Regeneration in hydra

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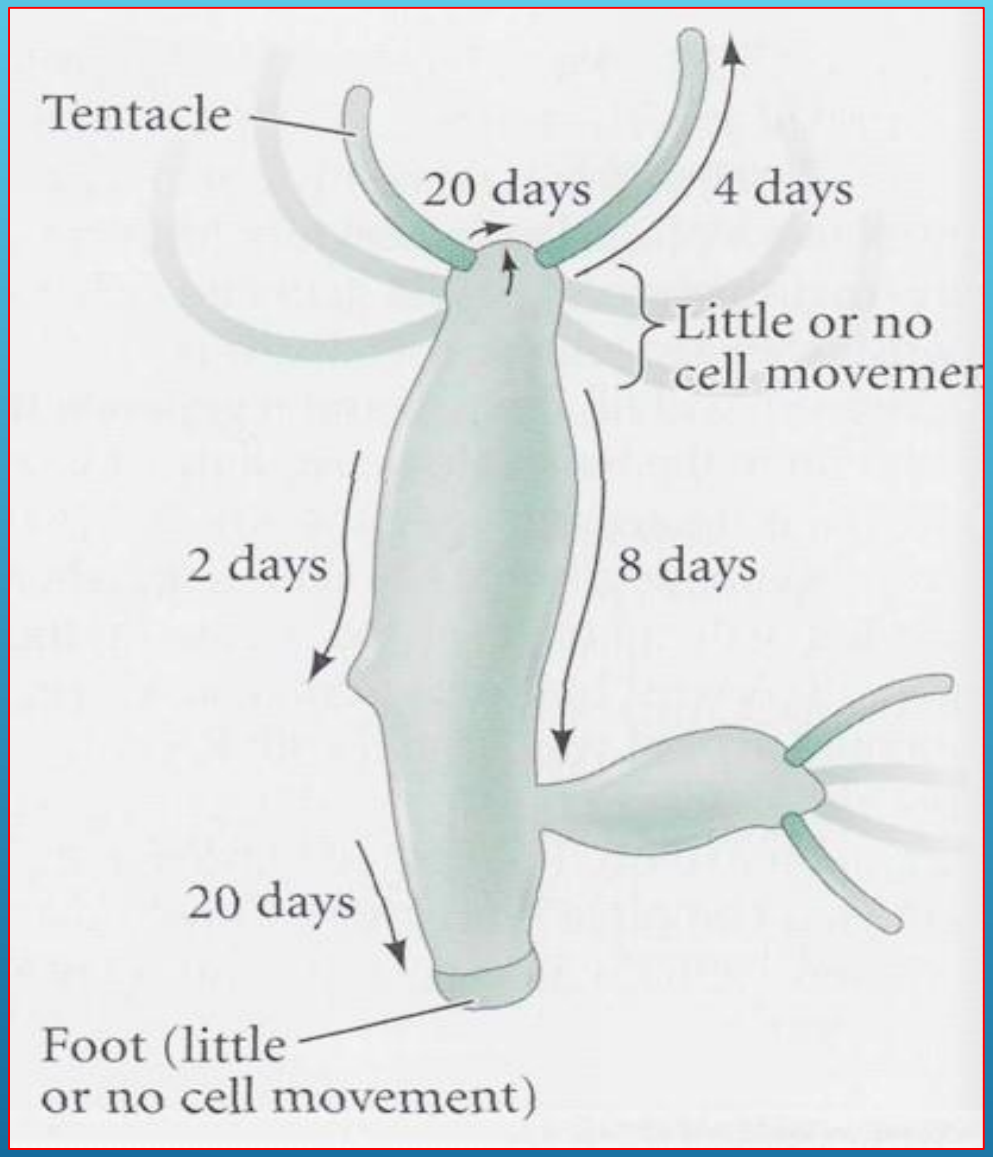
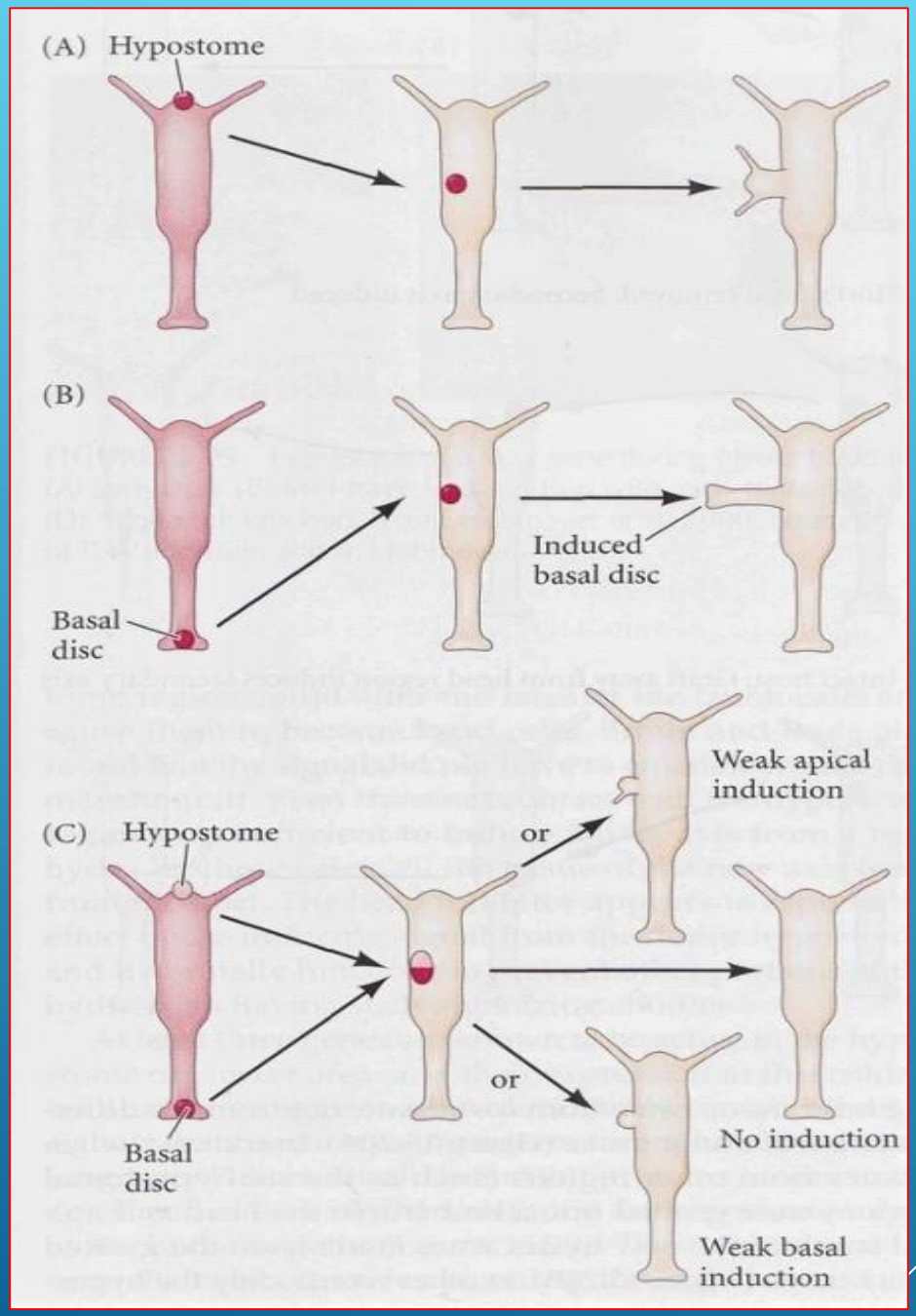
Introduction

