SECTION 3 : MOTION OF CELLS

LECTURE 8 : BEATING OF CILIA

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BB101 Spring 2023, IIT Bombay

Resources

Physical Biology of the Cell, Phillips, Kondev, Theriot, Garcia

Molecular Biology of the Cell. Alberts, Johnson,Lewis …. Walter

Article : CILIA RELATED DISEASES

Article The many modes of flagellar and ciliary beating

ARTICLE TALES OF THE UNEXPECTED

Recall : Diversity of Motion in different Cell types

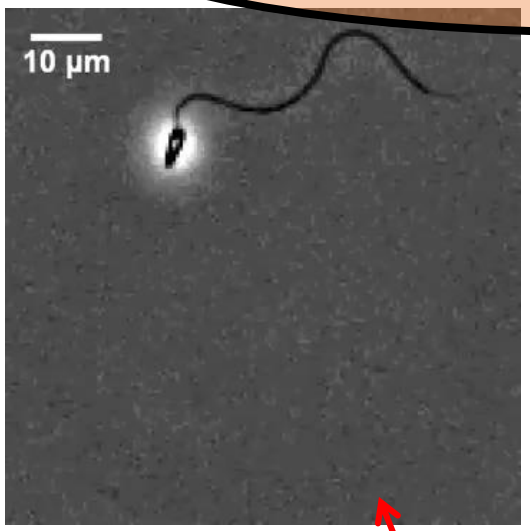
For today's Lecture

PROKARYOTE

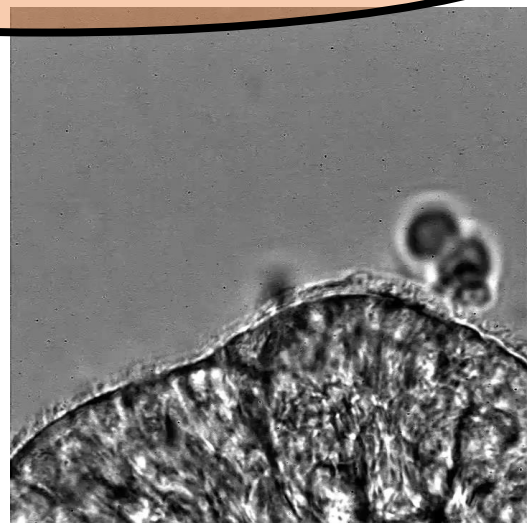
Bacteria

EUKARYOTES

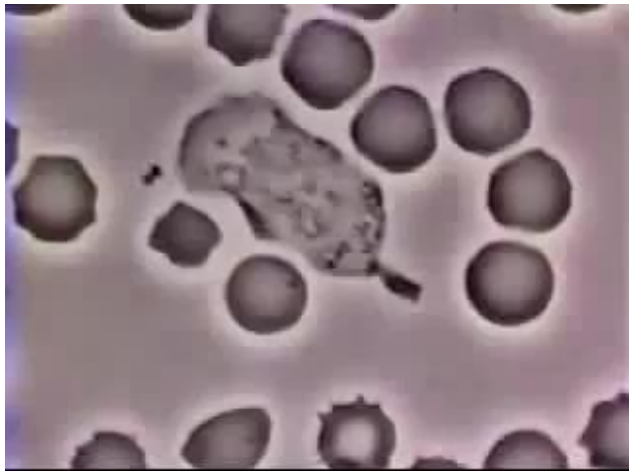
Sperm



Epithelial Cells
(e.g. Lung airway)



White Blood Cell
Catching bacteria

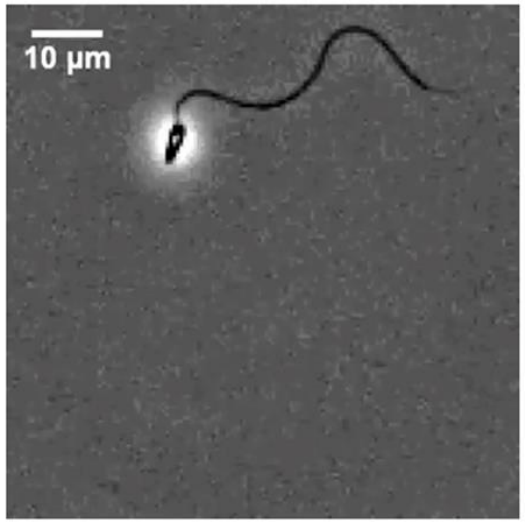


Both use "Flagella",
But mechanism is different
Rotary Motor Versus Dyneins

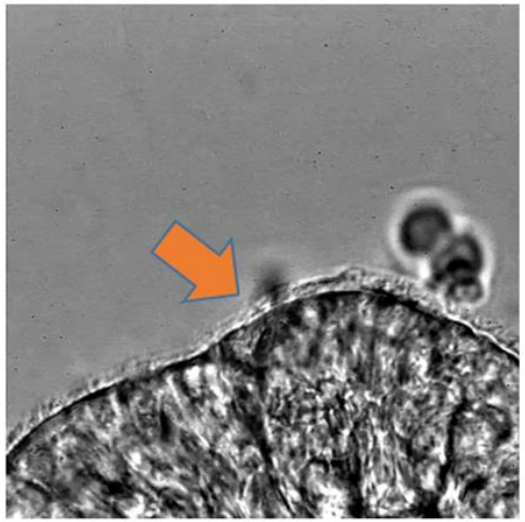
Flagella or Cilia
(Whip-like motion
Driven by Dynein)

Different Mechanism
Actin Polymerization and
Depolymerization

Whip-like motion



Generates Motion of Cell
(Swimming of Sperm, *Chlamydomonas*)

