Magnetically Modulated Hemodynamics in Stenosed Arteries: Insights into Wall Shear Stress and Microorganism Distribution

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ABSTRACT

This study investigates the effects of magnetic fields on blood flow through stenosed arteries, focusing on wall shear stress (WSS), pressure distribution, and microorganism behavior. Using COMSOL Multiphysics, we modeled the hemodynamics in a stenosed artery, varying key parameters such as Reynolds number (Re), Hartmann number (Ha), and Bioconvection Lewis number (Lb). Results show that increasing Re leads to significant WSS peaks in the stenosed region, posing a risk of endothelial damage. The application of a magnetic field (increased Ha) stabilizes the flow, reducing turbulence, smoothing WSS distributions, and lessening the pressure drop across the stenosis. Additionally, higher Lb values enhance convective microorganism behavior, leading to a more non-uniform distribution. These findings offer valuable insights for optimizing therapeutic strategies and designing medical devices to mitigate the adverse effects of arterial stenosis.

Keywords: Stenosed arteries, wall shear stress, bioconvection, MHD, Hartmann number, Reynolds number

AMS Classification Code: 76M10, 76W05, 76Z05, 76D05, 35Q92, 92C10, 92C35

1. INTRODUCTION

Arterial stenosis, characterized by the narrowing of blood vessels, disrupts normal blood flow and leads to complex hemodynamic challenges, including elevated wall shear stress (WSS) and turbulent flow. The role of hemodynamics in cardiovascular health, particularly in the context of arterial stenosis, has been extensively studied. Malek et al. [1] emphasized the impact of WSS on endothelial damage, which is linked to atherosclerosis progression. Chatzizisis et al. [2] further explored how variations in WSS influence vascular remodeling and coronary atherosclerosis, highlighting the importance of managing shear stress to prevent adverse events.

Tzirtzilakis [3] demonstrated that magnetic fields, characterized by the Hartmann number (Ha), can stabilize blood flow in stenosed arteries, reducing turbulence. Nacev et al. [4] explored how magnetic fields can be used to direct nanoparticles through the bloodstream to specific sites within the body and observed that magnetic fields could successfully guide nanoparticles into tissues adjacent to blood vessels, improving the efficiency of localized drug delivery while minimizing systemic exposure. Priyadharsini and Sheremet [5] conducted a numerical and sensitivity analysis on unsteady radiative magnetohydrodynamic (MHD) blood flow over a permeable artery showing that the Nusselt number significantly increases with the rise in the bioconvection Rayleigh number (Ra) and the magnetic parameter.

This study investigates the modulation of blood flow within stenosed arteries by applying magnetic fields, focusing on the behavior of nanoparticles and microorganisms in the bloodstream. By varying parameters such as the Reynolds number (Re), Hartmann number (Ha), and Bioconvection Lewis number (Lb), the research aims to understand their effects on WSS and the distribution of these particles. The objective is to utilize magnetic fields to reduce WSS, minimize pressure drops in stenosed regions, and optimize the distribution of nanoparticles and microorganisms, thereby providing insights that could improve therapeutic interventions and the design of cardiovascular medical devices.

2. PROBLEM FORMULATION & SOLUTION METHODOLOGY

This study uses a two-dimensional axisymmetric model of a stenosed artery to simulate blood flow, incorporating the effects of nanoparticles and microorganisms. The flow is governed by the Navier-Stokes equations, while the Transport of Dilute Species module in COMSOL Multiphysics models nanoparticle and microorganism behavior. The influence of magnetic fields is simulated through the Hartmann number, and the Bioconvection Lewis number is varied to study its effect on microorganism distribution. Realistic boundary and no-slip conditions are applied to accurately reflect physiological settings.

Simulations were conducted in COMSOL using the Laminar Flow, Heat Transfer, and Transport of Dilute Species modules, focusing on key non-dimensional parameters: Reynolds number (100–5000), Hartmann number (0–100), and Bioconvection Lewis number (1–100). A finite element mesh was utilized to resolve complex flow patterns, especially around the stenosis. Post-processing included analysis of velocity profiles, pressure contours, wall shear stress, and microorganism concentration to identify critical trends.

3. RESULTS AND DISCUSSION

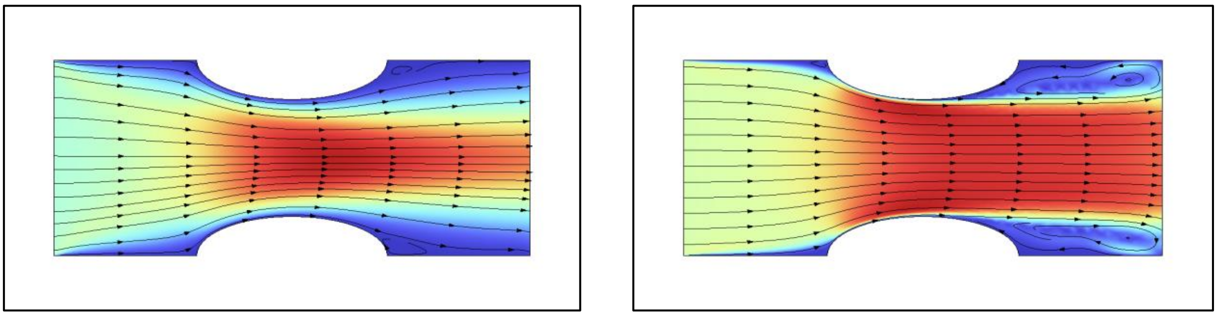

Figure 1. Surface velocity magnitude and streamlines for Re = 100 (left) and Re = 5000(right).