Hydra is a diploblastic freshwater cnidarian that has a head at its distal end and a foot at its proximal end. The foot or basal disc allows the animal to stick to the rocks or plants. The head consists of a canonical hypostome (containing the mouth) and a ring of tentacles beneath it. Cell movements is found in hydra throughout the entire body except two extremities. The cells of the body column are constantly undergoing mitosis and are eventually displaced to the extremities of the column, from which they are shed.


Tentacle
20 days
4 days
Little or no
cell movemer
2 days
8 days
20 days
Foot (little
or no cell movement)

Existence of a head activation and foot activation gradients

Every portion of the hydra body column along the apical-basal axis is potentially able to form both a head and a foot. However, the polarity of the hydra is coordinated by a series of morphogenetic gradients that permit the head to form only at one place and the basal disc to form only at another place. Evidence for such gradients was first obtained from grafting experiments begun by Ethel Browne in early 1900s. When hypostome tissue from one hydra is transplanted into the middle of another hydra, the transplanted tissue forms a new apical-basal axis, with the hypostome extending outward. When a basal disc is grafted to the middle of a host hydra, a new axis also forms, but with the opposite polarity, extending a basal disc. When tissues from both ends are transplanted simultaneously into the middle of a host, no new axis is formed, or the new axis has little polarity. These experiments have been interpreted to indicate the existence of a head activation (highest at the hypostome) and a foot activation gradient (highest at the basal disc).

