

A photograph of a clownfish (Amphiprioninae) swimming in an aquarium. The fish is orange with white stripes and is positioned on the left side of the slide.

The origin of vertebrates

Marc Kirschner
Dept. of Systems Biology
Harvard Medical School
Boston Massachusetts

Plan of Lecture

- Introduction: Vertebrate body plans and the odd phylum of *Hemichordates*
- The origin of the vertebrate nervous system: the hemichordate perspective

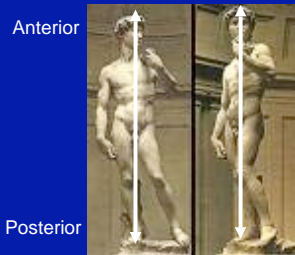
Plan of Lecture

- Telling the back from the front and what the chordates invented
- How the vertebrates got their chord

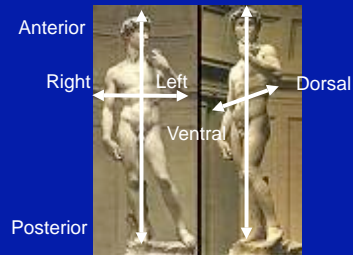
What do we vertebrates have in common?
How did these features arise in evolution?



Fundamentally, what we have
in common is a body plan



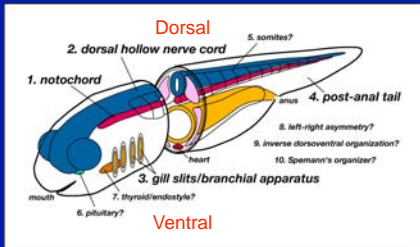
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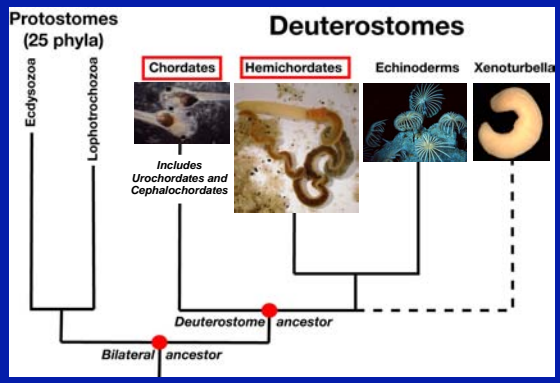
But body plans are shared with many metazoan phyla



What makes our phylum, the Chordates, special?



Why study hemichordates?



Not many good choices

To understand the Chordate origins, we need to step back from Chordates

- If we are too far, eg. flies, we cannot find the traces of the chordate developmental characters
- If we are too close, eg. within sea squirts, then all we see is the elaboration of these characters

Echinoderms are too weird to inform us about vertebrate body plans



Class: Crinoids; sea lilies

Class: Asterooids; starfish

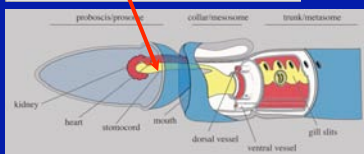
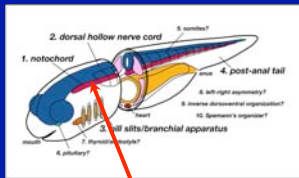
Class: Echinoids; sea urchins



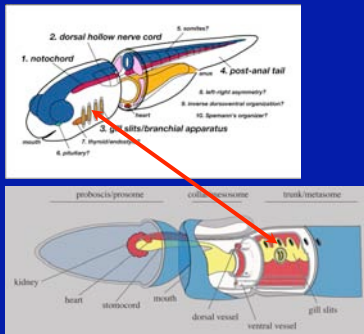
Class: Ophiuroids; brittle stars

Class: Holothuroids; sea cucumbers

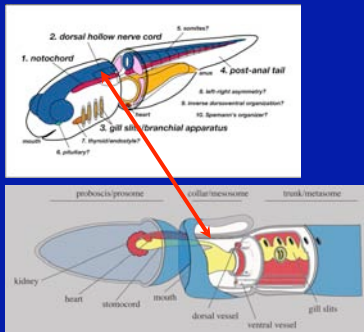
Enter the hemichordates and their not so obvious similarities with chordates



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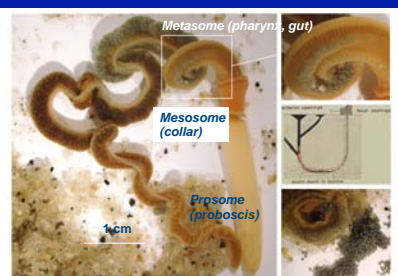


Enter the hemichordates and their not so obvious similarities with chordates



As we shall see, only one of these, gill slits are real homologies

The object of study: the Acorn Worm: *Saccoglossus kowalevskii*





Eggs spawned in the burrows

Encapsulated throughout early development

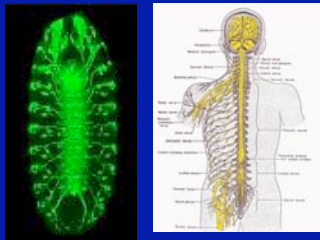


Is this the moment
for the
hemichordates to
make their big
contribution?