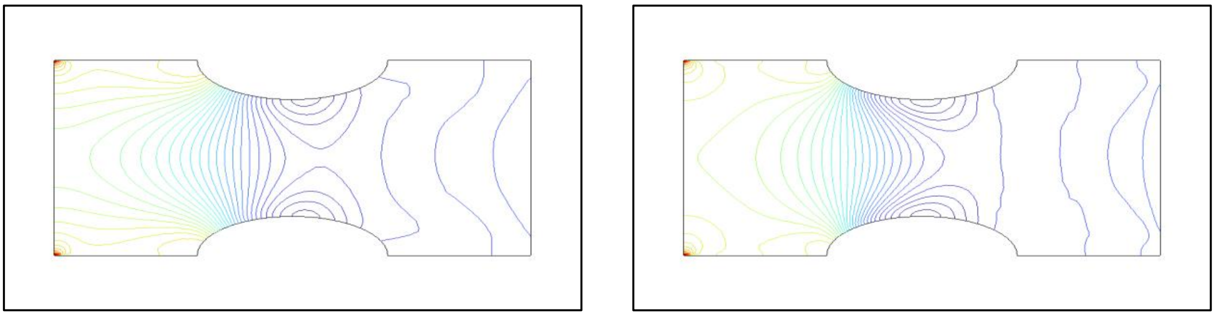

Figure 2. Pressure contours for Re = 5000 with Ha = 0 (left) and Ha = 100(right).

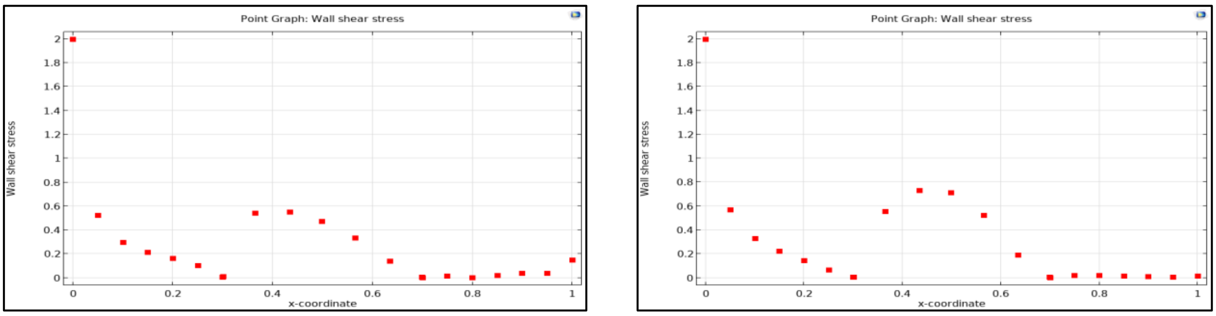

Figure 3. Wall shear stress for Re =100 and Ha =0 (left), Ha = 100(right).

1. At higher Reynolds numbers, the velocity profiles exhibit sharp peaks within the stenosed region, accompanied by flow separation downstream. This behavior indicates a transition towards turbulence, which can exacerbate endothelial damage.
2. The application of a magnetic field stabilizes the flow, reducing the severity of velocity peaks and smoothing out the flow separation. This stabilization effect is further reflected in the pressure contours, where the magnetic field reduces the steepness of the pressure drop across the stenosis, leading to a more gradual pressure recovery downstream. These findings suggest that magnetic fields could be employed therapeutically to moderate the hemodynamic stresses associated with severe stenosis.
3. The results indicate a significant variation in wall shear stress (WSS) with changes in Reynolds number. At higher Re = 5000, the WSS peaks within the stenosed region, indicating areas of potential endothelial damage. This finding is clinically relevant as high WSS is often associated with plaque rupture and the progression of atherosclerosis.
4. The application of a magnetic field Ha = 100 demonstrated a stabilizing effect on the flow, particularly in the regions downstream of the stenosis. This stabilization led to a reduction in turbulent effects and a more uniform WSS distribution, suggesting that magnetic fields could be used therapeutically to reduce the risk of complications associated with high WSS.
5. Varying the Bioconvection Lewis number (Lb) showed that higher Lb values resulted in more pronounced convective behavior, leading to a non-uniform distribution of microorganisms. This effect could be particularly significant in the context of targeted drug delivery, where controlling the distribution of therapeutic agents is critical.

4. REFERENCES

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