Automatic method to measure arterial branching angles from axial MR slices and invivo study on carotid bifurcation angle

N. Balu[1], W. S. Kerwin[2], C. Yuan[2]

[1]Bioengineering, University of Washington, Seattle, WA, United States, [2]Radiology, University of Washington, Seattle, WA, United States

Introduction

The angle between the internal carotid artery (ICA) and the external carotid artery (ECA) called the carotid bifurcation angle (BA), has been said to play an important biophysical role in determining susceptibility to atherosclerosis [1]. Recent studies [2,3] have shown that differences in bifurcation anatomy may explain individual and gender differences in atherosclerosis. A study of BA in patients with early atherosclerosis showed that ICA intima media thickness was positively correlated with BA [4]. While the measurement of carotid anatomy on radiographic images [2,3] depends on the projection angle, the measurements of BA in [4] are likely to be dependent on the angle of insonation and operator training. We have developed a method to measure orientation angles from axial MR images that are not dependent upon the angle of the artery to the MR slices as long as the slices pass through opposite walls of the artery. This method of plaque analysis from MR also allows simultaneous measurement of plaque burden from corresponding arterial segments. It was used to evaluate whether a positive correlation between BA and plaque burden persists in advanced atherosclerotic disease. Since the flow effects at the bifurcation depend upon the CCA and both branches, ICA and ECA, all three were taken into account in this invivo study.

Materials and Methods

T1 weighted 2D fast spin echo images (TR-800ms, TE-9.3ms, FOV-16cm, Slice thickness-2mm, matrix-512x512, NEX-2) were obtained on a 1.5T GE Signa scanner, from 10 patients scheduled for endarterectomy. These patients had >70% stenosis by carotid ultrasound. The inner and outer walls of each arterial segment (ICA, CCA and Common Carotid Artery (CCA)) were outlined on each slice by an observer. The plaque burden for each segment was calculated as the product of slice thickness and the difference in outer and inner wall contour areas. The average plaque burden for each segment per slice was then obtained. The orientation of each arterial segment was found as follows. The centroids of outer wall contours for each slice were fitted with a least squares line in three dimensions and the direction cosines of this regression line found for each segment. The difference in the direction cosines gives the difference in orientation between the segments and the projection of each pair gives the angle between the segments. The angle between the segments obtained from projection was corrected to the nearest acute angle to remove any influence of orientation. The plaque burden per slice for each segment was compared with the projection angles between segments. All steps are automatic after the outerwall contours are drawn. The angle measurement method works equally well with inner wall contours where multiple inner wall contours are dealt with by finding the convex hull of those contours and using the centroid of the convex hull. Since inner wall boundaries are more distinct in general compared to outer wall boundaries these may be used when image quality is not optimum or observer variability in drawing contours is a concern

Results

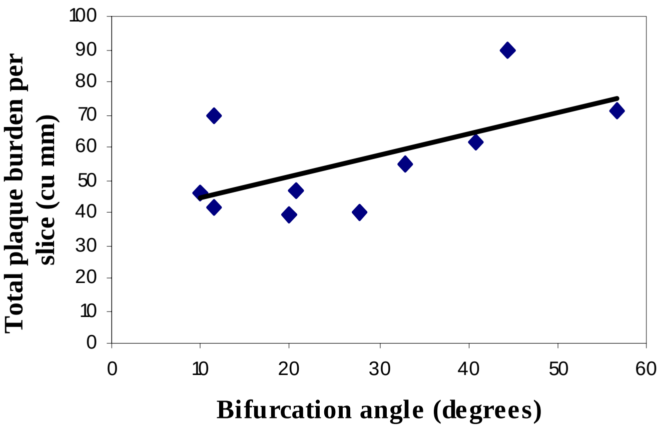
The plaque burden in ICA, ECA and CCA were positively and significantly correlated with total plaque burden (ICA R=0.84, p=0.002, ECA R=0.73, p=0.017, CCA R=0.93, p<0.0001). The total plaque burden was significantly and positively correlated with BA (R=0.62, p=0.028). The ICA and CCA plaque burdens were also significantly correlated to the BA (R=0.61, p=0.031 for the ICA and R=0.67, p=0.017 for the CCA) but the ECA plaque burden was not correlated to BA. The BA seems to be mostly due to the angle at which the ECA divides from the CCA. The correlation of the angle between ICA and CCA to BA was significant (R=0.91, p<0.001) while the angle between the ICA and CCA was not correlated with the BA.

Conclusions

A method to measure angles of inclination of arterial segments from axial MR images was developed. It allows automatic angle measurements during plaque burden studies. The results from the invivo study using this method indicate that the BA continues to play an important role with advanced atherosclerosis and increased BA tends to increase plaque burden. The ICA-CCA angle was found to be small compared to the ECA-CCA angle. Since flow conditions in the ECA would then be different from that of the CCA and ICA, this might explain why the plaque burden in the CCA and ICA are correlated with the BA but the plaque burden in the ECA is not. This study indicates that BA may be a possible risk factor for carotid atherosclerosis.

References

1. Hademenos GJ, Massoud TF, Biophysical Mechanisms of Stroke, Stroke, 28: 2067 – 2077, 1997
2. Schulz UGR, Rothwell PM, Sex Differences in Carotid Bifurcation Anatomy and the Distribution of Atherosclerotic Plaque, Stroke, 32:1525-1531, 2001
3. Schulz UGR, Rothwell PM, Major Variation in Carotid Bifurcation Anatomy- A Possible Risk Factor for Plaque Development?, Stroke, 32:2522-2529, 2001
4. Sitzer M, Puac D, Buehler A, Donata AS, Kegler S, Markus HS, Steinmetz H, Internal Carotid Artery Angle of Origin – A Novel Risk Factor for Early Carotid Atherosclerosis, Stroke, 34:950-955, 2003



Correlation between total plaque burden and bifurcation angle

Figure showing outerwall contours in 3D and fitted direction lines. (Red- CCA, Blue-ICA, Green-ECA)