Project Proposal for Simulating Mammalian Sperm in Viscous Media

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I. Introduction

Sperm motility is crucial for successful fertilization in mammalian reproduction. It is often the case that human infertility is linked to immotile and/or static sperm, and so understanding how sperm traverses physiological environments to fertilize an egg is beneficial to addressing infertility issues in humans as well as mammals. This proposal outlines a comprehensive research project to simulate the behavior of mammalian sperm within viscous fluids using MATLAB. The research will be focused around 4 areas that influence sperm motility: structure, dynamics, buckling behavior, and modulation of viscosity.

II. Structure

Within our research, considerations for sperm structure will be required to accurately represent the biological features of sperm within the simulation. As such, it will be necessary to acquire high resolution images to capture the structure of sperm within a 3D model. For example, the model will need to account for various accessory structures (acrosome, vacuoles, annulus, axonemal structures, etc.) and determine how each affects sperm motility. Additionally, material properties must be determined like the elasticity of the flagellum and the rigidity and mass of the head. In addition to material properties, we will also need to consider mechanical properties that define sperm structure, including viscoelasticity, density, and compliance. Another important part of rending the structure of sperm will be geometric features, like the dimensions and shape of the head and flagellum. Visualization is important as we aim to maintain biological realism in the simulation while also optimizing computational efficiency.

III. Dynamics and Motility

Our research will focus on simulating the dynamic characteristics of sperm in viscous fluid and analyzing different types of flagellum motion and their effectiveness.

A. Locomotion Method

One characteristic that makes sperm different from other micro-organisms with flagellum is the way they swim. A sperm moves its single flagellum laterally from side to side and propels itself in a way like tadpoles. On the other hand, prokaryotes such as E. coli rotate multiple flagella to create helical movement like using propellers. We will use our simulation to examine the efficiency of such a method and compare it to other micro-organisms.

B. Progressive and Non-progressive Motility

Sperm motility defines how efficiently a sperm moves through a medium. Progressive motility is where sperm can swim in a straight line and successfully reach an egg. Whereas non-progressive motility describes sperm that are moving slowly or in small circles. One factor that distinguishes progressive from non-progressive motility is the frequencies of the flagellum movement. Healthy sperm beat their flagella in a continuous, coordinated frequency. Any disturbance or delay in the motion can cause sperm to move inefficiently or even lead to non-progressive motility. This inhibits sperm's ability to reach an egg, which is why the proportion of progressive to non-progressive motile sperm is a key metric for doctors to evaluate sperm quality. By studying the dynamic behavior of sperm, we can have a better understanding of motility issues and gain insight into one of the major causes of mammalian infertility.

IV. Non-Linearity and Buckling

By drastically changing beating frequency, the flagellum of sperm can buckle and lead to a sudden change of swimming direction. This nonlinearity in motion can allow sperm to break free from strong current flow and navigate toward an egg. According to previous research, sperm can utilize multiple varying patterns of flagellum movement to deal with different scenarios, allowing them to be adaptive and survive in harsh environments and increase the possibility of successful fertilization. Additionally, different head shape and size can also affect the influence of nonlinearity flagellum motion. Our simulation will also attempt to address their correlation between sperm shape and buckling to provide us with a better understanding of how sperm navigates within physiological fluids.

V. Modulation of Fluid Viscosity

The final consideration that will need to be addressed in the simulation is the influence that modulating the viscosity of the surrounding medium has on sperm motility. To do this, it will be necessary to first determine whether the simulation will implement a Newtonian or non-Newtonian fluid model based on previous research. A mathematical model and/or set of equations must be used to represent the viscosity of the surrounding fluid. The simulation should allow for not only adjustments in viscosity parameters, but also applicable flow parameter changes (Reynolds number, inertial forces, flow patterns, etc.). All these simulation results must be validated against experimental data conducted by researchers to ensure that the modulation of fluid properties accurately reflect real-world scenarios. The simulation will need to address how changes in the environment will impact sperm progressive motility through a viscous medium with the goal of fertilizing an egg.

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