Modelling Deposition of Nano-particles in Blood Vessels.

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Background and Motivation
Intravascular delivery of nano-particles has shown potential in cancer therapy due to the particles' tendency to be collected in tumour tissue via dilated capillary fenestrations (pores). Thermal ablation (heating) or drug loading of the particles allows targeted treatment of the tumour. Currently the delivery mechanism is not fully understood, and so numerical simulations can provide a vital resource in quantifying this poorly understood process at the physical level.

Aims and Objectives
To assess the impact of blood viscosity models, vessel size and shape and also nano-particle size on particle-wall interactions using Computational Fluid Dynamics.

Methods
- Six vessel models were created with a length to diameter ratio of 23. (See Table 1 below.)
- Vessel geometries were discretised using hexahedral structured meshes with 300 to 340 thousand elements. Blood flow solutions were obtained using ANSYS-FLUENT.
- Inert gold particles of 4 sizes were released into the vessels with uniform distribution at 1% concentration and particle-wall collisions were calculated.
- All models incorporated drag force, Brownian motion and Saffman lift forces as important influences on particle behaviour.
- A non-Newtonian Herschel-Bulkley (H-B) model incorporating the viscoplastic and shear thinning properties of whole blood was compared to Newtonian blood in the artery cases, or plasma in the capillaries.

<table>
<thead>
<tr>
<th>Case No.</th>
<th>Vessel geometry</th>
<th>Vessel diameter</th>
<th>Inlet velocity</th>
<th>Blood model</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>straight terminal</td>
<td>0.6mm</td>
<td>8.1 cm/s</td>
<td>Newtonian blood</td>
</tr>
<tr>
<td>2</td>
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<td>0.6mm</td>
<td>8.1 cm/s</td>
<td>Herschel-Bulkley</td>
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<tr>
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<td>8.1 cm/s</td>
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<tr>
<td>5</td>
<td>straight capillary</td>
<td>10 micron</td>
<td>0.47 mm/s</td>
<td>Newtonian plasma</td>
</tr>
<tr>
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<td>10 micron</td>
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<td>Herschel-Bulkley</td>
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<tr>
<td>7</td>
<td>bent capillary</td>
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<td>Newtonian plasma</td>
</tr>
<tr>
<td>8</td>
<td>bent capillary</td>
<td>10 micron</td>
<td>0.47 mm/s</td>
<td>Herschel-Bulkley</td>
</tr>
</tbody>
</table>

Table 1: All cases used in nano-particle flow simulation

Results
Nanoparticle deposition fractions (NDF's) were calculated as the percentage of particles that contacted and thus were trapped by the vessel walls. Results are shown in Figures 3 & 4.

- NDF's were substantially higher in the capillaries than in the terminal arteries with average values of 69% and 3% respectively. This is most likely due to the dominance of Brownian motion at the capillary scale causing particles to deviate from the highly laminar streamlines.
- In all vessels NDF was noticeably reduced with increasing particle size, also attributable to Brownian motion dominance at the smaller scale.

Conclusion
These results indicate that nano-particles are likely to pass through small arteries but have a tendency to deposit in capillaries – a promising result for targeted treatment. Particle size, vessel geometry and blood viscosity appear as important factors influencing deposition of nano-particles.

Future Work
A discreet whole blood model incorporating deformable blood cells and cell-particle interaction needs to be developed in parallel with experimental studies to more accurately predict particle behaviour at the capillary level.