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Pulse wave velocity as a diagnostic Index: The pitfalls of tethering versus stiffening of the arterial wall

S. Hodis [a], M. Zamir [a,b]*

[a] Department of Applied Mathematics, University of Western Ontario, London, Canada N6A 5B7
[b] Department of Medical Biophysics, University of Western Ontario, London, Canada N6A 5B7

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ABSTRACT

Pulse wave velocity (PWV) is often used as a clinical index of aging, vascular disease, or age related hypertension. This practice is based on the assumption that a higher wave speed indicates vascular stiffening. This assumption is well grounded in the physics of pulsatile flow of an incompressible fluid where it is fully established that a pulse wave travels faster in a tube of stiffer wall, the wave speed becoming infinite in the mathematical limit of a rigid wall. However, in this paper we point out that the physical principal of higher pulse wave velocity in a stiffer tube is strictly valid only when the wall is free from outside constraints, which in the physiological setting is present in the form of tethering of the vessel wall. The use of PWV as an index of arterial stiffening may thus lose its validity if tethering is involved. A solution of the problem of vessel wall mechanics as they arise from the physiological pulsatile flow problem is presented for the purpose of resolving this issue. The vessel wall is considered to have finite thickness with or without tethering and with a range of mechanical properties ranging from viscoelastic to stiff. The results show that, indeed, while the wave speed becomes infinite in the mathematical limit of a rigid free wall, the opposite actually happens if the vessel wall is tethered. Here the wave speed actually diminishes as the degree of tethering increases. This dichotomy in the effects of tethering versus stiffening of the arterial wall may clearly lead to error in the interpretation of PWV as an index of vessel wall stiffness. In particular, a normal value of PWV may lead to the conclusion that vessel wall stiffening is absent while this value may in fact have been lowered by tethering. In other words, the diagnostic test may lead to a false negative diagnosis. Our results indicate that the reason for which PWV is lower in a tethered wall compared with that in a free wall of the same stiffness is that the radial movements of the wall are greatly reduced by tethering. More precisely, the results show that PWV depends strongly on the ratio of radial to axial displacements and that this ratio is much lower in a tethered wall than it is in a free wall of the same stiffness.

1. Introduction

Mechanics of the arterial wall have often been pursued separately from the fluid flow problem within the arterial lumen. The fluid flow problem has generally been considered in full but, because of the inherent difficulties, it has so far been combined with only a thin wall as a boundary condition (Atabek, 1968; Womersley, 1957). More recently, the mechanics of a thick wall have been considered but, again because of the analytical difficulties involved, this was only possible with partial coupling at the fluid–wall interface in the sense of simply imposing the boundary conditions at the interface rather than allowing these conditions to emerge naturally from the dynamics of the two media (Humphrey and Na, 2002; Hodis and Zamir, 2008, 2009a, 2009b).

Solution of the pulsatile fluid flow problem fully coupled to a thick arterial wall is important because it represents the physiological situation more realistically and, in particular, because including the wall thickness makes it possible to deal with the issues of tethering and of mechanical stiffness of the wall more fully. One of the most important issues which has yet to be resolved is that of the wave speed in a stiff/rigid free wall versus that in a viscoelastic but fully tethered wall. While in a rigid free wall the wave speed is infinite, the corresponding wave speed in a non-rigid but fully tethered wall has yet to be determined. It has been suggested that it is in fact finite and small rather than infinite (Atabek, 1968; Cox, 1968; Misra and Choudhury, 1984; Taylor, 1959), thus leading to a wide dichotomy between the two situations.

Determination of the wave speed in these two situations is important because the wave speed is often used as a clinical index of aging or disease. The assumption on which this practice is based is that a higher wave speed indicates vascular stiffening. This assumption may lead to false negative results if tethering is involved because, as stated above, it is suspected that tethering may actually lower the wave speed. The purpose of the present paper is to

* Corresponding author at: Departments of Applied Mathematics and of Medical Biophysics, The University of Western Ontario, London, Canada N6A 5B7.
E-mail address: zamir@uwo.ca (M. Zamir).

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