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Research paper

Mechanical events within the arterial wall under the forces of pulsatile flow: A review

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ABSTRACT

Under the dynamic conditions of pulsatile flow, the forces exerted by the fluid on the vessel wall create considerable displacements and stresses within the thickness of the vessel wall. We review a series of analytical options for exploring the dynamics of the vessel wall, specifically displacements and stresses within the depth of the vessel wall, under a range of conditions including the degree of external tethering and the mechanical consistency of the wall material. It is shown that one of the most important effects of tethering is that of drastically restricting radial displacements of and within the vessel wall. This restriction in turn places limits on the length and speed of the propagating wave. Specifically, the wave speed is significantly reduced as a result of tethering. This has important consequences because the wave speed, or pulse wave velocity as it is referred to in the clinical setting, is used as an index of vascular stiffening in relation to aging or age related hypertension. It is found further that the extent of displacements and shear stresses within the vessel wall depend critically on the relative proportions of viscous and elastic content within the wall. In particular, loss of viscous consistency leads to higher shear stresses within the wall, thus putting higher loading on elastin and may ultimately lead to elastin fatigue. As elastin gradually fails, its load bearing function is presumably taken over by collagen which renders the vessel wall less elastic and more rigid as is observed in the aging process.

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1. Introduction

Under the oscillatory forces of pulsatile flow, the arterial wall suffers considerable stresses and strains in the radial as well as in the longitudinal direction. Much of the focus in the past has been on forces acting directly on the endothelial layer of the wall, namely the pressure and shear forces exerted by the fluid (Atabek, 1968; Mirsky, 1967; Morgan and Kiely, 1954; Womersley, 1957) or on only the radial motion of the

arterial wall (Holzapfel et al., 2002; Masson et al., 2008), with the longitudinal motion being neglected by a fairly general consensus that it is negligibly small compared with the radial motion. The consequences of these forces on displacements and stresses within the wall thickness have been largely ignored on the assumption of a negligibly thin wall.

More recently it has become apparent that displacements and stresses within the wall thickness are highly significant and that the forces exerted by the fluid on the endothelial

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