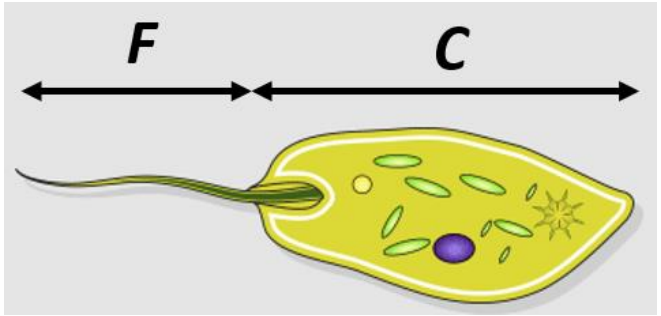


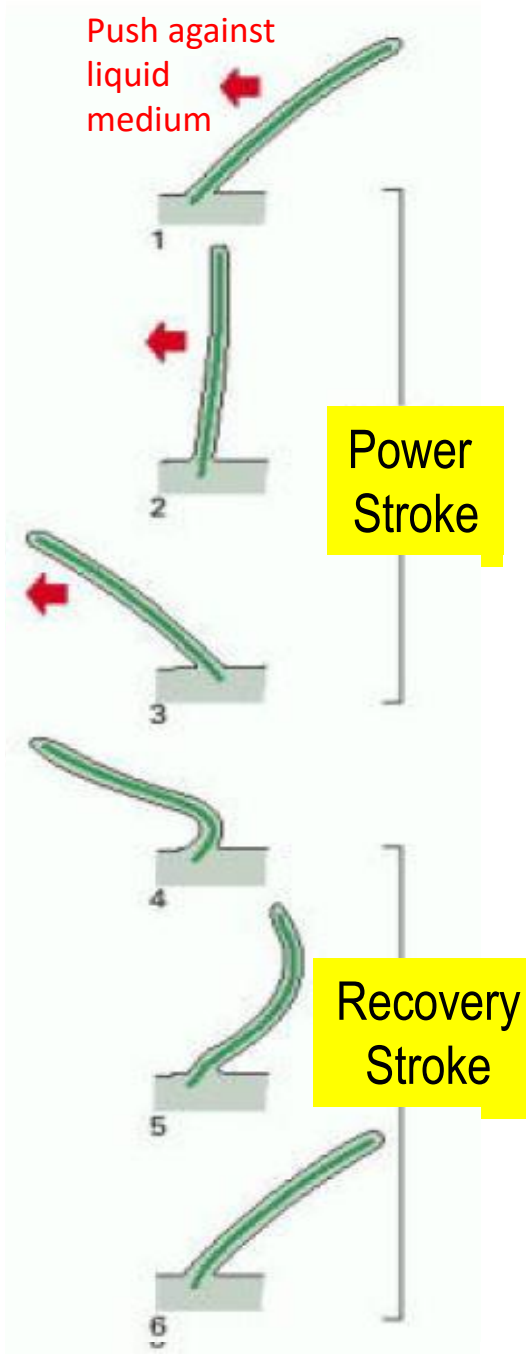
Generates fluid flow
(e.g. lungs, nodal cilia in left-right asymmetry)

Question

Ratio F/C : Is this ratio same for Cilia and Flagella?

What do you understand from this Ratio ?



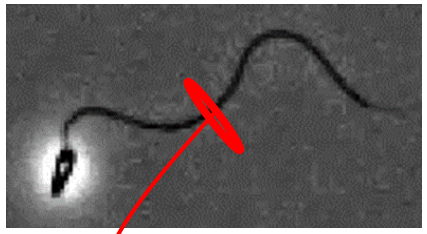


Whip-like motion shows two distinct "Strokes". WHY ?

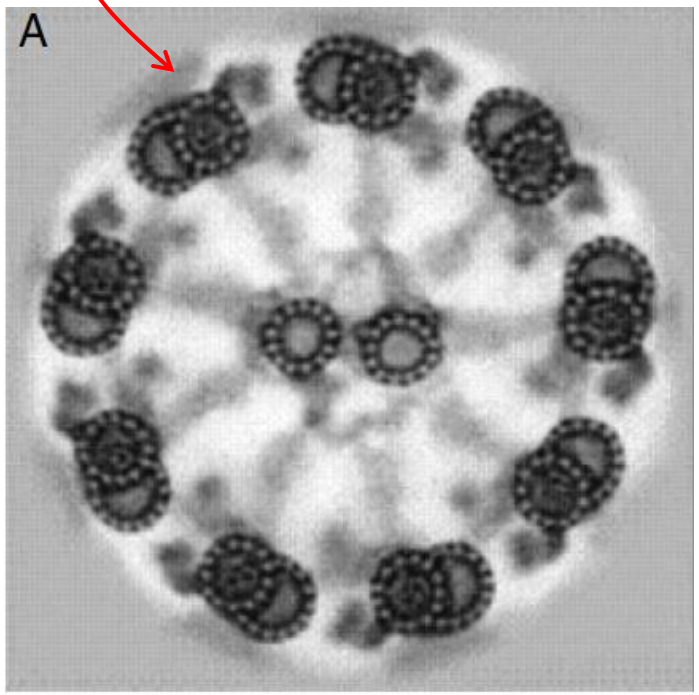
Breatstroke Video

Mix/Unmix Video

What is inside the Cilia or Flagella in Eukaryotes ?

