IMPACT OF SICKLE CELL DISEASE FOR OXYGEN TRANSPORT IN INTRACRANIAL ANEURYSMS

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Introduction

Neurological complications are more common in patients with sickle cell disease (SCD), with subarachnoid hemorrhage (SAH) of an intracranial aneurysm (ICA) among the most common[1]. Due to the polymerization of sickle hemoglobin at low oxygen tension, the apparent viscosity of the blood increases[2] in SCD. Increased viscosity affects blood flow resistance which could affect oxygen advection, further reducing oxygen levels and driving a cascade contributing to ICA formation and weakening.

Our aim in this study was to investigate how the geometry and blood rheology affect oxygen transport and consequently oxygen availability in an idealized ICA, testing the hypothesis that feedback between oxygen level, blood viscosity, and oxygen transport can aggravate the reduction in available oxygen in SCD.

Methods

Primitive geometries were used, in which an arched 4-mm diameter cylindrical tube represented the vessel, and an attached 9-mm diameter spherical bulge represented the aneurysm. Two parameters were studied: (1) the ratio between the aneurysm throat length and the aneurysm diameter (Lt/Da), and (2) the vessel curvature (κ).

The Carreau-Yasuda model with parameters dependent on the level of sickle hemoglobin (HbS)[4] was used for the blood rheology. Oxygen transport in the blood and in the vessel wall was modeled using Fickian diffusion. A pulsatile velocity waveform and constant oxygen concentration were imposed at inlet. Outlet boundary conditions were fixed pressure and no axial oxygen gradient. A full factorial study was done on three factors: (1) HbS level, (2) aneurysm throat / aneurysm diameter ratio), and (3) vessel curvature, resulting in a total of 36 geometries and over 140 cases. Simulations were performed at the Minnesota Supercomputing Institute

Results

The average Peclet number in the aneurysm ranged from 30-4000, meaning that even for more the extreme cases, oxygen transport was dominated by advection. Figure 1A and 1B compare the normalized oxygen distribution for the non-sickle and sickle cases, respectively for one geometric case. For smaller throat sizes, there is reduced oxygen transport, as quantified by Sherwood number through the aneurysm wall was lower in the sickle case as shown on Fig. 1C vs. Fig. 1D, even for large throat sizes.

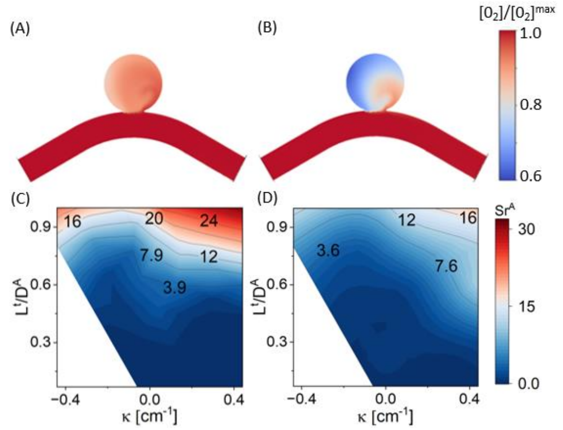

Figure 1: Normalized oxygen distribution for (A) non-sickle and (B) sickle in a plane cut for k=0.14 cm^{-1} and Lt/Da=0.3 calculated at peak of the cardiac cycle. Color maps show time average values of Sheerwood number.

Figure 2 shows the normalized oxygen level in the aneurysm as a function of vessel curvature and HbS level. Increased HbS (more severe disease) decreased the oxygen level, especially for smaller throat sizes.

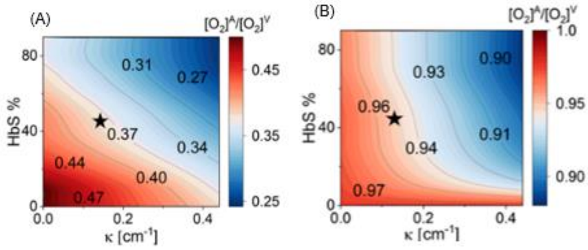

Figure 2: Normalized oxygen distribution maps for (A) Lt/Da=0.1, (B) Lt/Da=0.6. Values are time averaged.

Discussion

Oxygen availability is a potential issue in intracranial aneurysms. Aneurysm oxygen level was lower than the arterial level in all simulations, even those using healthy blood parameters, and the problem as more pronounced for SCD blood parameters. The higher viscosity of the sickle blood increases the effect of the narrow throat, and the poor oxygen transport can lead to even greater increase in blood viscosity. While this study can say nothing about the potential biological consequences of reduced oxygen availability in an aneurysm, it identifies oxygen availability as an important factor to consider.

References

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