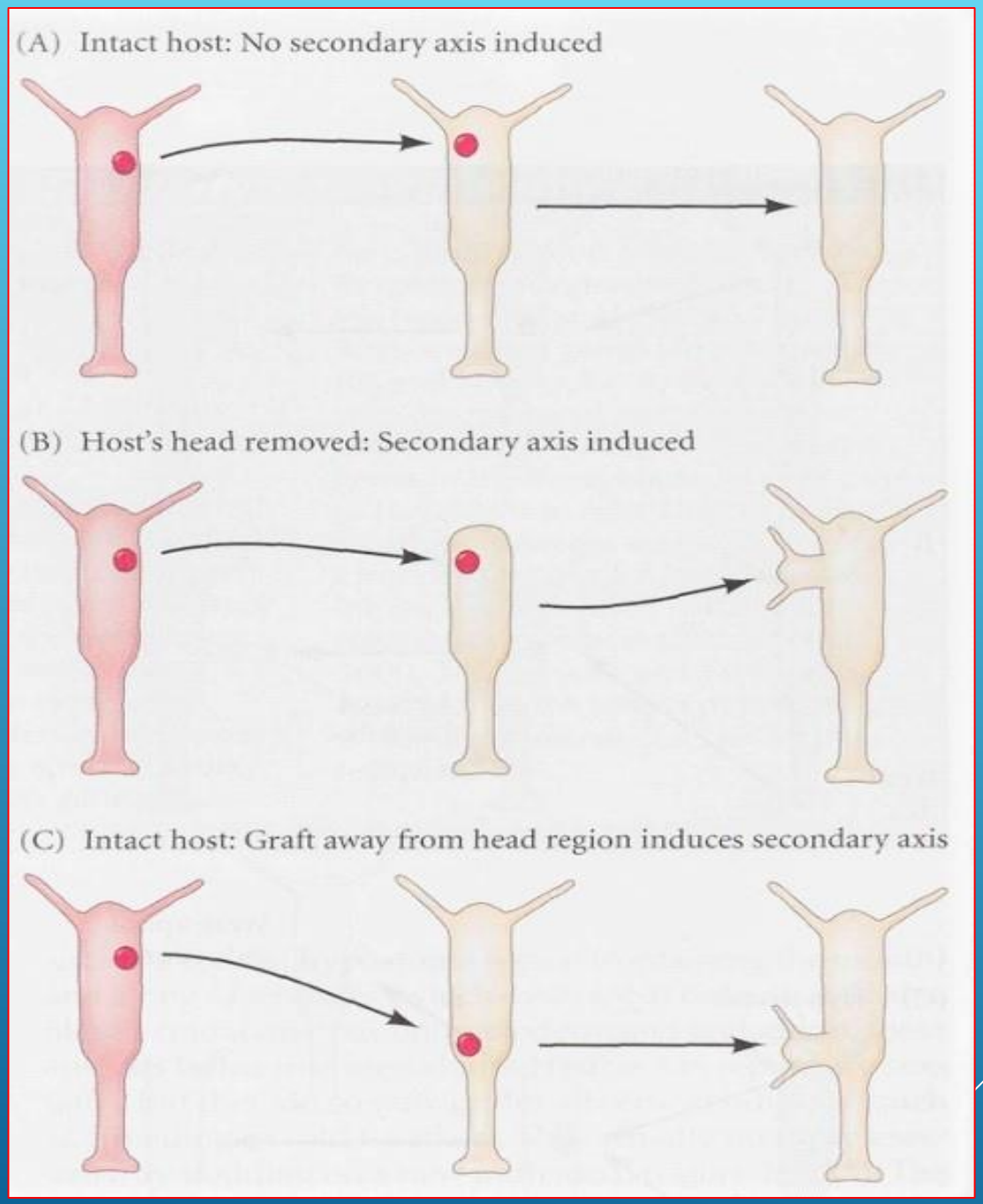

(A) Hypostome
(B)
Induced basal disc
Basal disc
(C) Hypostome
or
Weak apical induction
or
No induction
Basal disc
Weak basal induction

Head activation molecules

The head activation gradient can be measured by implanting rings of tissue from various levels of a donor hydra into a particular region of the host trunk. The higher the levels of head activator in the donor tissue, the greater the percentage of implants that will induce the new heads. The head activation factor is concentrated in the head and decreases linearly toward the basal disc. Three peptides have been associated with this head activation gradient. Two of them, Heady and Head Activator, are critical for head formation and the initiation of the bud. The other, Hym301, regulates the number of tentacles.

Head inhibition gradient

The tissues of hydra body column can form a head, but it is impossible if there is already an intact head. In 1926, Rand et al. showed that normal regeneration of the hypostome is inhibited when an intact hypostome is grafted adjacent to the amputation site. Moreover, if a graft of sub-hypostomal tissue (region just below the hypostome, where there is a relatively high concentration of head activator) is placed in the same region of a host hydra, no secondary axis is formed. The host head appears to make an inhibitor that prevents the grafted tissue from forming a head and secondary axis. However, if subhypostomal tissue is grafted to a decapitated host hydra, a second axis is formed. A gradient of this inhibitor appears to extend from the head down the body column and can be measured by grafting subhypostomal tissue into various regions along the trunk of host hydra. This tissue will not produce a head when implemented into the apical area of an intact host hydra, but it will form a head if placed lower on the host. Thus, there is a gradient of head inhibitor as well as head activator.


(A) Intact host: No secondary axis induced
(B) Host's head removed: Secondary axis induced
(C) Intact host: Graft away from head region induces secondary axis

Hypostome acts as an organizer

Ethel Browne noted that the hypostome acted as an organizer of the hydra. This notion has been confirmed by Broun and Bode (2002), who demonstrated that……

When transplanted, the hypostome can induce host tissue to form a second body axis.

The hypostome produces both the head activation and head inhibition signals.

The hypostome is the only self-differentiating region of the hydra

The head inhibition signal is actually a signal to inhibit the formation of new organizing centers.

Broun and Bode's experiments

By inserting small pieces of hypostome tissue into a host hydra whose cells were labeled with India ink, Broun and Bode found that the hypostome induced a new body axis and that almost all of the resulting head tissue came from host tissue, not from the differentiation of donor tissue. In contrast, when tissues from other regions (such as subhypostomal region) were grafted into a host trunk, the head and apical trunk of the new hydra were made from grafted donor tissue. In other words, only the hypostome region could alter the fates of the trunk cells and cause them to become head cells. Broun and Bode also found that the signal did not have to emanate from a permanent graft. Even transient contact with the hypostome region was sufficient to induce a new axis from a host hydra. In these cases, all the tissues of the new axis came from the host. The head inhibitor appears to repress the effect of the inducing signal from the donar hypostome, and it normally functions to prevent other portions of the hydra from having such organizing abilities.