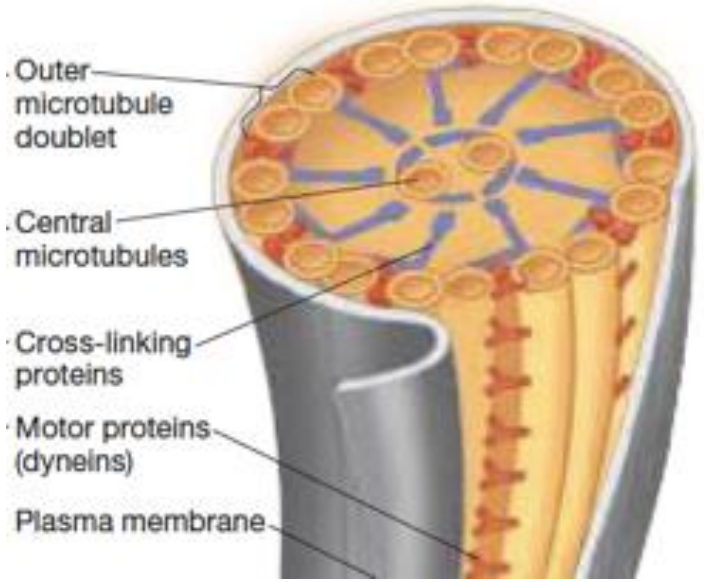


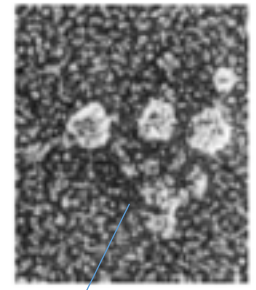
Cross section under Electron Microscope

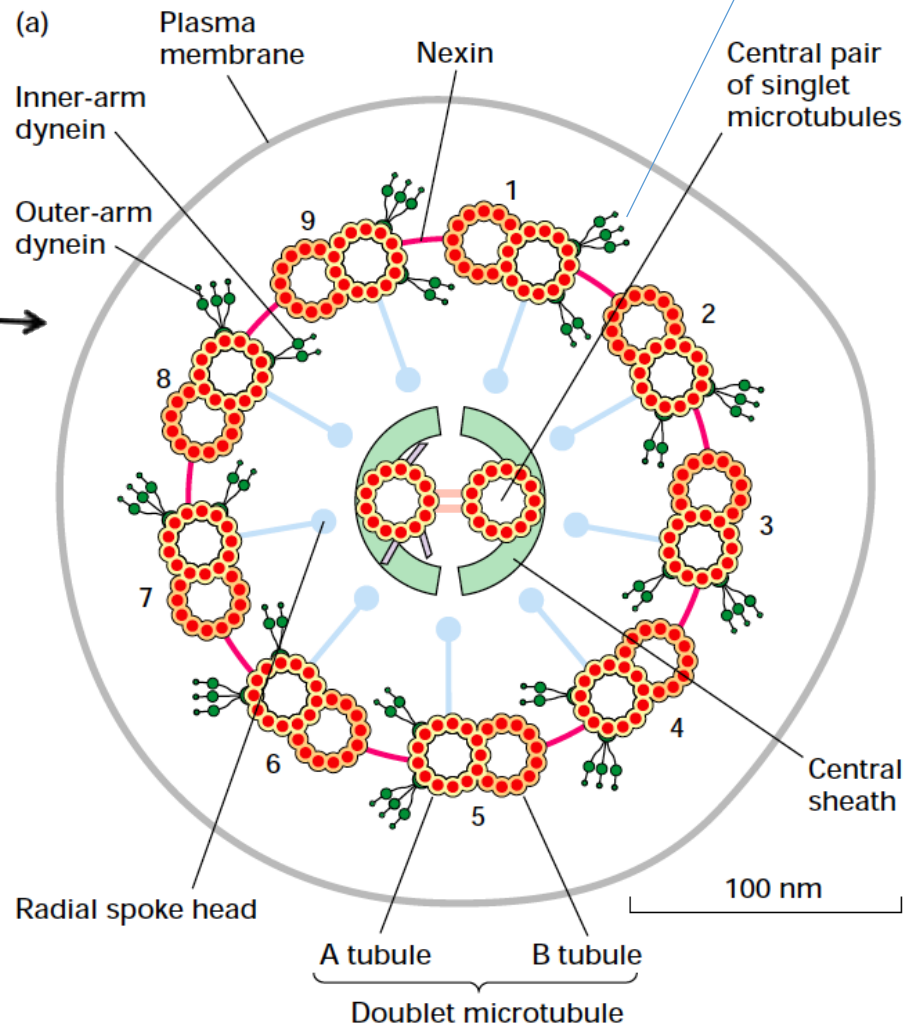


0.2 micron

"9 + 2" Microtubule arrangement





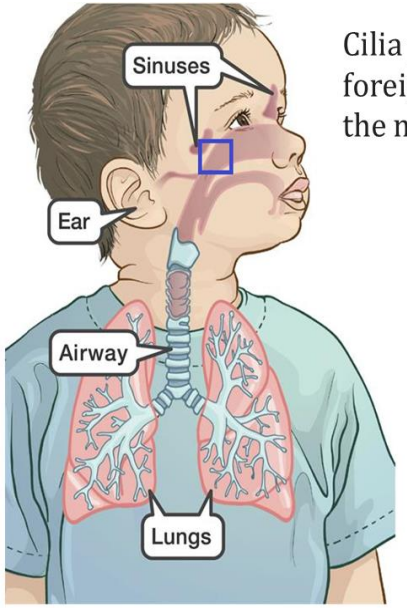


The Human aspect : Diseases related to Cilia

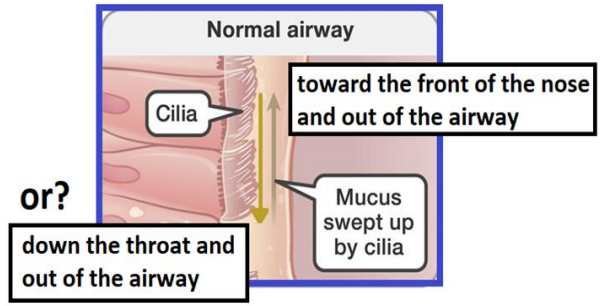
Your body has :-

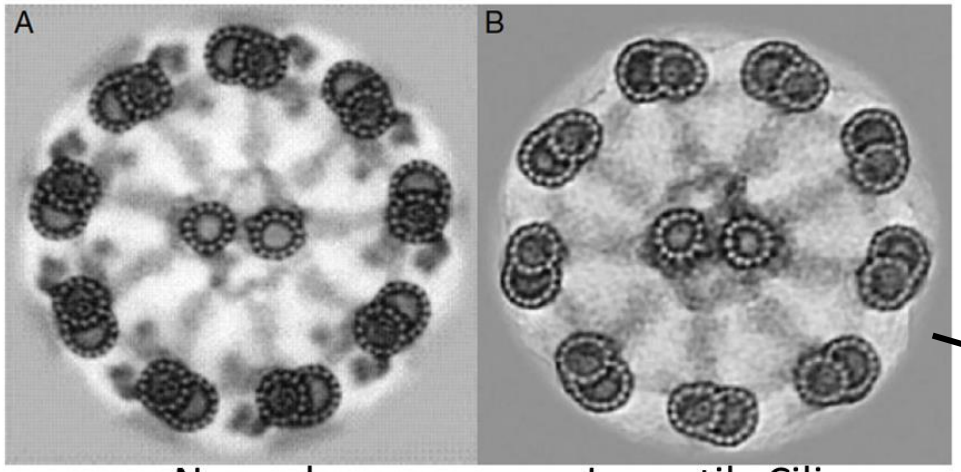
(1) *Mucus-propelling cilia.* (2) *Water-propelling cilia.* (3) *Nodal cilia.* (4) *Monocilia.*
(5) *Rudimentary cilia.* (6) *Olfactory cilia.* (7) *Photoreceptor cilia.* (8) *Sperm flagellum.*

Why do we swallow frequently ?



Cilia provide the force necessary to transport foreign materials in the respiratory tract toward the mouth where they can be swallowed





