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EFFECT OF HEAD ROTATION AT THE PRONE POSITION ON THE GEOMETRIC FEATURES OF THE HEALTHY CAROTID BIFURCATION

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INTRODUCTION

The influence of posture change on the geometry and hemodynamics of the carotid bifurcation has not been thoroughly studied [1,2,3]. Such changes may alter the hemodynamic variables that are generally associated with the development of atherosclerosis, such as low oscillating wall shear stress (WSS) and particle residence times. Glor et al. (2004) had reported changes in the right carotid bifurcation geometry with leftward rotation of the head. We have previously reported that geometric differences in the right and left carotid bifurcation occur with a rightward rotation of the head [3].

To investigate the geometric changes in the carotid geometry that occur in the prone sleeping position with rightward head rotation, we have performed studies in 10 healthy young volunteers. We defined specific geometric parameters of the carotid bifurcation, such as bifurcation angle, asymmetry angle, planarity angle, tortuosity and mean curvature, and compared their corresponding values in two head postures: 1) the supine neutral position, and 2) the prone sleeping position with head rotation to the right (~80 degrees).

MATERIALS AND METHODS

The group of volunteers consisted of ten healthy men of mean age of 35 years (range 25 to 50 years). The study was approved by the Cyprus Bioethics committee (2006).

Magnetic resonance (MR) images were acquired using a 3T MRI instrument (Philips Medical Systems, the Netherlands). The built-in quadrature body coil and a commercially available phased array coil were used for excitation and signal detection respectively. The details and settings in the MRI acquisition were described previously [3,5]. Each subject was imaged in two different scanning sessions on the same day corresponding to the two head postures examined. Two of the subjects were scanned again on a different day to allow a limited reproducibility study.

Virtual Model Development

The solid surface models were constructed by slice-by-slice manual segmentation (ITK-Snap, Paul Yushkevich, Penn Image Computing and Science Laboratory (PICSL), USA) and saved in .stl format. The 3D geometry of the carotid bifurcation was processed using the vascular modeling toolkit (VMTK) [4]. For the 3D lumen reconstruction surface, a smoothing technique from VMTK utilizing the Taubin algorithm which preserves the volume enclosed by the arterial surface was used. Using various features of the VMTK package, specific important geometric parameters, such as bifurcation angle, internal carotid artery (ICA) angle, ICA planarity angle, in-plane asymmetry angle, curvature and tortuosity, were identified and determined according to relevant published definitions [4,5].

RESULTS

Figure 1 shows the virtual reconstructed models of the 9th volunteer for the neutral and prone head postures indicating the qualitative changes in geometry due to head rotation. Figure 2 shows the median value and the range of each geometric parameter for the ten volunteers studied Data are presented for both carotids and both postures examined. Figure 3 shows the change in ICA angle for all volunteers studied.

Reproducibility studies:

To assess the precision of the reconstruction and the geometric parameter estimation we repeated the scanning, segmentation and reconstruction procedures for two volunteers. The results demonstrated that, for both volunteers, the calculated values of bifurcation and ICA angles, tortuosity and curvature showed

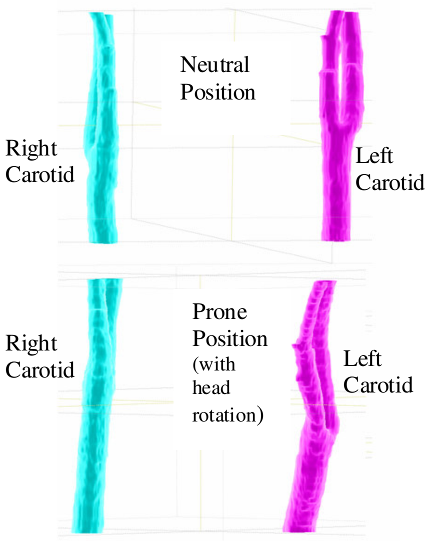

Figure 1. Reconstructed solid models (9th volunteer) of both carotid bifurcations for the two head postures, neutral (above) and prone with rightward head rotation (below).

