How did Vertebrates evolve from Invertebrates?

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Some Definitions

Vertebrates are animals WITH a backbone, Invertebrates are animals WITHOUT a backbone

Putting “animals” into context

All LIFE began in water around 3.5 – 4.1 billion years ago –
but in 21st century, no consensus on definition of “life” (New Scientist 4Nov2023 referred to 123 definitions!)

For this talk I’ll use

Life is characterized by growth, reproduction, functional activity, and continual change before death, with DNA as the molecule coding all the organisms’ characteristics

Which works, but excludes viruses….

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Modern taxonomy divides life into **Prokaryotes** **(without a nucleus in their cells) and** **Eukaryotes** **(with a nucleus in their cells)**

Prokaryotes *(unicellular life forms)* are **bacteria** and **archaea ; in prokaryotes DNA is "loose" within the cells**

Eukaryotes *(mostly multicellular life forms)* are **animals, plants & fungi; in eukaryotes DNA is held in the nucleus**

Animals are divided into invertebrates and vertebrates, plus an "in between group" – the protochordates

All animals alive today have invertebrate ancestry

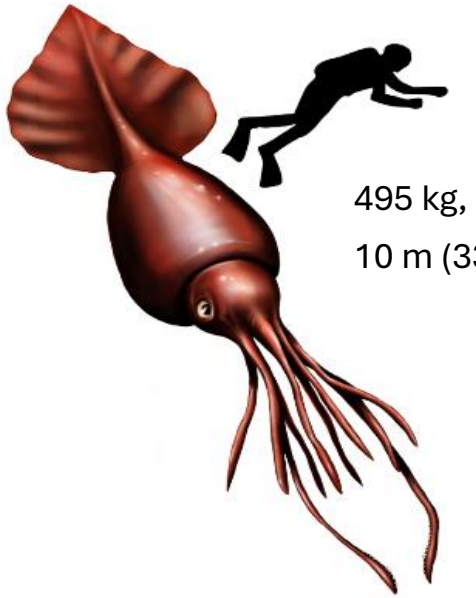
Life is COMPLEX …
it wasn't until 2022 that the FIRST full 3D model of a bacterium cell was created – based on the SIMPLEST bacterium known *(mycoplasma genitalium)*

How did Vertebrates evolve from Invertebrates?

Invertebrates come in many shapes & sizes

Gastrotrichs
0.06mm-3mm;
multicellular
eukaryote

To giants like The Colossal Squid



495 kg, maybe as much as 600–700 kg.

10 m (33 ft) to 14 m (46 ft)

So do vertebrates

Brazilian flea toad
(*Brachycephalus pulex*),
7 mm (0.28 in)

Blue whale the heaviest animal ever **(199,000 kg)** .

Around **30 m (100 ft)**

Patagotitan mayorum, a titanosaur from Late Cretaceous was **longer** *(probably **37 m (121 ft)*** but **lighter** *(around **69, 000 kg)***

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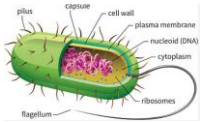
Now we've set the scene for invertebrates vs vertebrates, we need to go back to their common ancestors

Physics & chemistry before biology

Conditions on earth "in the beginning" were such that (eventually) molecules were formed that spontaneously formed membranes that delineated an "inside" from the "outside", which in time (a LOT of time) became unicelluar organisms.



Bacterium
free living, unicellular prokaryote
motile (flagellum) [.5 – 5 um]

After a lot more time, these organisms started to consume ("eat") each other – some proving more successful than others

Defence and Offence

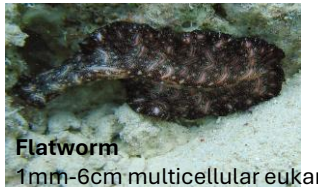
At some stage unicellular organisms joined with others to make "mats" of cells – perhaps as a defence against predators (being too big to be eaten).

Some organisms used the protein **collagen** *(a three stranded protein helix)* to bind the cells into multicellular sheets – these are **the proto-animals [viz vertebrates]**

*Proto - plants used **cellulose** (a sugar) to support & connect cell walls, many that were to become invertebrate animals used **chitin** (a protein), as did those that became fungi*

Some multicellular organisms stayed small and / or simple, avoiding the "cost" of developing dedicated respiratory or circulatory systems, relying on diffusion to distribute materials; simple digestive systems

Gastrotrichs
0.06mm-3mm; multicellular eukaryote



Flatworm
1mm-6cm multicellular eukaryote

But size matters.....In addition to deterring predators, multicellularity also means tasks can be divided amongst cells – some becoming responsible for "eating", some for obtaining oxygen, some for circulating materials including oxygen among and between the cells.

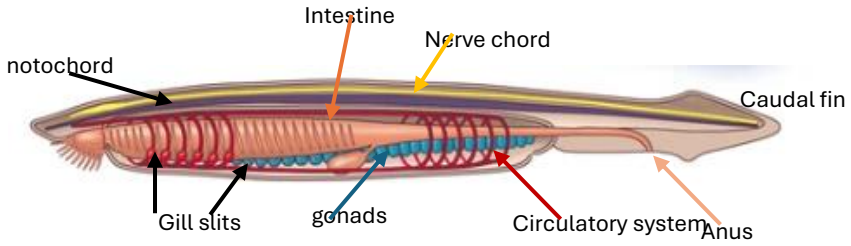
How did Vertebrates evolve from Invertebrates?

Another feature of most (?all) animals is controlled movement *(at some life stage)* i.e. are they are motile.

Vertebrates *(and some invertebrates)* use **muscles** to enable movement.
Muscles are **contractile** cells that function in opposing pairs (*example biceps and triceps; they **do not extend**),* and as such, work by having something to "pull" against

Hunting / pursuing food drives development of polarities in the body – with a front end, where sensory organs and the opening to gut are likely to be located, and a tail end where the waste can be expelled; such polarity in turn promotes bilateral symmetry

A cylindrical shape is efficient for movement in water, or through muds. Cylindrical animals move by alternately contracting muscles on one side of the body as they relax those on the other side. The body curve this action creates, propels the animal forward (or back).



Amphioxus aka lancelet 6.5 – 8 cm, marine,

Muscles need something to pull against.
In amphioxus, a primitive, marine proto-vertebrate, there is a stiffened region in the centre of their bodies, called the notochord.

The notochord is made of glycoproteins encased in a sheath of **collagen fibres**, wound into two opposing helices which are held in **vacuolated, turgid cells.**
it serves as a flexible, rod-like support structure, against which muscles can pull

Which makes the notochord a possible BACK BONE prototype

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Another potential intermediate stage in the development of **bone** would be **cartilaginous** fish *(modern day sharks, rays etc).*

Cartilage is also made of **collagen** and **proteoglycans** and is also flexible but rigid enough to provide anchors for muscles

In embryos of bony animals the first bones are just cartilage – which then becomes mineralised to become proper bone

In time (millennia!) the chemistry of the rigid internal structures changed from just collagen to include calcium phosphate (as hydroxyapaptite) – the hard bit of **bone**.

Internal and external forces created the optimal design for bones, depending on the animal's life-style!

In particular, the **development of [pentadactyl] limbs** and moving **from water onto land** where the effects of **gravity** are much more significant

Some aquatic invertebrates developed a sort of endoskeleton that didn't involve bone (eg the "cuttlebone" inside cuttlefish)

Other invertebrates *(particularly land based ones)* developed an **exoskeleton**- the main component of which is the protein **chitin** – in crustacea the exoskeleton is made more rigid with **calcium carbonate**

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Thank you!

Any questions??

References:

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