GEOMETRIC CHARACTERIZATION OF THE NORMAL AND MILDLY DISEASED HUMAN CAROTID BIFURCATION

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INTRODUCTION

The geometry of the carotid bifurcation has been proposed as a possible risk factor for atherosclerosis, by virtue of the purported role of local hemodynamics in early stages of atherosclerotic plaque development [1]. In this context it is of interest to study asymptomatic subjects with mild carotid artery disease. Instead, investigations of carotid bifurcation geometry and hemodynamics have tended to focus on young, healthy vessels or, less frequently, incidental findings of mild disease from angiographic or post-mortem examinations.

As part of a larger effort to study the role of geometric and hemodynamic factors in early atherosclerosis using image-based CFD techniques, we recently characterized selected geometrical factors derived from magnetic resonance imaging (MRI) of patients with previously diagnosed mild carotid artery disease. A control group of young, healthy volunteers was also studied to identify possible differences between these two populations.

METHODS

We recruited 25 asymptomatic subjects (12M/13F; 63±10yr) with bilaterally mild atherosclerosis (defined as <30% stenosis based on duplex ultrasound criteria) from patients enrolled in independent studies of plaque progression at SPARC [2]. The control group of 25 ostensibly normal subjects (14M/11F; 24±4yr) was recruited from staff at our Imaging Research Labs. Our University Research Ethics Board approved all protocols, and informed consent was obtained.

As detailed in [3], both carotid bifurcations of each subject were imaged using serial black blood MRI, from which images the lumen boundaries were outlined semi-automatically and reconstructed to produce the 3-D lumen surface. Centerlines extracted from these surfaces were then used to compute the following geometrical factors: branch angles [4]; tortuosity [5]; curvature [6]; and (non-)planarity [7]. The significance of group and sex differences was tested using two-tailed t-tests. A paired t-test was used to test for left/right differences.

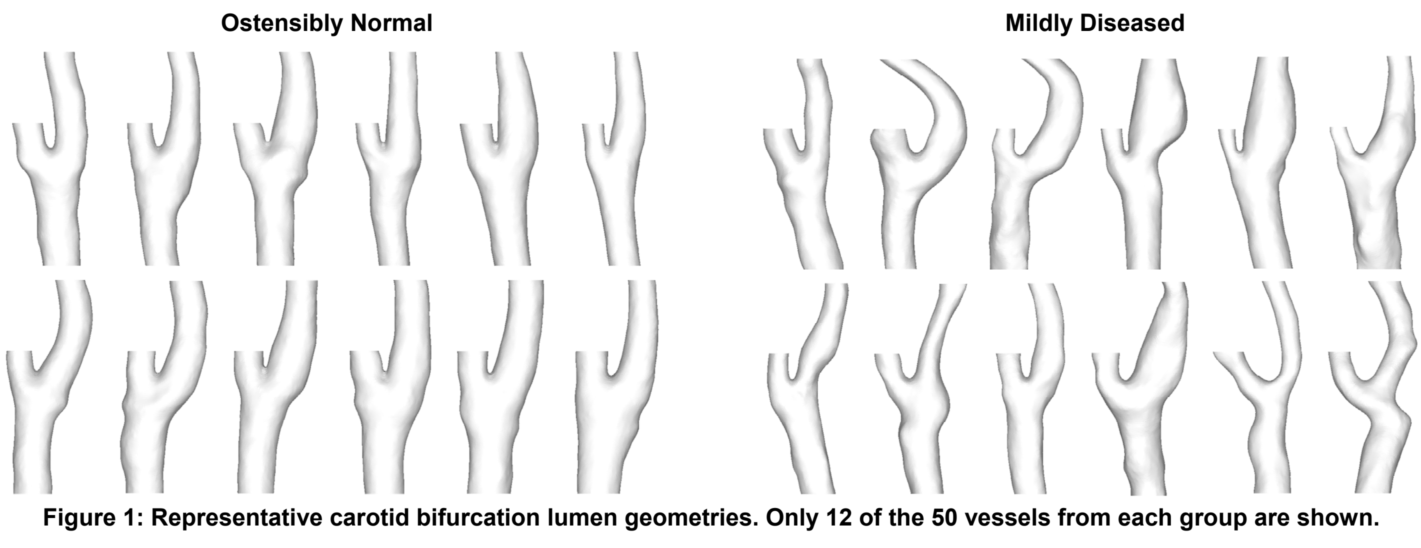

Figure 1: Representative carotid bifurcation lumen geometries. Only 12 of the 50 vessels from each group are shown.

