification of the Residual Lumen Geometry in Measuring Carotid Stenosis**

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## Simplification of the Residual Lumen Geometry in Measuring Carotid Stenosis

With interest, we read the article by Bartlett et al<sup>1</sup> on measuring carotid artery stenosis with CT angiography (CTA). The authors found excellent correlations between the cross-sectional area of the contrast lumenogram and the narrowest diameter at the site of stenosis as well as between the cross-sectional area of the contrast lumenogram and the calculated area derived from the narrowest stenosis. Thus, the authors concluded that measurement of the narrowest stenosis is a reliable predictor of the cross-sectional area of carotid stenosis despite the irregular shape of the remaining lumen. We would like to give the following comments on these important results.

It has already been shown that detecting and quantifying a high-grade stenosis (>75%), which should be treated surgically according to the available data, are usually no diagnostic problem independent of the chosen diagnostic tool (ie, CTA, MR angiography, sonography, or conventional angiography) and the technique of measuring carotid stenosis (ie, North American Symptomatic Carotid Endarterectomy Trial, European Carotid Surgery Trial, common carotid artery method, or even eyeballing).<sup>2,3</sup> This is confirmed by the current study. Figures 6 and 7 show an excellent correlation between the measured and calculated cross-sectional stenosis area and the narrowest diameter of the contrast lumenogram in a case of high-grade stenosis with the remaining area of <4 mm<sup>2</sup> and the remaining diameter of <1.5 mm, respectively, at the site of stenosis. However, the exact determination of a carotid stenosis, ranging from 40% to 70%, corresponding roughly to a remaining area between 3 and 12 mm<sup>2</sup> and a remaining diameter between 1.7 and 4 mm, respectively, revealed a wider scattering of the values (ie, worse agreement) as shown by Figs 6 and 7. The eccentric, oval, and irregular shape of moderate vessel area stenosis cannot be correctly quantified by the sole measurement of the narrowest diameter and use of the  $\pi \cdot r^2$  formula, which is only valid for round stenosis. Because it has been recently shown that surgery is also beneficial for patients with 50%–69% symptomatic stenosis, correct graduation of such a “moderate” stenosis is of great importance for the patient’s further treatment.<sup>4</sup>

Another important point is the determination and correlation of the remaining and the original area at the site of the stenosis, which was not considered by Bartlett et al.<sup>1</sup> Because of the large variability in size and configuration of the carotid bulb, it is ambiguous whether the determination of absolute values for the remaining area alone is sufficient. Therefore, the calculation of the ratio between the remaining and original area seems to be closer to the true stenosis area.<sup>2</sup> Unlike high-resolution B-mode sonography combined with color-flow imaging and MR imaging, CT does not allow an exact delineation of the original area because of the limited soft-tissue contrast.

Last but not least, measurement of the remaining area detected by CTA lumenogram is hampered by blur and halo artifacts as shown by the figures. These artifacts lead to an indistinct edge definition due to a decrease of the peripheral enhancement compared with that in the center of the vascular lumen, which has a direct impact on the accuracy of measuring lumen diameter and area stenosis.<sup>5</sup>

From our point of view, determination of high-grade proximal carotid artery stenosis by means of CTA with the analysis of the remaining diameter and area as suggested by Bartlett et al<sup>1</sup> is as accurate as other noninvasive diagnostic techniques.<sup>3</sup> However, quantifying moderate stenosis (40%–69%) by the suggested technique carries some risks of failing to achieve correct quantification and may lead to wrong therapeutic decisions.

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## Reply:

We thank Drs. Schulte-Altdorneburg and Ahlhelm for their interest in our work “Correlation of Carotid Stenosis Diameter and Cross-Sectional Areas with CT Angiography”<sup>1</sup> and our other related works.<sup>2–4</sup> Their concerns over detection of “moderate” stenosis, quantification of absolute stenosis versus relative stenosis, and the accuracy of measurement are important issues that relate to all imaging techniques and statistical methods of carotid stenosis quantification.

All methods of carotid stenosis quantification are relatively flawed, despite the imaging technique (ie, CT angiography [CTA], MR angiography [MRA], duplex sonography, or conventional angiography). It has been shown that severe carotid stenosis ( $\geq 70\%$  stenosis according to North American Symptomatic Carotid Endarterectomy Trial [NASCET]) can be reliably detected by all the various imaging techniques.<sup>5,6</sup> On the other hand, the detection of moderate carotid stenosis (50%–69% stenosis according to NASCET) has been more challenging for all imaging techniques.<sup>5,6</sup> This point is again demonstrated by our study, showing a relatively greater variability in the correlation of carotid stenosis diameter and cross-sectional area in patients with 50%–69% stenosis (corresponding to absolute millimeter measurement of the narrowest residual stenosis between 2.2 and 1.4 mm, respectively). Nonetheless, our study proved that the ability to predict the cross-sectional area from the narrowest stenosis diameter on CTA was excellent, with an  $r^2$  value of 0.76 (taking all data into account from no stenosis through severe stenosis).<sup>1</sup>