Normal Immotile Cilia

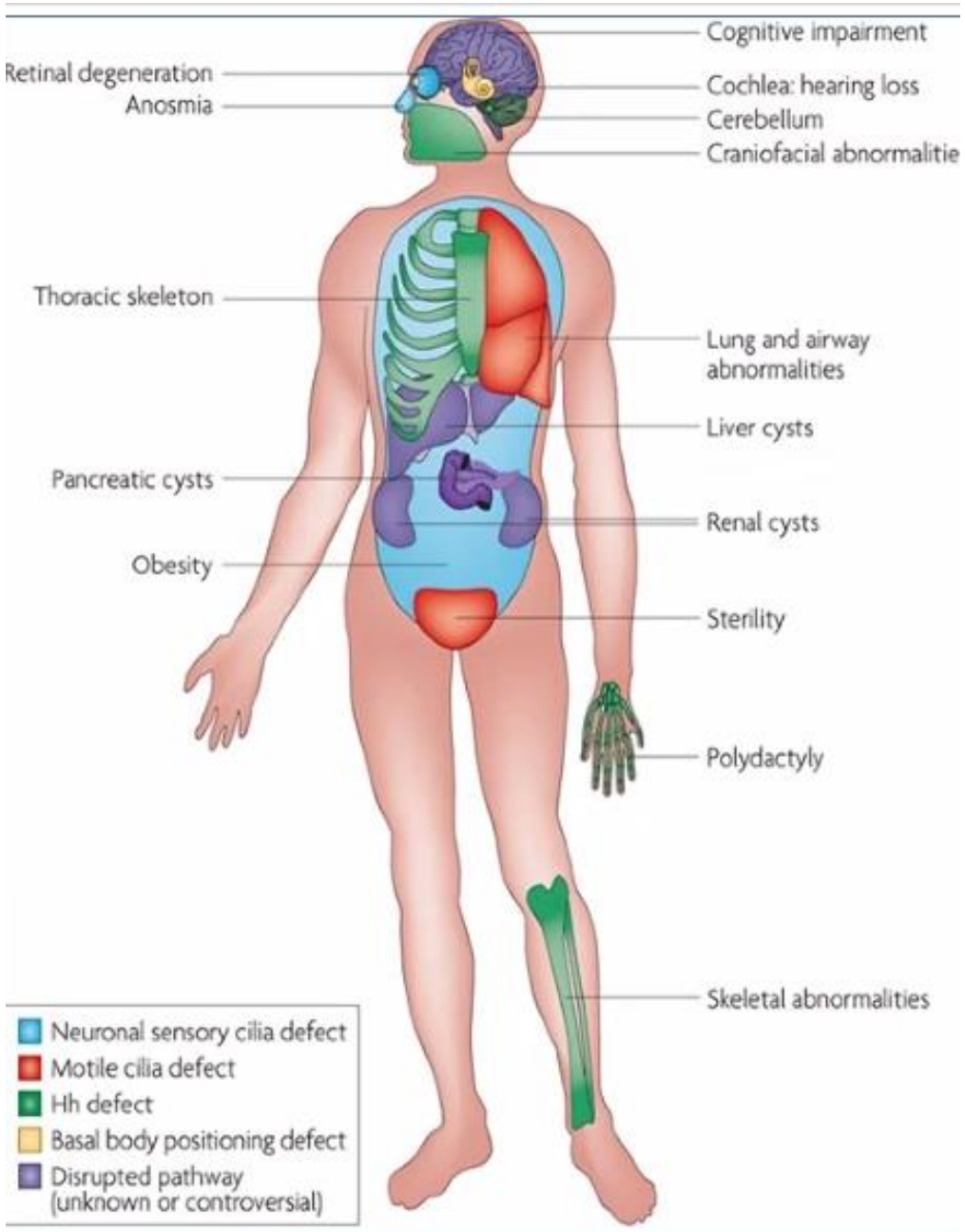
What is missing here?

Cystic Fibrosis : Paralysis of Cilia
Superviscous Mucus → Choking, Bacterial infection

Immotile-cilia syndrome	Male infertility	Female infertility
→ Sperm lack Dynein arms (immotile sperm) → Patients cannot transport inhaled particles along the lung airway → Chronic sinusitis		In the oviduct, cilia help transport eggs down the fallopian tube.

