The Physics and Dynamics of Human Sperm

The laws of physics apply everywhere within the universe, as it basically includes everything in space and time.
- Living matter, scientifically speaking, are sac of chemicals clustered within a plasma membrane. Humans are merely larger collection of communicating matter.

In accordance with this view, even the human body with its constituent cells obeys the laws of physics. Newton's laws hold true even within our bodies. We're gonna be looking into fluid dynamics and how it relates to human sperm:
- Sperm always travels in a liquid medium from the lumen of seminiferous tubules which is filled with testicular fluids formed by Sertoli and Leydig cells, and then into the epididymal lumen where sperm starts to flap its flagella powered by ancient organisms buried in our cells, the mitochondria.
- And through the proteinaceous and inorganic mesh of epididymal fluids, sperm emerges into the vas deferens and is further decorated there with more nutrients and cholesterol and finally reaches the urethra to mix up with other contents of the semen.
- Therefore in order for sperm to travel from two points in space it'll have to swim its way through all of these fluids (with the help of peristaltic contractions of male genital tract).

The laws of physics govern this journey, as it also govern the billions of chemical processes that happen each second in our body.

Let us examine this further:
- Physicist Edward Purcell calculated that if you push a bacteria and then let go, it will stop in about a millionth of a second. The same holds true for a sperm.
- The physicist Osborne Reynolds figured out a number that can predict how a fluid will behave, and it's called Reynolds number.

Reynolds number = Size (of the swimmer) x speed x density \ Viscosity.

- What this means is that creatures of different sizes inhabit vastly different worlds. For example, because of its huge size a whale inhabits the large Reynolds number world and if it flaps its tail once, it can coast ahead for an incredible distance.
- Meanwhile, human sperm lives in a low Reynolds number world. If a sperm were to stop flapping its tail, it wouldn't even coast past a single atom.

Low Reynolds Number: World of Low Reynolds Number

- Reynolds number encompasses several factors. It explains the behavior of fluid meaning, it explains the forces between the molecules themselves, these forces are caused by the acceleration of the fluid molecules against each other and the object submerged (as we remember Force = mass x acceleration.)
- Simply put, Reynolds numbers is the ratio of the **inertial forces** divided by the **viscous forces.**
- **Inertial forces** describes the all the forces exerted by the fluid, and how it interacts with the object. The inertial force takes into account all forces acting on the body
- We're also factoring the viscous force which takes into account the forces opposing the body's motion.

When the Reynolds number is small the **viscous** forces dominate.
- For a sperm, inertia is totally irrelevant. If you're at a very low Reynolds number, what you're doing at the moment is entirely determined by the forces that are exerted on you at that moment, and by nothing in the past.

- Imagine being submerged in a swimming pool full of highly viscous molasses, then move your arm at the speed of the hands of a clock. If under those ground rules you're able to move a few meters in a couple of weeks, then you qualify as a low Reynolds number swimmer, i.e. a sperm.

Motion at Low Reynolds Number: Cilia and Flagella

Having described how hard it for motion at a low Reynolds number world, how would microbes or sperm get anywhere then?

- Some actually are immotile, like Yersinia pestis, the bacterium responsible for the plague and perhaps the most successful pathogen along with Mycobacterium tuberculosis. Both are immotile, but instead they wait for nutrients to come their way. They evolved and equipped themselves with pumps and transporters to better utilize their use of nutrition.

is for Two motions can be used at a low Reynolds number world by biological organisms:

1- **Flexible paddle method (cilia):** They flex their cilia to create more drag on the power stroke (during which the cilium pushes the fluid) than on the recovery stroke (when the cilium goes back to its initial position) as shown in figure 1.

2- Corkscrew method (flagella): instead of flapping their flagella back and forth, sperm wind their flagella like a corkscrew as shown in figure 2 .