The ambiguity of these “moderate” carotid stenoses does not end with quantification. The ability to detect a consistent benefit of carotid endarterectomy for these patients has also proved highly challenging. The NASCET concluded that the benefit of carotid endarterectomy was less in patients with 50%–69% stenosis and did not exist for some subgroups such as women and patients with multiple risk factors.<sup>7</sup> In its initial report, the NASCET<sup>8</sup> had already shown the greatest benefit of endarterectomy in patients with 90%–99% stenosis, medium benefit in patients with 80%–89%, and less in those with 70%–79%. For the 50%–69% group, NASCET found even less benefit, if any at all.<sup>8</sup>

Quantification of carotid stenosis—either by absolute millimeter measurements, relative area reduction, or other various ratio calculations—is only part of the diagnostic picture. Characterization of the carotid plaque may ultimately prove to be predictive of ipsilateral stroke risk in addition to degree of stenosis, despite absolute luminal

measurement or the relative luminal reduction. MR imaging provides noninvasive methods of qualifying carotid plaque.<sup>9</sup> CTA shows some promise in the qualification of plaques as well, showing plaques as being fatty or calcified or having varying densities.<sup>4</sup>

Halo artifacts and indistinct edge definition are a challenge in CTA, as they are with other angiography techniques whether performed by MRA, digital subtraction angiography (DSA), or old film-screen techniques. This is inherent in x-ray physics as well in that of digital imaging display. There is inherent limitation to how much magnification one can do to carry out a measurement because magnification will blur the edges. For NASCET, measurements obtained showed an extremely high kappa of consistency,<sup>8</sup> despite this limitation. In our study, we placed our measurement calipers half-way between the visualized attenuated CTA contrast luminogram edge and the outer halo,<sup>1-4</sup> mimicking measurements acquired in NASCET, which then used a jeweler's eye piece to look at stenosis on angiographic films and DSA.<sup>8</sup>

CTA is now the preferred angiographic technique at many sites to quantify carotid stenosis due to the lack of stroke risk, ease of standardization of CTA, the quick time for the examination (seconds to acquire images from arch to vertex), and the high-quality data produced. It is understandable that those in favor of duplex sonography carotid imaging could be concerned about the capabilities of carotid CTA. Duplex sonography is an excellent screening technique to detect carotid plaque within a narrow window in the neck, with correlations to percentage stenosis from angiography that generally have rather wide numeric ranges. Due to the stroke risk and the resource-intensive nature of conventional angiography, the decision to perform endarterectomy is based on sonography data in some centers, without more accurate angiographic measures. Carotid duplex sonography scanning, however, is also relatively labor-intensive, requiring very highly skilled technologists to achieve accuracy. Adding orbital and transcranial Doppler is required if some distal information of the intracranial circulation is desired.

CTA can be performed within a few seconds without stroke risk and with excellent visualization of all vessels from arch to vertex. Compared with MRA, sonography, and conventional angiography, CTA is the fastest, is easily standardized (between patients, scanners, and technologists), and provides high-resolution images of the intracranial/extracranial vessels as well as the surrounding soft tissues. Additionally, CTA has no stroke risk and demands little time of labor-intensive resources.

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## Fatal Recurrent Subarachnoid Hemorrhage after Endovascular Aneurysm Occlusion from Overdistention of the Aneurysm Wall

We read with great interest the article by Bendszus et al<sup>1</sup> in which successful coil embolization was followed by fatal re-rupture 2 weeks later.

In reviewing the case presentation, we made a number of observations from which we would like to propose an alternative explanation of the eventual outcome. Although there are obviously institutional differences in how patients like these are managed, we noted a number of unique points that may have contributed to an increase in periprocedural risk.

The conventional and CT angiographic images submitted are of high quality and demonstrate an aneurysm of the basilar terminus measuring approximately two thirds of the diameter of the basilar artery. It is not clear how the aneurysm was determined to be 3 mm in diameter, but because the average basilar artery typically measures approximately 3 mm in diameter, one would suspect that the actual dimension of the aneurysm would more likely be in the range of 2–2.5 mm. The neck of the aneurysm is not well demonstrated by angiography but appears rather well defined by CT angiography and would not be considered wide-necked. On the basis of the images submitted, we would suggest that the coils selected may have been too large and that the aneurysm might well have been successfully treated with fewer 2- or 2.5-mm coils, without the need for balloon assistance. We do not routinely proceed directly to the balloon-assist technique until we have first attempted direct unassisted coil embolization. We would also suggest that although balloon assist is useful in the placement of the coils within wide-necked aneurysms, using a balloon might lead to overpacking in small aneurysms. This can result in a relatively greater degree of pressure against the wall of the aneurysm that could, in turn, lead to an increased risk of rupture. We have long since learned, from the experience of endoluminal balloon embolization of aneurysms, that increased and asymmetric stresses on the wall of an aneurysm predispose to rupture.

One principal advantage of the detachable coil technique over balloon embolization is a lower and more symmetric distribution of radial forces within a treated aneurysm and proved association of a lower incidence of aneurysm rupture. We would point out that the dimensions of the coil mass in Fig 2A are significantly larger than those of the untreated aneurysm in Fig 1A. It would, therefore, appear likely that the aneurysm was overdistended, resulting in a tear of the ventral wall, by use of 12-cm oversized coils and the balloon-assist technique. The patient was subsequently diagnosed with vasospasm. Assuming that the patient was being volume expanded and was hypertensive at the time of her re-rupture, it is quite possible that the increased volume and pressure in the face of an overpacked aneurysm