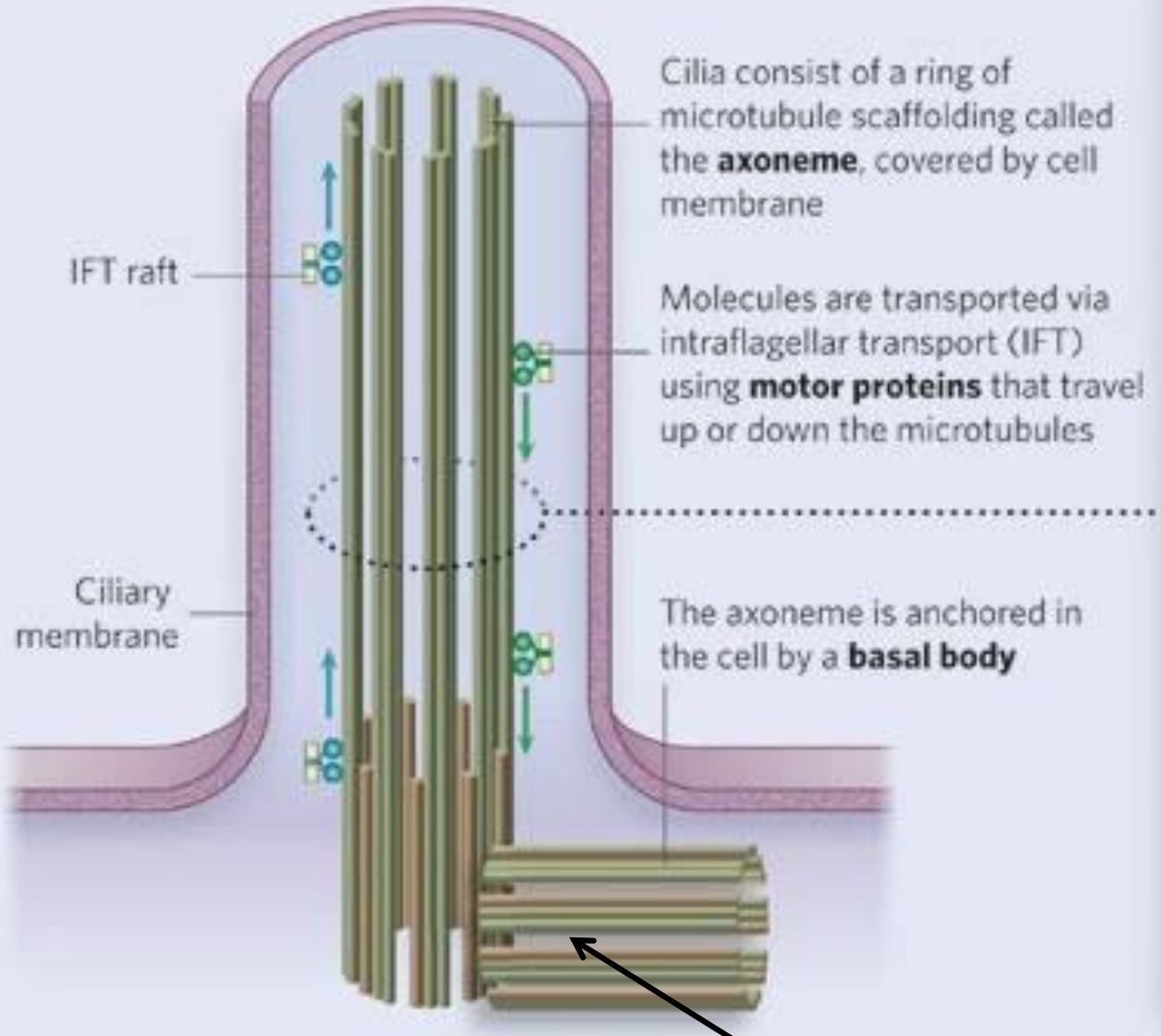
LINK : CILIA RELATED DISEASES

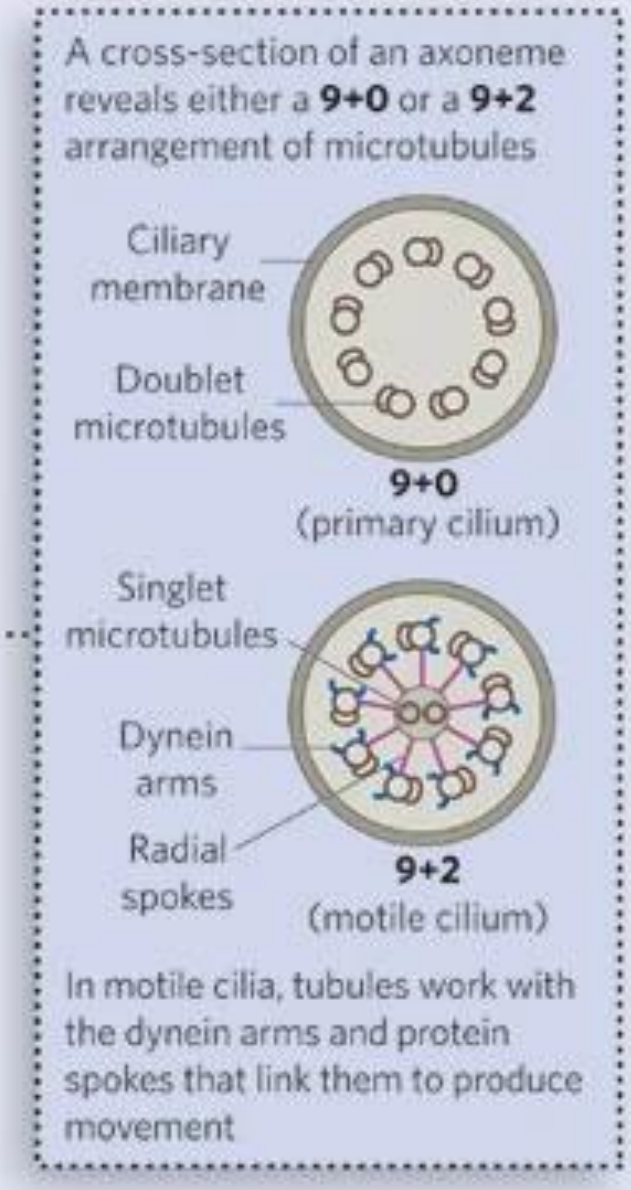
Parts of the body affected by Ciliary diseases



Goetz and Anderson *Nature Reviews Genetics* **11**, 331-344 (May 2010)

THE CILIUM DISSECTED





[LINK TO PAPER]