Part 1. The origin of the vertebrate nervous system

Marc Kirschner
 Dept. of Systems Biology
 Harvard Medical School
 Boston Massachusetts

The long history of hypotheses on chordate origins focus on the origin of the vertebrate nervous system



Drosophila CNS
 Ventral side

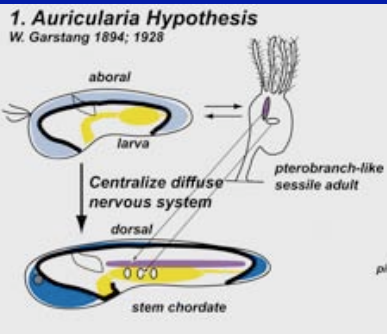
Human CNS
 Dorsal side

The classical hypotheses can be basically divided into two groups - one that reconstructs the ancestor of chordates to a larval life history stage on one that derives chordates from adults.

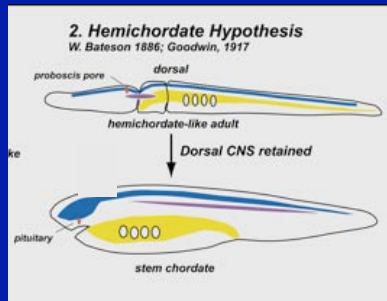
Garstang was very influential and formed the inspiration for a entire school of thought people like Berrill.

Many of these hypotheses are based on the derivation of nervous system.

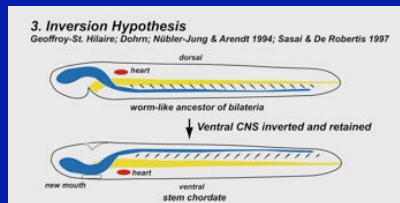
Theories of chordate origins: mostly of historical interest



As a common ancestor for the deuterostome phyla echinoderms (sea urchins and star fish), enteropneusts (hemichordates: acorn worms) and chordates (tunicates, lancelets and vertebrates) Garstang proposed an ancestor resembling an auricularia type echinoderm larva. The auricularia possesses a ciliated ring, directly underlain by a nerve cord. This ciliated ring separates an aboral and an oral epithelial region. During the evolution of the chordate branch, the ciliated ring would shift dorsally and fuse in the mid-dorsal region. The ciliated ring of the auricularia would be homologous to the vertebrate neural ridges. The aboral epithelial field, internalised if the neural ridges fuse, were to evolve into the neural plate. Evidence for this view was found in comparative microscopic anatomy studies between echinoderms, hemichordates and amphioxus. Ultrastructural correspondences were found between the so-called multipolar cells -- part of the larval ciliated band -- of the studied echinoderm and



Due to molecular studies this bizarre one is of great interest

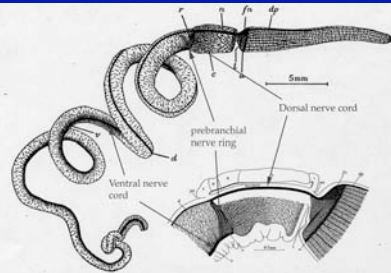


Our experimental strategy

- Find the worms
- Work out the early embryology
- Identify interesting genes
- Examine gene expression
- Design RNAi experiments
- Interpret the results

The organization of the nervous system in *Saccoglossus* is nothing like vertebrates or insects

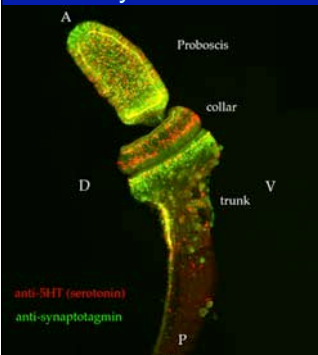
It is a diffuse nerve net
Dorsal and ventral cords are axon tracks



E. Knight-Jones
1952

We have been focusing on nervous system organization as the two cords have been variously proposed as the homologue of the chordate dorsal nerve cord.

The nerve cells are not localized but symmetrical around the body



Early neuronal markers are distributed symmetrically

The top part of the slide shows a diagram of a chordate embryo with a central yellow spot representing the neural plate. Labels 'Chordate' and 'Hemichordate' are above the diagram. Below the diagram is a 2x4 grid of microscopy images showing gene expression patterns in various chordate embryos, including labels like 'not1/2/3' and 'ap1/tenascin'.

Despite the fact that Saccoglossus has no CNS, the patterning genes are expressed in the same pattern as they are in the vertebrate forebrain

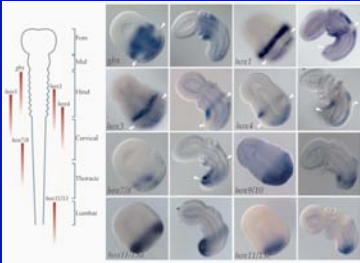
The slide features a 3x4 grid of images. The first column shows schematic diagrams of a mouse brain with regions labeled 'mx', 'mx2-1', and 'bf-1'. The subsequent columns show microscopy images of Saccoglossus embryos at 'early development' and 'late development' stages, with corresponding gene expression patterns labeled 'mx', 'mx2-1', and 'bf-1'.

