Patient-specific modeling and predicting blood viscosity in sickle cell anemia

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Motivation

Sickle cell anemia (SCA): a highly complex, inherited blood disorder exhibiting hetero-genous cell morphology and abnormal rheology.

Sequence of events in sickle patients proceeds from sickle hemoglobin polymerization, to cell deformation, to vaso-occlusion and then to sickle cell disease.

SCA is often characterized as a rheological disease.

Individual patients with SCA have highly variable clinical phenotypes, and the clinical severity of symptoms can range from mild to very severe.

By using a multiscale red blood cell (MS-RBC) model based on parameters derived from patient-specific data, we present a mesoscopic simulation study to explore the rheological and hemodynamic characteristics of blood SCA.

Multiscale RBC Model

The MS-RBC model is constructed by a network of viscoelastic springs combined with bending energy and constraints for surface-area and volume conservation.

Triangular mesh:
- each vertex – a coarse-grained particle
- each edge – a viscoelastic bond
- bending resistance of lipid bilayer
- shear resistance of cytoskeleton
- constant surface area
- constant volume

Clinical / Experimental Data

Selected hematologic parameters obtained from clinical / experimental data of sickle patients are summarized here:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Normal blood</th>
<th>Mild SCA</th>
<th>Severe SCA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hb (g/L)</td>
<td>140–150</td>
<td>100–120</td>
<td>80–90</td>
</tr>
<tr>
<td>Hct (%)</td>
<td>35–45</td>
<td>30–32</td>
<td>20–30</td>
</tr>
<tr>
<td>MCHC (g/dL)</td>
<td>32–36</td>
<td>30–35</td>
<td>30–34</td>
</tr>
<tr>
<td>MCV (fl)</td>
<td>70–100</td>
<td>50–70</td>
<td>40–60</td>
</tr>
</tbody>
</table>

General characteristics and morphological analysis of sickle RBCs in sickle patients:

Summary

We first examine the shear viscosity of sickle blood flow at Hct = 40% with three distinct types (granular, elongated and classic sickle types) of sickle RBCs:

Sickle RBC suspensions exhibit different viscosity values for different cell morphologies.

Blood Viscosity in SCA

We then carry out numerical simulations to probe the shear viscosity of patients in SCA based on the clinical/experimental data with four different cases at three different conditions (oxygenation state, short-term hypoxia and long-term hypoxia).

Simulation setup:
- Cell mixtures:
  - Normal RBCs
  - Sickle RBCs
  - Sickle RBCs with HU treatment
- Different cell shape:
  - Biconcave (red)
  - Granular (cyan)
  - Elongated (purple)
  - Typical sickle (blue)

Calculated shear viscosity values of patients with SCA:

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