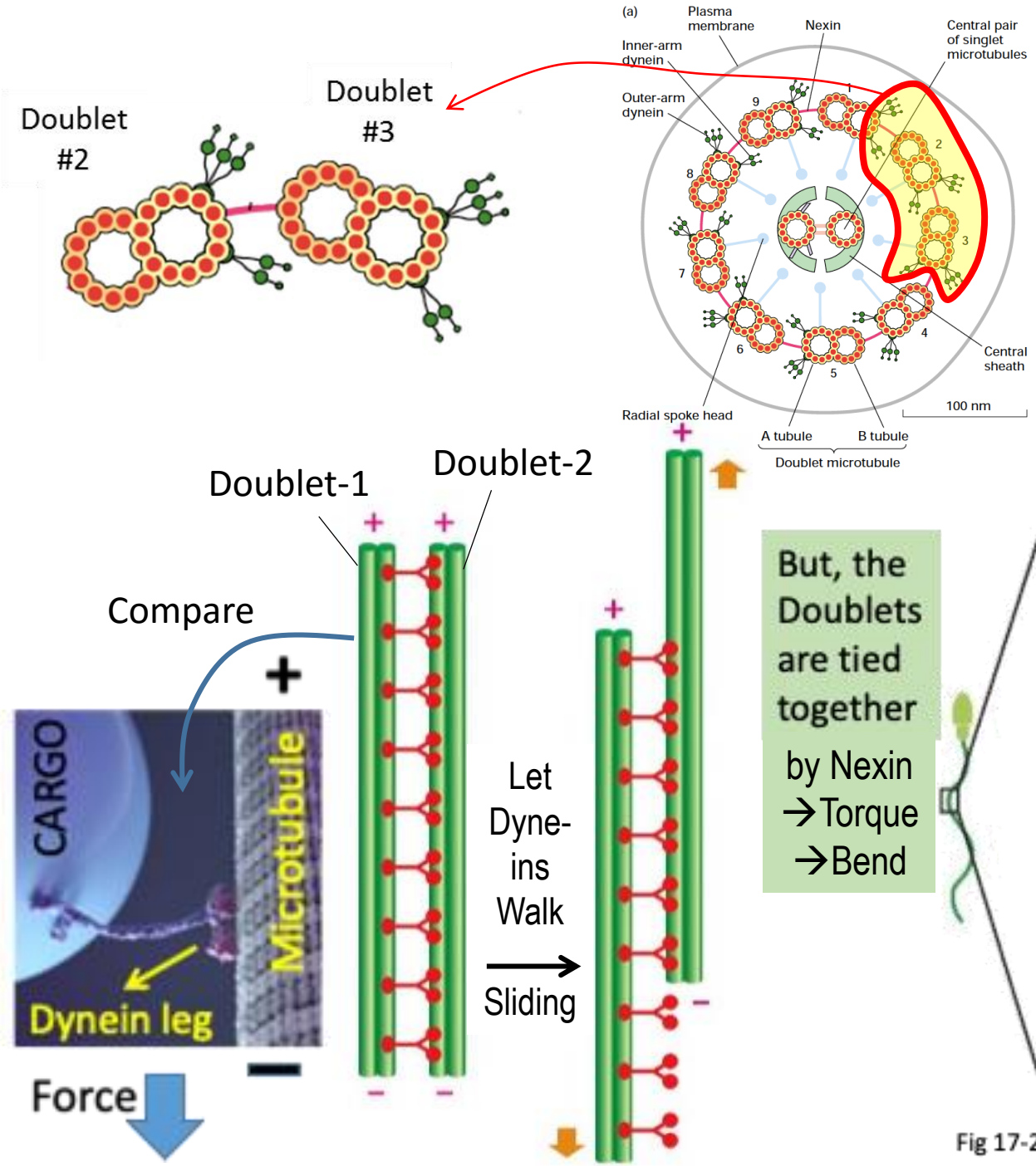


Fig 17-27, Essential Cell Biology, Garland Science 4th Ed

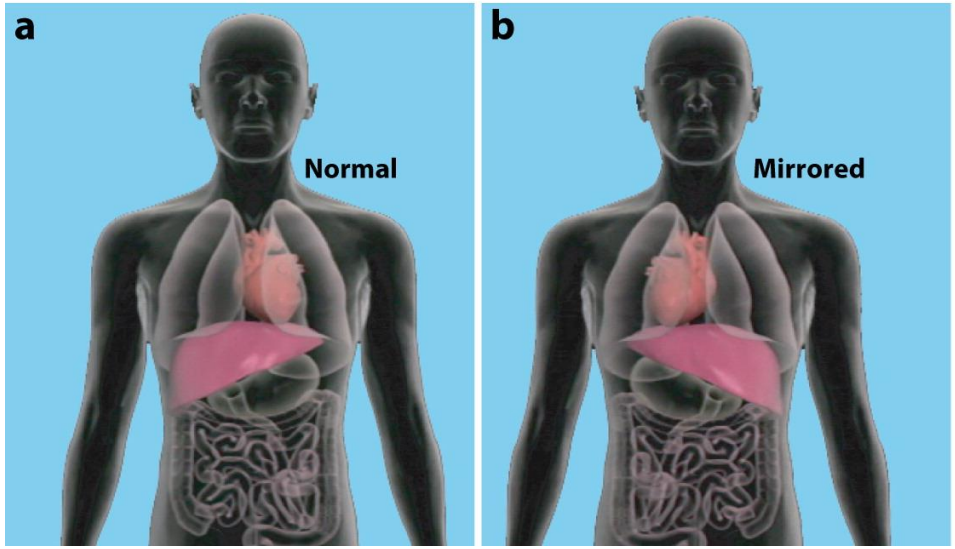
Interesting & Less Understood

1. If Dyneins on all doublets generate force together, then cilia bending is not possible

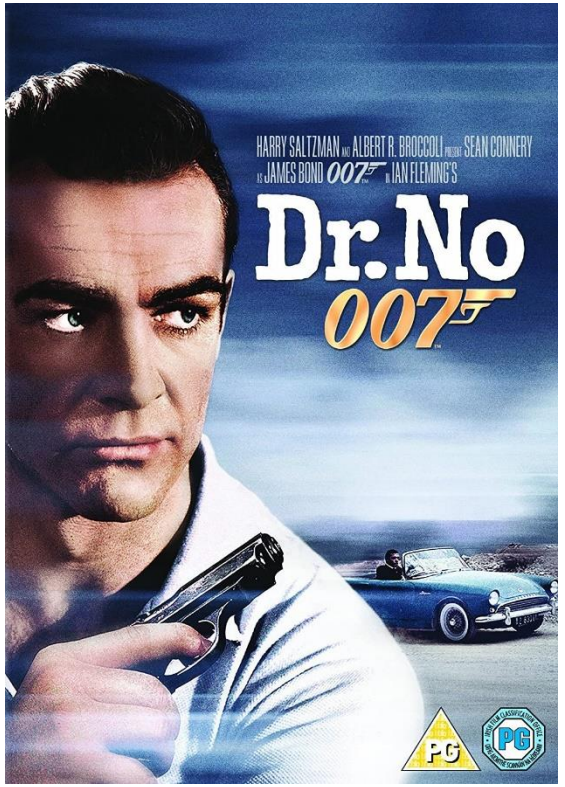
(up and down forces on each doublet would cancel out)

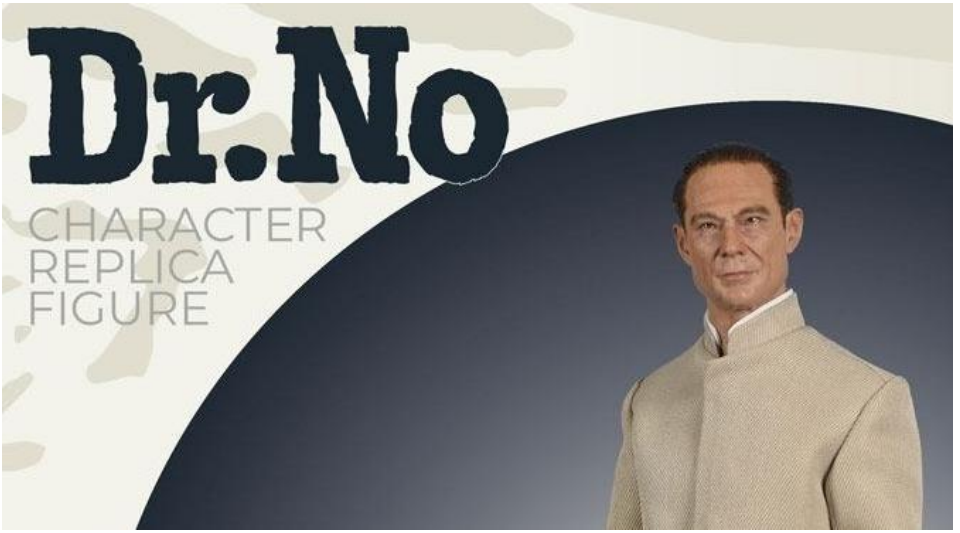
2. Dyneins on each of the doublets may be activated sequentially around the circle to bend the flagellum in a three-dimensional wave → Orientation of Central pair ?
3. But how does the wave propagate along length of cilia? The Central Pair was found to rotate during beats → Why?

Situs inversus is a rare congenital condition in which all of an individual's internal organs in the thorax and abdomen are positioned on the opposite side to where they should be. The liver, for instance, is now on the left, the spleen on the right. Flipped, for want of a better word.



Hirokawa N, et al. 2009.
Annu. Rev. Fluid Mech. 41:53–72





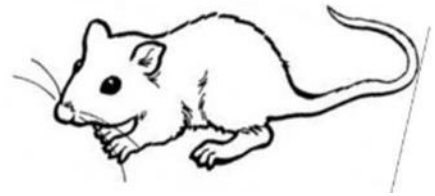
Artists and writers have explored the implications of situs inversus. Understandably so: it makes for a cracking plot twist. The titular character in Ian Fleming's 1958 James Bond novel Dr No is saved from a bullet because of his dextrocardia. In Her Fearful Symmetry, Audrey Niffenegger introduces

[Article in The Guardian]

Immotile Cilia patients have Situs inversus

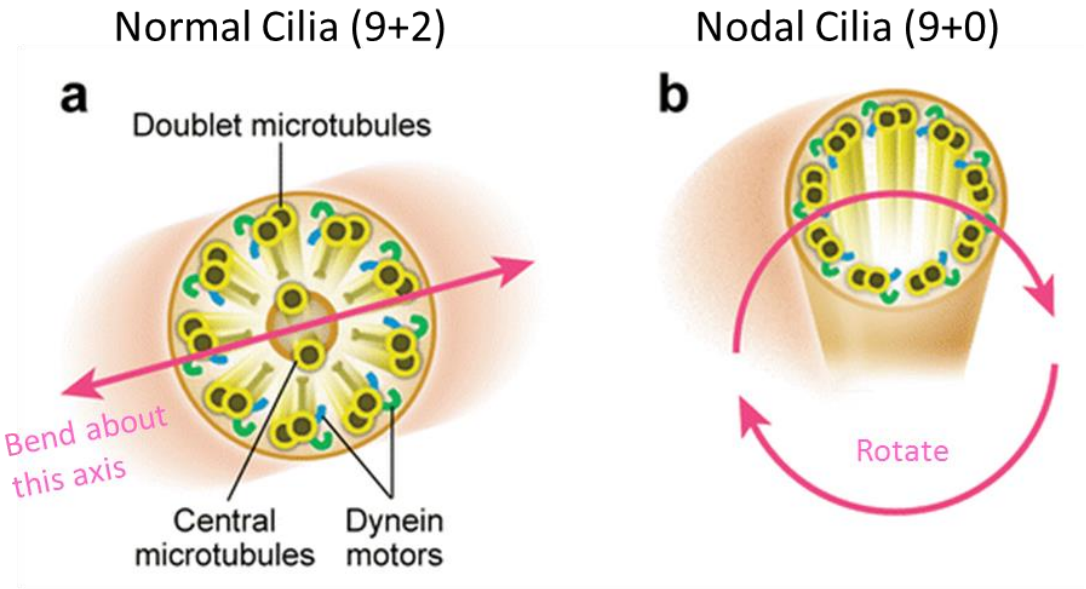
(Arrangement of the internal organs is a mirror image of normal anatomy)

A = Anterior, P = Posterior



Mono-cilia in the mouse embryo node are primary **(9+0)** cilia, lacking the central pair of microtubules.

