INTERACTING BOUNDARY LAYER FLOW IN A STENOSIS.

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INTRODUCTION

In spite of an abundant literature about magnitude and effects of wall shear stresses (WSS) at the early stage of development of atherosclerosis and mural thrombosis, there are no reports about the evaluation of high shear stresses in advanced occlusive lesions. However, they are likely to play a role in the mechanism of thrombo-embolism and artherosclerotic plaques rupture. Navier Stokes solvers are now very accurate to compute WSS. Nevertheless, we pretend that the asymptotic method provides a better understanding of the structure of the flow and of the relevant scalings as well. Computational time is very short, so the parameters may be changed easily and their influence can be analysed. For example, the use of an interactive boundary layer direct method allowed us to propose a simple scaling law between maximal WSS, flow Reynolds number and geometrical parameters of the stenosis [1], which can be used in clinical practice. But this method did not allow to compute the separation downstream the stenosis. Our aim is therefore to complete the analysis of the flow, including separation, by use of the IBL semi inverse coupling method [2].

METHOD

The geometry is a circular pipe of initial radius R_0 with a stenosis (of small curvature) of length $2\theta R_0$ (chosen as longitudinal scale) and of radius reduction α. Reynolds number $Re=\bar{U}_0 R_0/\nu$ is large enough so that Boundary Layer theory holds. To evaluate the flow in this geometry we use the Interacting Boundary Layer (IBL) method which comes from aerodynamics. The pure relevant asymptotic method (at infinite Re) for those flows is the triple deck theory [3]; but the IBL, although not strictly a pure asymptotic method, is nevertheless very accurate even at moderate Reynolds number. The fluid is supposed to be incompressible, Newtonian and the flow to be laminar, stationary and axisymetrical. The two last hypotheses are in fact very restrictive in biomechanical flows, but they are widely used in complete Navier Stokes computations [4]. The key of the IBL method is to suppose that the flow is structured in two layers, the perfect fluid core and the boundary layer whose displacement thickness δ_1 increases under the action of the perfect fluid velocity; then the growth of δ_1 interacts with the perfect fluid velocity by flux conservation (in fact the perfect fluid "sees" the boundary layer as an increment of the effective artery shape). The inverse iterative method is the following: δ_1 is updated at every iteration until the velocity at the edge of the boundary layer matches the perfect fluid velocity.

RESULTS

Results are given for the case θ=1. In fact, changing this length parameter is equivalent to divide the Reynolds number by the same factor (this similarity result is simply obtained using θR_0 as the reference length for the adimensionalisation). Moreover, results are insensitive to the entry profile (i.e. the upstream boundary layer thickness) after a short entry region, whose length increases with Re and decreases with α. As expected from experimental results and Navier Stokes simulations, at fixed radius reduction increasing the Reynolds leads to separation of the flow after the throat (see figure 1); the same result occurs at constant Reynolds increasing α. As far we know, the IBL inverse method was never employed to study such internal flows. Its short CPU time (<5 min) is promising.

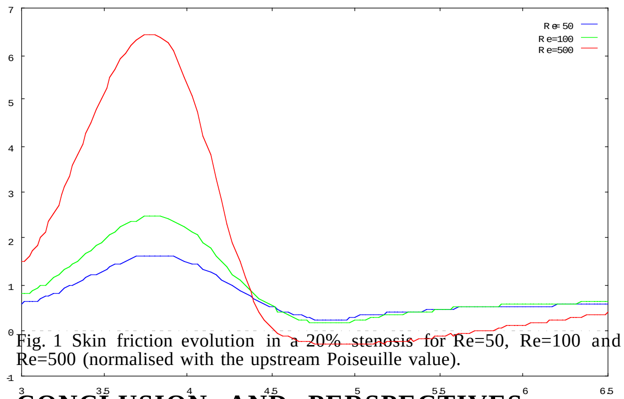

Fig. 1 Skin friction evolution in a 20% stenosis for Re=50, Re=100 and Re=500 (normalised with the upstream Poiseuille value).

CONCLUSION AND PERSPECTIVES

An alternative method to a complete Navier Stokes resolution has been presented, the results are comparable and involve a much smaller computational time and a better physical understanding. Note that this method may be applied in any internal flow even in turbulent régime, in this case an *ad hoc* closure relation has to be used. This method will allow the study of the numerous geometrical configurations (i.e. α value) and Reynolds number influence upon separation length and maximal reverse WSS in the recirculating zone.

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