ANALYSING WALL SHEAR STRESS PROFILES AND STRUCTURAL BEHAVIOR IN CAROTID BIFURCATIONS

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Introduction

Near-wall hemodynamics and structural stress of the vasculature might be involved in the initiation of atherosclerosis at the carotid bifurcation [1,2]. Most of the literature has generally focused on either structural or hemodynamic quantities, although their coupling can be implemented in fluid-structure interaction (FSI) approaches. In this regard, rigid-wall simulations have recently shown that the intra-cycle variability of wall shear stress (WSS) topological skeleton is associated with intima-media thickening after carotid endarterectomy [1]. Here, fully coupled two-way FSI simulations accounting for arterial wall prestress, vessel anisotropic material properties, and external tissue support are performed to explore the nature of the relationship between hemodynamic and wall structural quantities.

Methods

Seven healthy carotid bifurcations models were reconstructed from magnetic resonance (MR) angiography [1] including 15 radii of the common carotid artery (CCA). Arbitrary Lagrangian-Eulerian formulation-based FSI simulations were carried out, modelling the vessel wall as a fiber-reinforced anisotropic nonlinear material (Holzapfel-Gasser-Ogden model). The initial loading state and the fibers orientations were obtained through wall vessel prestress [4]. Subject-specific flow rates from MR measurements [1] were used for the CCA inflow boundary condition (BC) and for tuning three-element Windkessel models at the external and internal carotid artery (ECA and ICA) outflow sections. Viscoelastic support from external tissues was accounted imposing a Robin-type BC [3]. All simulations were carried out in SimVascular [3]. The near-wall hemodynamics was characterized in terms of the canonical WSS-based quantities time-average WSS (TAWSS) and oscillatory shear index (OSI). In addition, the WSS topological skeleton was characterized in terms of variability of the WSS contraction/expansion action on the endothelium, by the topological shear variation index (TSVI) [1]. Wall mechanics was characterized in terms of cycle-averaged maximum principal stress (σ_1) and strain (ε_1). Model-specific 20th percentile (TAWSS) and 80th percentile (σ_1, ε_1, OSI, and TSVI) values were used to quantify the relative surface area (SA) below (TAWSS) or above (σ_1, ε_1, OSI, TSVI) threshold values. The relationship of WSS-based and structural quantities was evaluated in terms of (i) co-localization of SAs, and (ii) a sector-based statistical analysis, where hemodynamic descriptors were averaged over 1.5mm/30° luminal sectors and divided into model-specific low, mid, and high tertiles to perform a statistical analysis (Student's t test) on the associated structural quantities.

Results

SI values for the couplets of hemodynamic and structural quantities are reported in Table 1, highlighting a moderate co-localization: SAs of hemodynamic descriptors were mainly located at the carotid bulb, while the highest σ_1 and ε_1 were located around the bifurcation apex. Sectors exposed to low TAWSS values exhibited the highest σ_1 (Figure 1). Sectors exposed to high OSI exhibited higher σ_1, but not ε_1, than sectors exposed to low OSI. Conversely, sectors exposed to high TSVI exhibited higher σ_1 and ε_1 values than low TSVI sectors.

SI	TAWSS	OSI	TSVI
$\boldsymbol{\sigma_1}$	0.33±0.07	0.31±0.07	0.29±0.08
$\boldsymbol{\varepsilon_1}$	0.24±0.05	0.25±0.06	0.29±0.07

Table 1: SIs (mean±SD) between hemodynamic and structural quantities

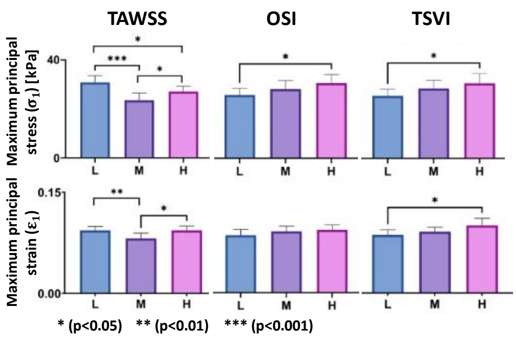

Figure 1: Model-specific hemodynamic vs. structural quantities. Histograms represent model-specific tertiles (L: low tertile; M: mid tertile; H: high tertile).

Discussion

The present findings suggest a complex relationship between hemodynamic and structural quantities, with model-specific differences deserving further investigations.

References

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