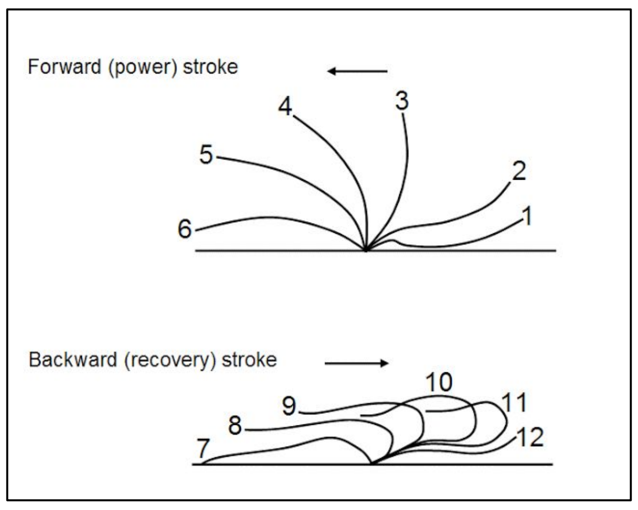

Figure 1

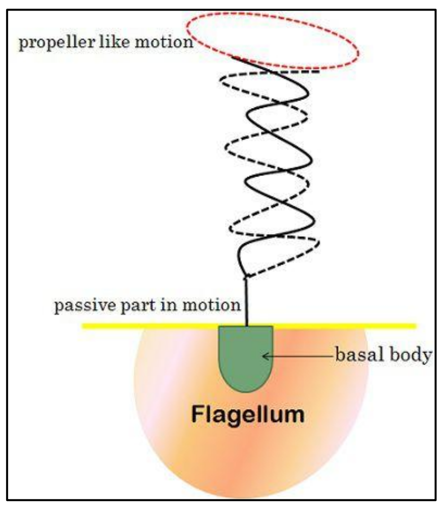

Figure 2

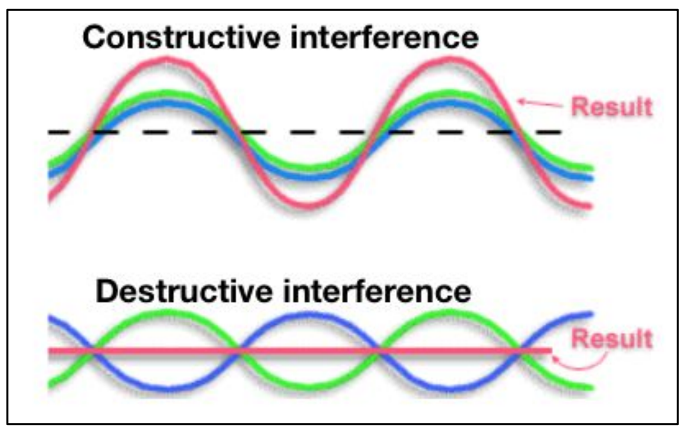

Figure 3

Cooperation of Sperm

Imagine having to travel at such great distances only to fertilize the egg, facing dangers on your way such as acids. Would it not be safer to swim in groups? Indeed, but not only safer, it is energetically better. In this situation it'll be helpful to think of a sperm motion as a wave.

- Wave interference is when two individual waves meet. We have two types of wave interference:

  1- Constructive interference: waves that combine in phase. The resulting amplitude is twice as large as the amplitude of an individual wave.
- An example for this is soundwaves, sound waves can combine and reinforce each other to create a louder noise. Same can be said for water waves.

  2- Destructive interference: waves that combine out of phase. The two waves will cancel each other out and the resulting amplitude is zero.
- Noise-cancelling headphones have their own built-in microphone and when it detects a sound wave, the headphone will create a destructive wave (an opposite wave) to counteract the constructive wave.

It turns out that sperm cooperate so that their phases lock in.

- When two swimmers with the same flagella-waveform are swimming in phase (constructive intercerence) they dissipate the least amount of mechanical energy, and they reinforce each other to reach their destination by amplifying each other's waves.
- In figure 4 we see two swimmers (sperms) with different velocities and therefore they are said to be "out-of-phase" since their created waves are not amplifying one another. As soon as their waves synchronize, as in (g), they can amplify each other's waves and reach their destination in a more efficient manner.

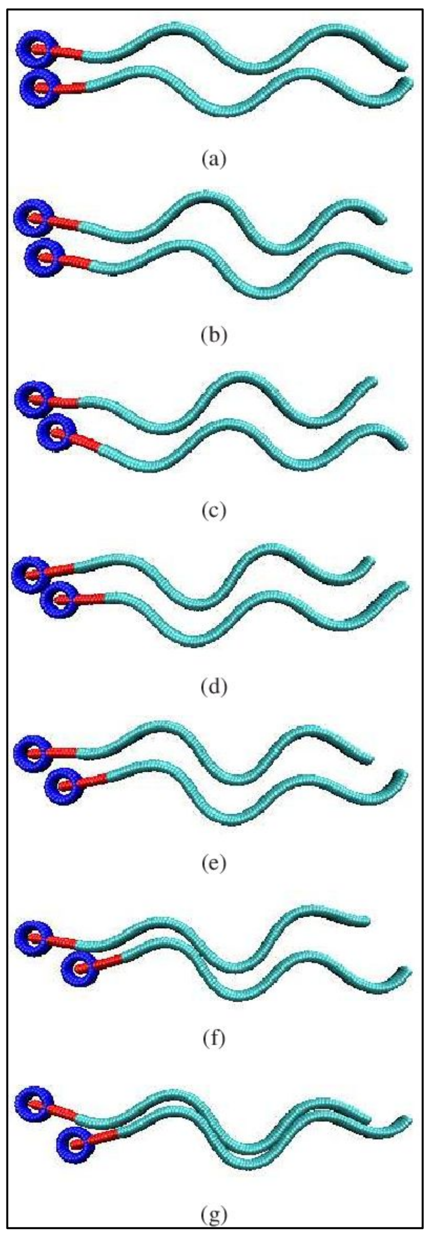

Figure 4