(9+0) cilia rotate (rather than bend)



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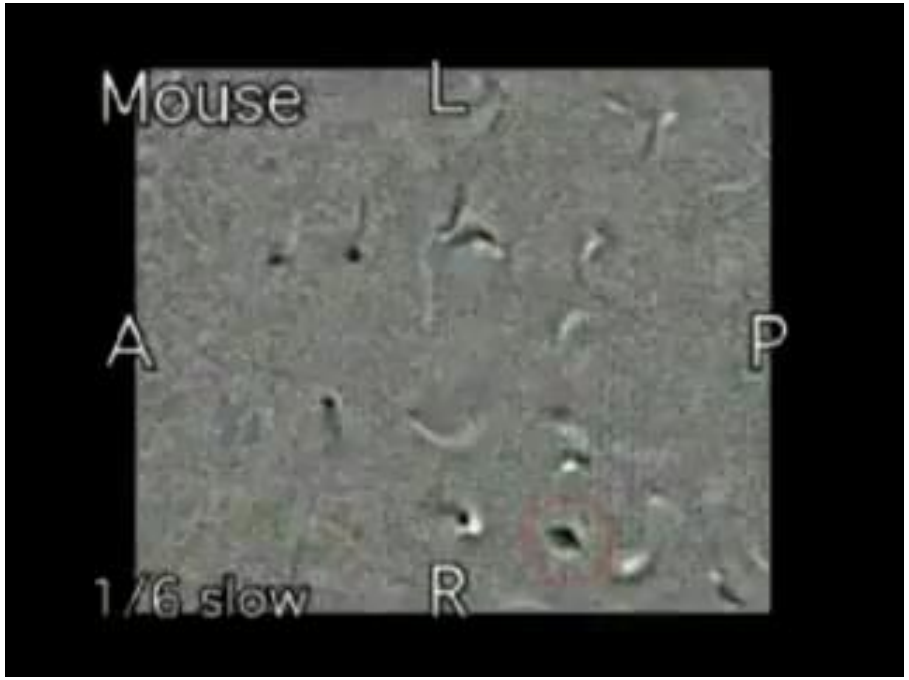


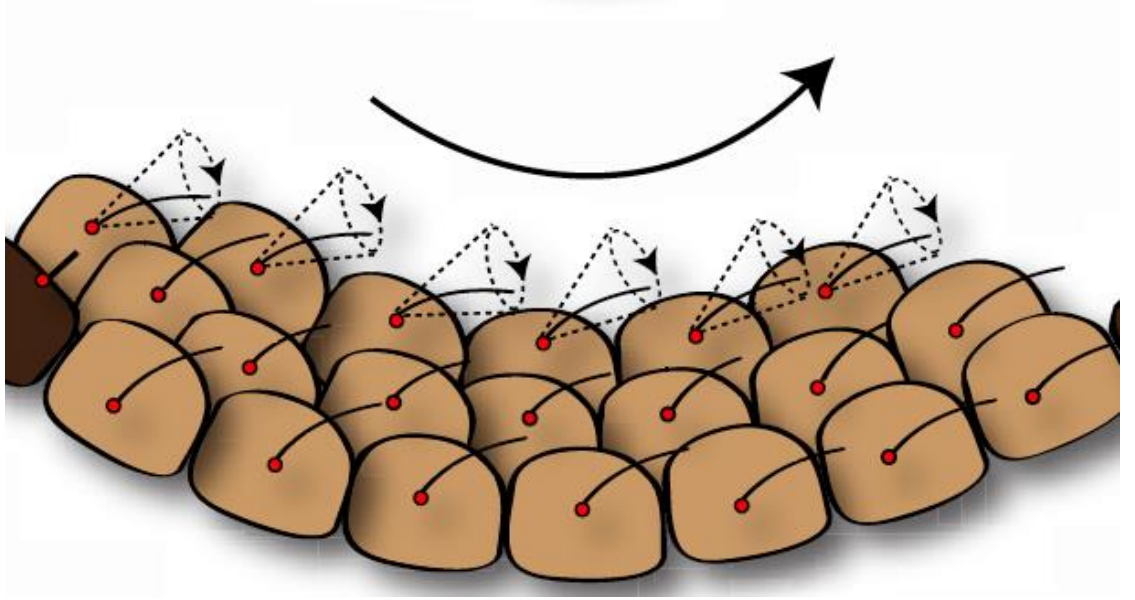
Link to Video

Nearly half of immotile Cilia patients have Situs inversus

(Condition in which the arrangement of the internal organs is a mirror image of normal anatomy)

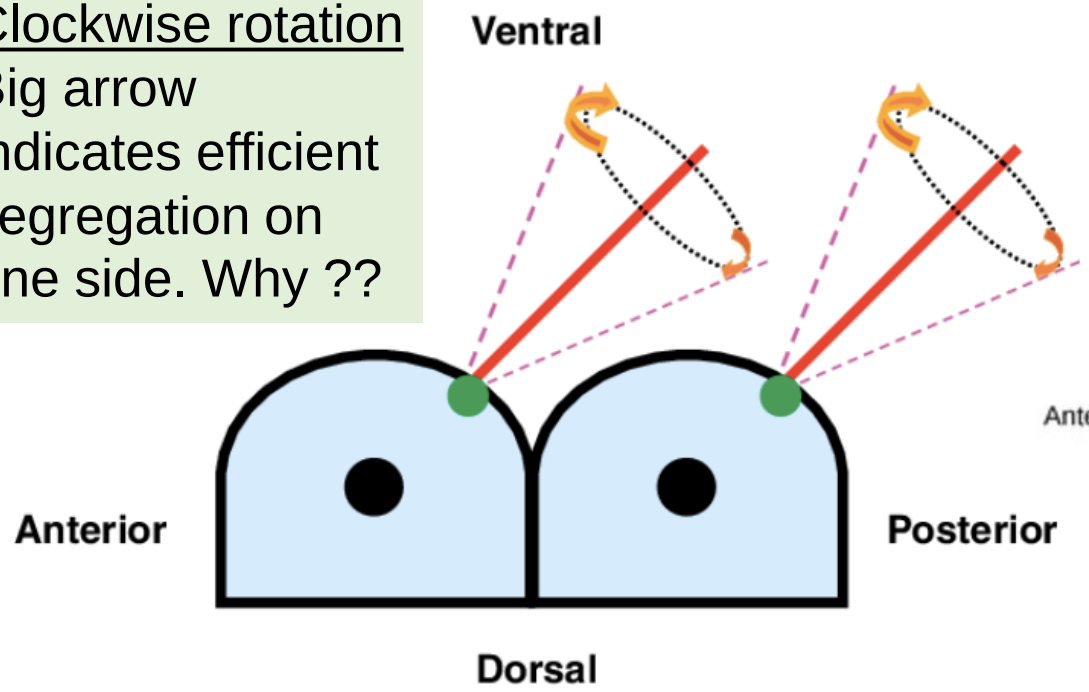
The mono-cilia in the mouse embryo node are primary **(9+0)** cilia, lacking the central pair of microtubules