Though it has no fore or mid brain the geographical markers are there

The slide displays a 4x4 grid of images. The first column contains schematic diagrams of a hemichordate embryo with regions labeled 'i', 'ii', 'ip', and 'd'. The following columns show microscopy images of gene expression patterns in hemichordate embryos, with labels 'pax6', 'bar11', 'irx', and 'otx' corresponding to the regions in the diagrams.

Notice a marked shift in the posterior limit of expression of this group of genes in hemichordates.

For Hox gene expression in more posterior regions the homologies persist



A. Hemichordate

B. Generalized chordate

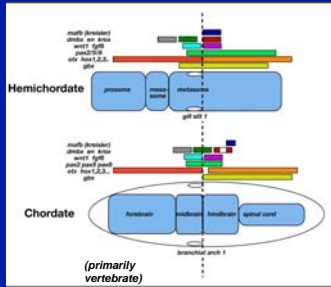
C. Neural plate

A conserved domain map in Hemichordates and Vertebrates

The diagrams show the expression of various Hox genes in three different chordate models. Panel A (Hemichordate) shows genes like Hox1, Hox2, Hox3, Hox4, Hox5, Hox6, Hox7, Hox8, Hox9, Hox10, Hox11, Hox12, Hox13, Hox14, Hox15, and Hox16. Panel B (Generalized chordate) shows Hox1, Hox2, Hox3, Hox4, Hox5, Hox6, Hox7, Hox8, Hox9, Hox10, Hox11, Hox12, Hox13, Hox14, Hox15, Hox16, Hox17, Hox18, Hox19, Hox20, Hox21, Hox22, Hox23, Hox24, Hox25, Hox26, Hox27, Hox28, Hox29, Hox30, Hox31, Hox32, Hox33, Hox34, Hox35, Hox36, Hox37, Hox38, Hox39, Hox40, Hox41, Hox42, Hox43, Hox44, Hox45, Hox46, Hox47, Hox48, Hox49, Hox50, Hox51, Hox52, Hox53, Hox54, Hox55, Hox56, Hox57, Hox58, Hox59, Hox60, Hox61, Hox62, Hox63, Hox64, Hox65, Hox66, Hox67, Hox68, Hox69, Hox70, Hox71, Hox72, Hox73, Hox74, Hox75, Hox76, Hox77, Hox78, Hox79, Hox80, Hox81, Hox82, Hox83, Hox84, Hox85, Hox86, Hox87, Hox88, Hox89, Hox90, Hox91, Hox92, Hox93, Hox94, Hox95, Hox96, Hox97, Hox98, Hox99, Hox100. Panel C (Neural plate) shows Hox1, Hox2, Hox3, Hox4, Hox5, Hox6, Hox7, Hox8, Hox9, Hox10, Hox11, Hox12, Hox13, Hox14, Hox15, Hox16, Hox17, Hox18, Hox19, Hox20, Hox21, Hox22, Hox23, Hox24, Hox25, Hox26, Hox27, Hox28, Hox29, Hox30, Hox31, Hox32, Hox33, Hox34, Hox35, Hox36, Hox37, Hox38, Hox39, Hox40, Hox41, Hox42, Hox43, Hox44, Hox45, Hox46, Hox47, Hox48, Hox49, Hox50, Hox51, Hox52, Hox53, Hox54, Hox55, Hox56, Hox57, Hox58, Hox59, Hox60, Hox61, Hox62, Hox63, Hox64, Hox65, Hox66, Hox67, Hox68, Hox69, Hox70, Hox71, Hox72, Hox73, Hox74, Hox75, Hox76, Hox77, Hox78, Hox79, Hox80, Hox81, Hox82, Hox83, Hox84, Hox85, Hox86, Hox87, Hox88, Hox89, Hox90, Hox91, Hox92, Hox93, Hox94, Hox95, Hox96, Hox97, Hox98, Hox99, Hox100.

Important signaling centers are conserved- eg. the vertebrate midbrain-hindbrain boundary in a brainless hemichordate

The remarkable ancestry of the midbrain-hindbrain boundary



The hemichordate pattern is more vertebrate-like than amphioxus or ascidians. Yet the hemichordate has nothing resembling a midbrain or hindbrain...

Conclusions

- Conservation of transcriptional pattern despite the fundamental organizational differences
- Patterning genes are not reliable markers of any specific neuroanatomical organization
- Much of the regulatory networks involved in vertebrate brain regionalization were established early in deuterostome history.
- Nerve nets may be complex

Are we correct to think that a decentralized nervous system was the ancestral state?

Or did centralization occur once in an early ancestor and did the vertebrates merely shift the dorsal/ventral axis?