RESULTS

As shown in Figure 1, the older, mildly diseased carotid bifurcation demonstrates a marked inter-subject variability in terms of both branch angle and curvature. Conversely, the geometry of the normal carotid bifurcation is remarkably consistent, characterized by an acute bifurcation angle and relatively straight branches. These qualitative impressions are confirmed by a quantitative analysis of the vessel centerlines summarized in Figure 2. In particular, all but one of the geometric parameters evaluated was highly significantly different between the two groups. However, no significant differences were seen between male/female and left/right vessels within either group.

DISCUSSION

Our study represents the first attempt to characterize the three-dimensional geometry of the carotid bifurcation for asymptomatic and normal populations. To place our findings in the context of previous studies, we note that bifurcation angle for the older, mildly diseased population (mean 34°; range 6°–80°) was consistent with values derived from angiographic [8,9] but not post-mortem [10] studies of similar populations. This may reflect differences between the relatively small samples or the definition of bifurcation angle; however, it may also result from the overestimation of bifurcation angle known to occur during exposure of the vessel prior to fixing [11].

It is interesting to note that the bifurcation angle for the young, healthy volunteers was markedly lower (mean 16°; range 3°–35°) than that generally considered in the context of model studies of the "normal" human carotid bifurcation [12,13]. Moreover, contrary to these popular Y-branch models of the carotid bifurcation, the normal carotid artery is decidedly more like the "tuning fork" models suggested by recent studies [14,15].

Finally, our study demonstrates the marked effect that aging and/or early disease have on the geometry of the carotid bifurcation. From this data alone it is of course not possible to separate these factors; however, recent work by Smedby et al. [16] suggests that geometry is the cause and disease is the effect. Either way, our findings further emphasize the importance of considering individual geometry in studies of hemodynamics and vascular disease.

CONCLUSIONS

The geometry of the young, healthy human carotid bifurcation is remarkably consistent compared to the variable geometry of the older, mildly diseased carotid artery. Whether this is a cause or effect of disease remains to be determined, but it does suggest that the normal carotid bifurcation geometry and hemodynamics, while convenient for image-based modeling studies, may not be representative of an older or mildly diseased population or vice-versa.

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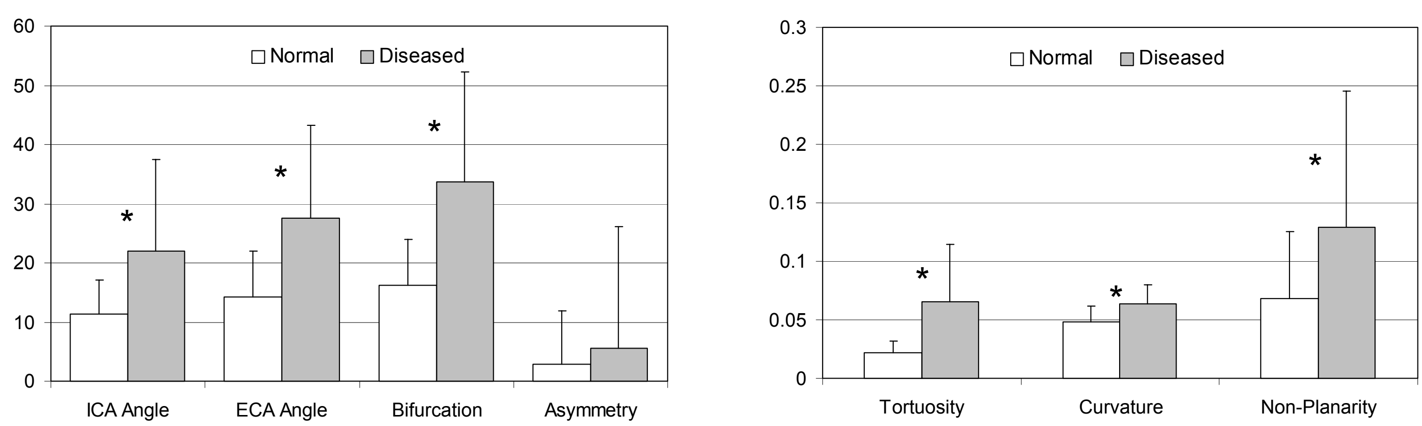

Figure 2: Significant differences (* denotes p<0.001) between parameters derived from the geometries of ostensibly normal (N=50) and mildly diseased (N=50) groups. Note also the uniformly larger standard deviations (ie, error bars) in the mildly diseased group, reflecting the wider geometrical variation in this population. On the left panel, ICA and ECA angles refer to, respectively, the acute angles (in degrees) between the common and internal and external carotid arteries. Bifurcation refers to the angle between the ICA and ECA. Asymmetry refers to the difference between the ICA and ECA angles. Note that the ICA and ECA angles do not necessary add up to the bifurcation angle owing to the non-planarity of the vessels.