EFFECT OF CONTRAST MATERIAL PROPERTIES DURING INJECTION INTO CORONARY BLOOD FLOW

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1. Introduction

Coronary arteries are the supplying blood vessels for the heart itself. Ischemic heart disease or coronary artery disease is when a plaque builds up inside the coronary artery and blocks the blood flow. This narrowing can decrease the flow rate of oxygen-rich blood entering the heart muscles that can lead to heart attacks and cardiac arrests. It is the main cause of death according to WHO for at least the last 16 years [1].

In order to enhance the visibility of the vessel during medical imaging an iodinated contrast material (ICM) is injected into the artery. However, another diagnostic purpose exists for ICM injection as well.

The TIMI (Thrombolysis in Myocardial Infarction) [2,3,4] frame-count analysis is a blood velocity measurement method, using the movement of the ICM interface in blood. First, the physician captures the time instant at which the ICM is visible in the images and follows the propagation of the front up to a certain distal marker in the artery. From the recorded time interval between the two instants and the measured length between the two captured points an estimate for the average blood velocity can be made. The goal of this project is to analyze two types of ICMs (Visipaque (iodixanol), Omnipaque (iohexol)) (GE Healthcare AS, Oslo, Norway) with numerical simulations. In this numerical study we investigated the two clinically relevant flow conditions namely the hyperemic state that corresponds to a hyperemic flow condition and the normal state. In both cases the point of interest was to examine the effects of ICM viscosity and density.

2. Numerical methods

We performed numerical simulations on an artificial two-dimensional geometry in order to exclude any non-material property related effect in this part of the investigation. A straight tube (vessel section) with physiologically correct dimensions was taken similarly to [5], so that bends and curves will not affect the simulations (see Fig. 1).

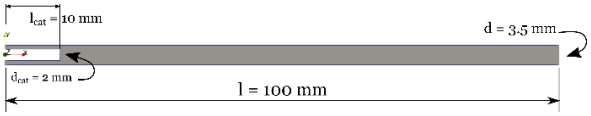

Fig. 1. Model for the two-dimensional simulations.

It consists around 400K cells to ensure proper identification of the contrast-blood front. To address the objectives, the unsteady Navier-Stokes equations were solved numerically in the conserved form with a commercial software suite using the finite volume method. The two-phase flow problem was solved by utilizing the mixture model implemented in ANSYS CFX. The boundary conditions were set to ensure physiological blood flow [6] and clinically applied ICM injection conditions that can be observed in Fig. 2.

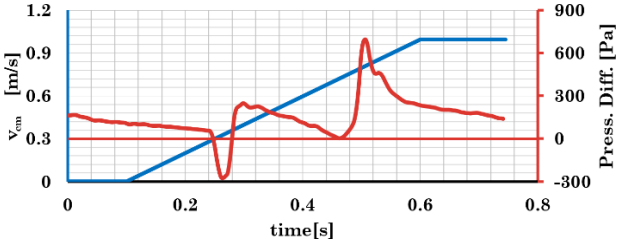

Fig. 2. Boundary conditions: Blood flow inlet condition with red and CM with blue.

The material properties used in the study for the ICMs can be found in Table 1. for the two different temperatures.

Table 1. Material properties.

	Omnipaque (iohexol)	Visipaque (iodixanol)
Density [kg/m^3]@20°C	1406	1356
Viscosity [Pa s]]@20°C	0.0204	0.0254
Density [kg/m^3]@37°C	1406	1303
Viscosity [Pa s]]@37°C	0.0104	0.0114

A total of eight 2D simulations were performed when the injection time instant was kept constant and only the material properties were changed for the normal and hyperemic flow condition.

3. Results

First to inspect the results qualitatively, contour plots of volume fraction distributions were analyzed. Interestingly, the two types of ICMs was observed to behave similarly, both under hyperemic and normal conditions. Comparing the two flow conditions it was observed that under the hyperemic conditions the influence of material properties is negligible (not shown in the abstract). On the other hand, under normal flow conditions perceivable differences were identified, as shown in Fig. 3. but since the effect is not large a more detailed quantitative analysis was performed.

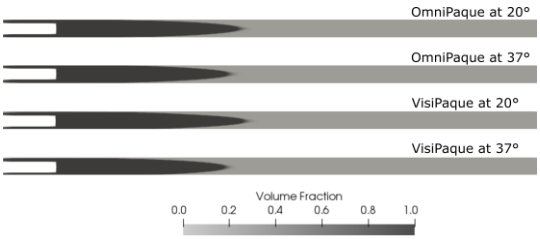

Fig. 3. Volume fraction distributions at a certain time instant under hyperemic condition.

In order to explain the mechanism through which the viscosity affects the front propagation, we plotted the two quantities (flow rate and volume fraction) as the function of time at the inlet boundary depicted in Fig. 4.

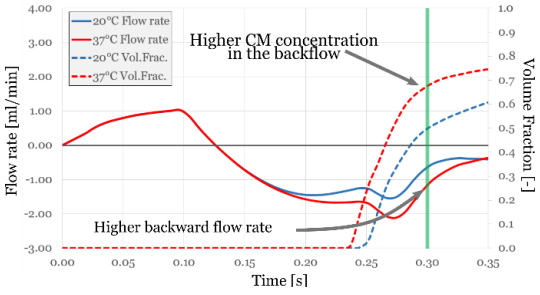

Fig. 4. Volume fraction and flow rate as the function of time on the inlet boundary. The green vertical line shows the above captured time instant.

When the CM was at body temperature (when the viscosity is lower) the ICM concentration was 20% higher in the observed time instant (t =0.3s). Additionally, Figure 4. tells us that more fluid leaves the domain at the inlet than with higher ICM viscosity (when the ICM enters at 20°C). To provide an explanation for this phenomenon one should have a look at Figure 2. Notice that for a short time negative pressures appear from 0.24 s to 0.28 s. During this interval the CM is much slower than the blood, thus the blood still dominates the flow field, thus more CM - with lower viscosity - will "follow" the blood with the back flow. Because of this the higher viscosity ICM phase front is ahead, since the blood can carry the ICM along less.

4. Conclusions

In this study the numerical investigation on the interplay between the contrast materials and blood flow was presented. Based on our results the ICMs of the two examined types (Visipaque, Omnipaque) behave similarly under both hyperemic and normal conditions. Under the hyperemic condition the effect of viscosity is less dominant as inertial forces govern the two-component fluid flow. The effect of not heating up the ICM to body temperature is noticeable, since the viscosity of the ICM at 20°C is two times as much as at 37°C. As a result of this difference, the less viscous the ICM - the ICM viscosity is closer to that of blood viscosity - the more it will adapt to the blood flow velocity.

Acknowledgements

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