Introduction
Blood coagulation is the complex process by which blood forms clots. It involves the interplay between biochemical and physical processes that occur at different scales (Fig. 1). All these factors can be summarized with the Virchow’s triad: deviation from normal physiological hemodynamics, injuries to the vascular endothelium layer and changes of the constituents of blood.

Fig. 1 Blood clot with multiple length scales; http://emedicinehealth.com (left) and http://jsgreen.tamu.edu (right).

Objective
Understand how macroscopic changes in blood flow result in the initiation of the coagulation cascade. In order to resolve this question it is necessary to analyze hemodynamics at the macroscopic level (i.e. continuum scale) coupled with the mesoscopic one (i.e. red blood cells scale).

Methods
The heterogeneous multiscale method (HMM)\(^1\) is taken into account: it is a general framework that permits to implement a concurrent coupling between two different scales (Fig. 2).

A mesoscopic subproblem is associated to each macroscopic integration point; on each subproblem boundary conditions based on the macroscopic velocity gradient tensor (\(L\)) are imposed. By means of each mesoscopic solution, the macroscopic stress tensor (\(\tau\)) is obtained by averaging the mesoscopic stresses over the mesoscopic domain\(^2\).

In this project, continuum dynamics are applied to model the blood flow at the macroscopic scale, while particle dynamics to model red blood cells at the mesoscopic scale will be applied.

Results
In order to test the numerical coupling, the momentum equation coupled with the incompressibility constraint is solved on the macroscopic scale (where a quadratic velocity profile is imposed at the inlet) and the Stokes problem is solved on the mesoscopic scale. The macroscopic velocity field and pressure distribution are in good agreement with the standard Poiseuille flow (Fig. 3).

Fig. 3 Poiseuille flow on the macroscopic domain (pressure distribution and velocity field) and velocity field on different mesoscopic domains.

Discussion
The next step to validate the numerical coupling is to introduce time on both levels. In this case, the mesoscopic domain moves in time according to the macroscopic shear profile and to the mesoscopic time step. In order to move the mesoscopic mesh in a consistent way, an arbitrary Lagrangian-Eulerian method (ALE)\(^3\) on the mesoscopic level will be implemented.

References