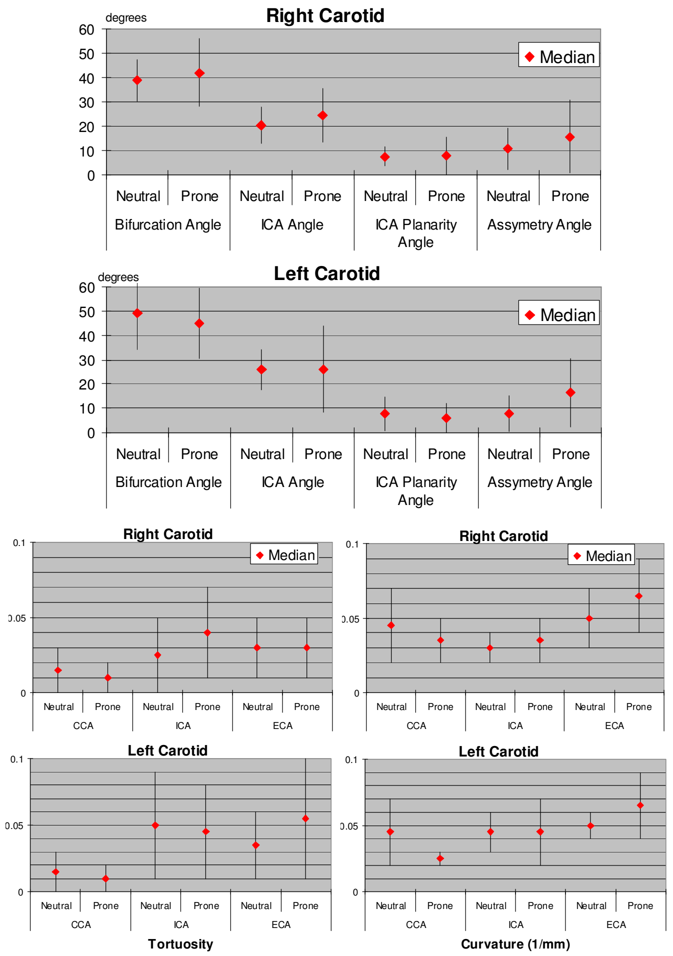

Figure 2. Median values and range limits of the geometric parameters estimated from all 10 volunteers. Data are shown for both carotids and head postures.

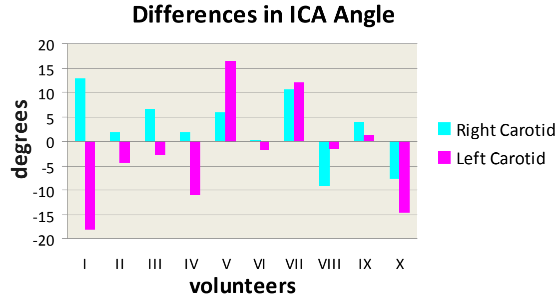

Figure 3. Differences between neutral and prone position for the ICA angle for both carotids and all volunteers.

deviations less than 15% in both postures. The ICA Planarity and asymmetry angle estimations showed significant variations indicating a high degree of uncertainty in the reconstruction process.

Discussion

There are significant changes in geometric parameters with posture change in individual volunteers, however, these changes appear random, with no strong correlation between head posture and any specific geometric parameter studied.

Zhang et al. (2009) and others, have reported that ICA and CCA tortuosity, curvature and area ratio of ICA to ECA are important parameters in the disturbance level and formation of low/oscillating WSS regions at the carotid bulb.

Our earlier studies [3], also indicate that small changes in geometric parameters with head rotation can cause significant changes in the hemodynamic parameters important in the development of arterial disease.

Therefore our present results on a greater number of volunteers, indicated that there are random and frequently significant changes in geometric parameters at the prone position which is a frequent sleeping posture for many subjects and patients. The effects of such changes to the flow field in the carotid bulb and the development of carotid disease are unknown. The effects of such geometric changes on the structural integrity of carotid stents and the stress distribution on unstable plaque are also unknown and need to further be investigated. Hemodynamic studies and comparisons between geometries are currently in progress.

ACKNOWLEDGMENTS

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