(9+0) cilia rotate (rather than bend)

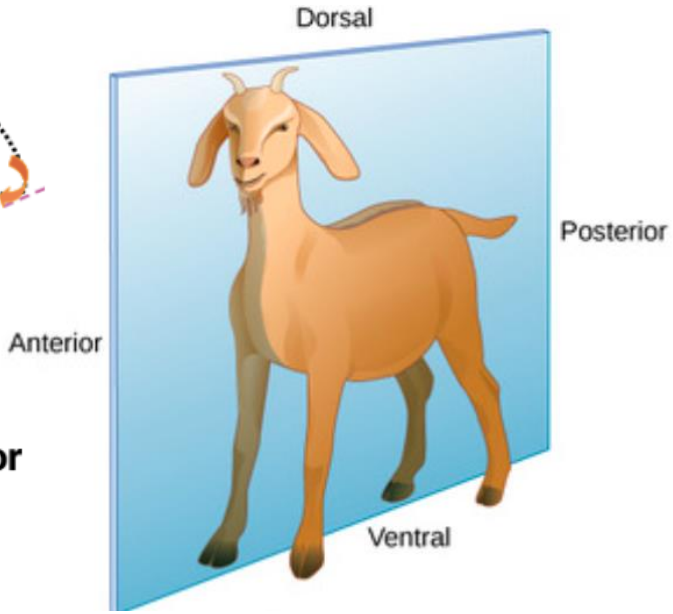


For more details **Left–right asymmetry: cilia stir up new surprises in the node**

Clockwise rotation
Big arrow indicates efficient segregation on one side. Why ??



After it grows up …



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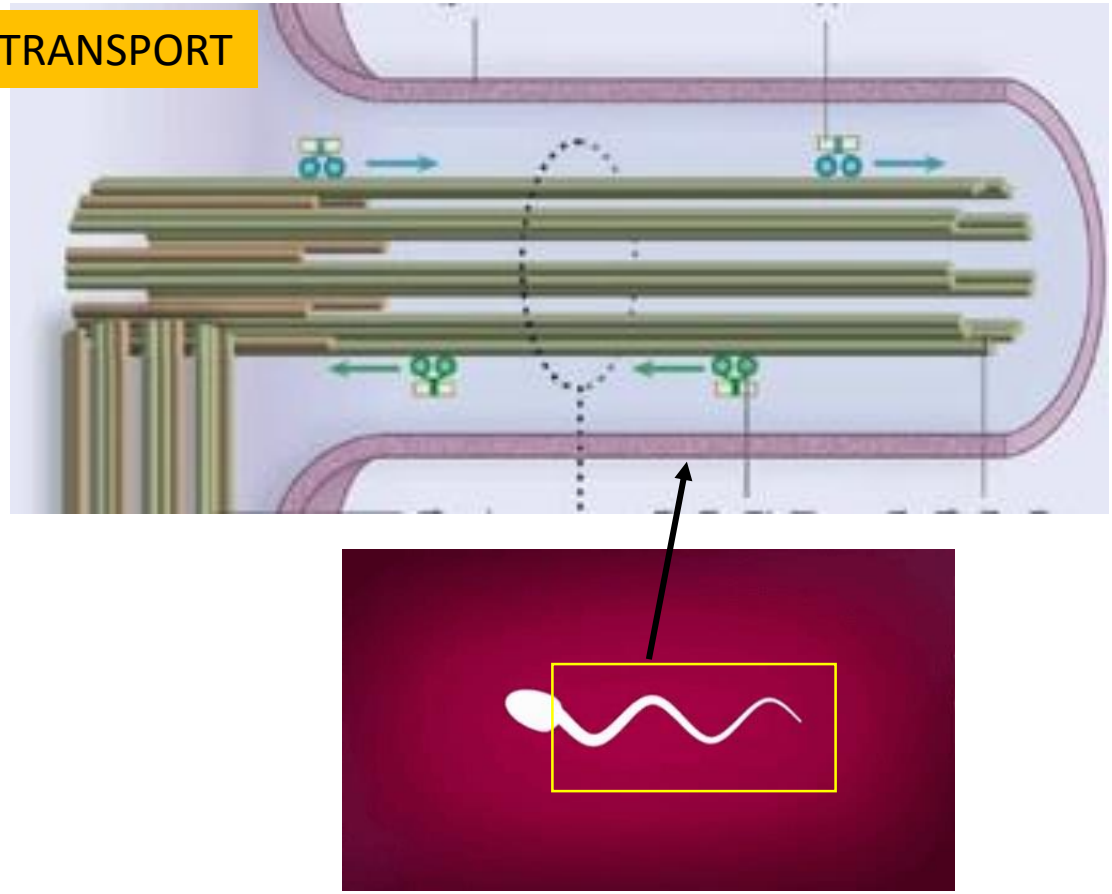
INTRA-FLAGELLAR TRANSPORT



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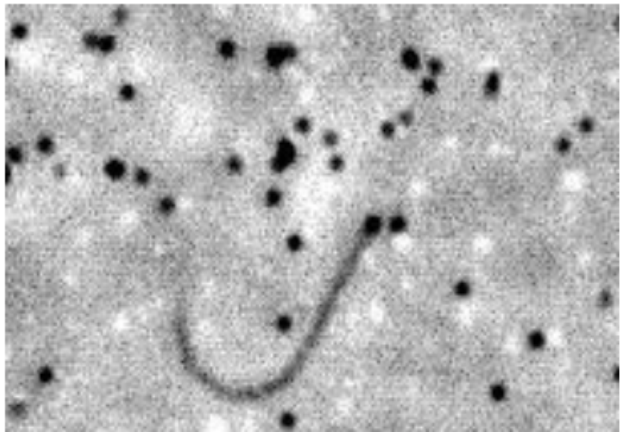

Ciliary oscillations driven by molecular motors cause fluid motion at micron scale. Stable oscillations require a significant source of dissipation to balance the energy input of motors. Conventionally, it stems from external fluid. We have shown, in contrast, that external fluid friction is negligible compared to internal elastic stress through a simultaneous measurement of motion and flow field of an isolated and active Chlamydomonas cilium. Consequently, internal friction emerges as the sole source of dissipation for ciliary oscillations. We combine these experimental insights with theoretical modeling of active filaments to show that an instability to oscillations takes place when active stresses are strain-softening and shear-thinning.

DOI: 10.1126/sciadv.abb0503