Numerical Study of Blood Flow in Stenotic Artery

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Abstract:
In the present study, we investigate the behaviour of the human blood in a stenosed blood vessel. The human blood is studied as a Newtonian as well as non-Newtonian fluid. We consider three rheological models of the shear-thinning non-Newtonian models and compare them with the Newtonian model. The blood flow through a stenosed blood vessel is studied numerically by solving the three dimensional Navier-Stokes equation along with the continuity equation and particular rheological model. Distribution of velocity, pressure, wall shear stresses and flow recirculation characteristics are determined for two time steps of the cardiac cycle. Present results indicate a significant influence of the shear-thinning viscous behaviour of a human blood on the most important hemodynamic parameters that play a key role in formation of atherosclerotic plaques. Last but not least, a systematic grid refinement analysis as well as numerical accuracy study IS performed and present numerical results may be treated as the benchmark.

Zusammenfassung:
Die gegenwärtige Studie beschäftigt sich mit dem Verhalten von menschlichem Blut in verengten Blutgefäßen. Das menschliche Blut wird dabei sowohl als newtonsche als auch nicht-newtonsche Flüssigkeit untersucht und durch entsprechende Modelle beschrieben. Wir berücksichtigen drei rheologische, nicht-Newtonsche Modelle zur Strukturviskosität und vergleichen diese dann mit dem newtonischen Modell. Der Blutfluss durch verengte Blutgefäße wird auf der Basis der dreidimensionalen Navier-Stokes Gleichung, zusammen mit der Kontinuitäts-Gleichung sowie einem speziellen rheologischen Modell, numerisch untersucht. Die Geschwindigkeits- und Druckverteilung, die Verteilung der Scherkräfte an den Gefäßwänden, sowie die Wirbelbildungs- und Rückfluss-eigenschaften werden für zwei Zeitstufen des Herzzyklusses bestimmt. Die gegenwärtigen Ergebnisse deuten auf einen bedeutenden Einfluss des strukturviskosen Verhaltens von menschlichem Blut auf die wichtigsten hämodynamischen Parameter, welche eine Schlüsselrolle in der Ausbildung von arteriosklerotischer Plaque spielen, hin. Abschließend werden eine systematische Rasteranalyse sowie eine numerische Exaktheitsstudie durchgeführt. Die gegenwärtigen Ergebnisse können dabei als Vergleichswerte dienen.

Résumé:
Dans cette étude, nous explorons le comportement du sang humain dans des vaisseaux sanguins sténosés. Le sang humain est considéré ici comme un fluide Newtonien ou non Newtonien. Nous comparons trois modèles non Newtoniens avec le modèle Newtonien. L´écoulement du sang à travers un vaisseau sanguin sténosé est étudié numériquement en résolvant les équations de Navier-Stoke tridimensionnelles en même temps que l'équation de continuité et en considérant le modèle rhéologique approprié. Les distributions de vitesse, de pression, de contraintes de cisaillement aux parois, et les caractéristiques de re-circulation de l'écoulement sont déterminées pour deux étapes temporelles du cycle cardiaque. Les résultats présentés montrent l'influence importante du comportement rhéo-amincissant du sang humain sur les paramètres hémodynamiques les plus importants qui jouent un rôle clé dans la formation des plaques athérosclitiques. Pour finir, mais non pour le moindre, une analyse systématique de raffinement de maille, ainsi qu'une étude d'exactitude numérique, sont faites et les résultats numériques présentés peuvent être considérés comme une nouvelle référence en la matière.

Key words: numerical modelling, blood flow, stenosis, non-Newtonian fluid

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- Reverse flow region – It is characterized with the negative wall shear stresses and it forms immediately (but later for non-Newtonian fluid) downstream of the stenosis. Non-Newtonian viscous behaviour substantially reduces the vortex length and the magnitude of flow separation in comparison to a Newtonian fluid.
- Pressure drop – The maximum reduction in pressure occurs, similar as the peak in axial velocity, slightly downstream of the narrowest part of stenosis. Non-Newtonian models have similar lowest pressure values, major differences are visible between Newtonian and non-Newtonian fluid. Last but not least, the shear-thinning blood rheology increases overall pressure drop for more than 15% relative to Newtonian fluid.
- Wall shear stress distribution – The narrower passage of the stenosis and accompanying implication on the axial velocity give rise to a higher wall shear stress (WSS) in the converging part of the stenosis. Peaks in the WSS are observed for Newtonian and non-Newtonian fluid and they occur slightly upstream of the narrowest part of stenosis. More visible differences in wall shear shear stress magnitude are between Newtonian and non-Newtonian models.

There are potential limitations in this work due to the following assumptions: (a) rigid wall and (b) steady flow conditions. Concluding, it is proposed that future work should include more realistic conditions, such as pulsatile nature of blood flow and elastic walls.

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