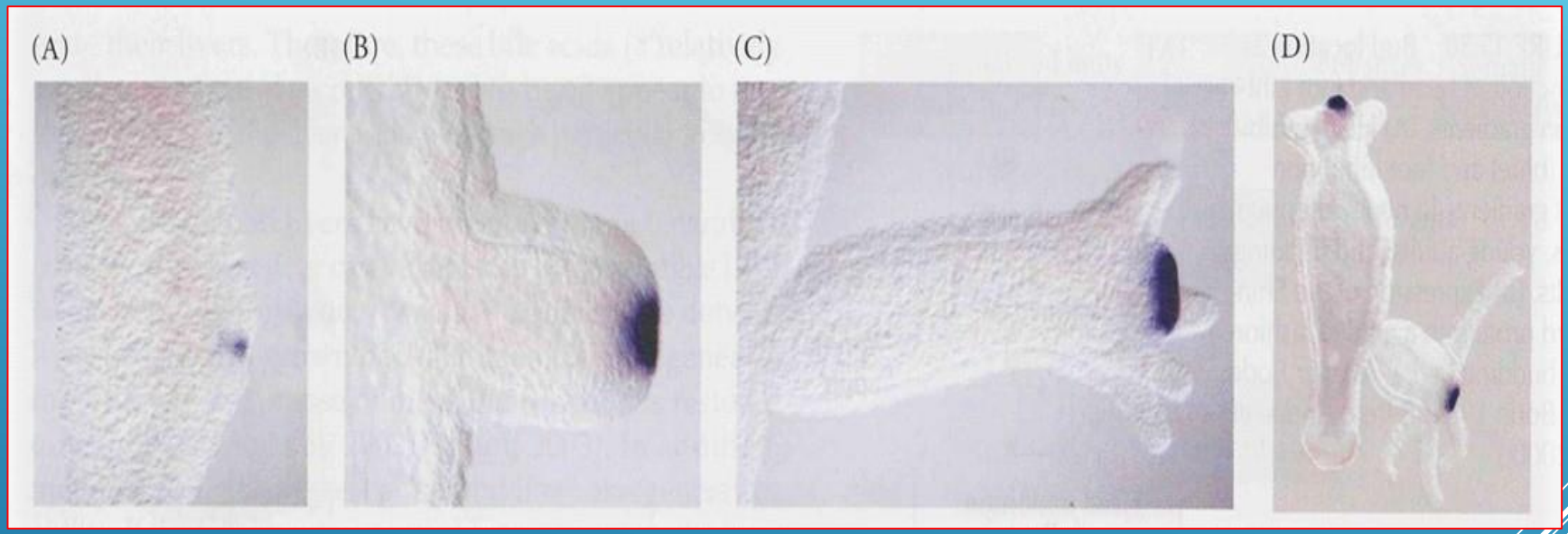
Genes in hypostome that provide organizing activity

At least three genes are known to be active in hypostome organizing area and their expression in hydra suggests an evolutionarily conserved set of signals that functions as organizers throughout the animal kingdom.

1st, A set of Wnt proteins is seen in apical end of the early bud, defining hypostome region as the bud elongates. These proteins act to form the head organizer: signaling through canonical Wnt pathway, they inhibit GSK3 to stabilize β-catenine in the cell nucleus. If GSK3 is inhibited throughout the body axis, ectopic tentacles form at all levels, and each piece of the trunk has the ability to stimulate the outgrowth of new buds.

2nd, The expression of another vertebrate organizer molecule Goosecoid, is restricted to the hypostome region.

3rd, Moreover, when the hypostome is brought into contact with the trunk of an adult hydra, it induces expression of the Brachyury gene, just as vertebrate organizers do – even though hydras lack mesoderm.

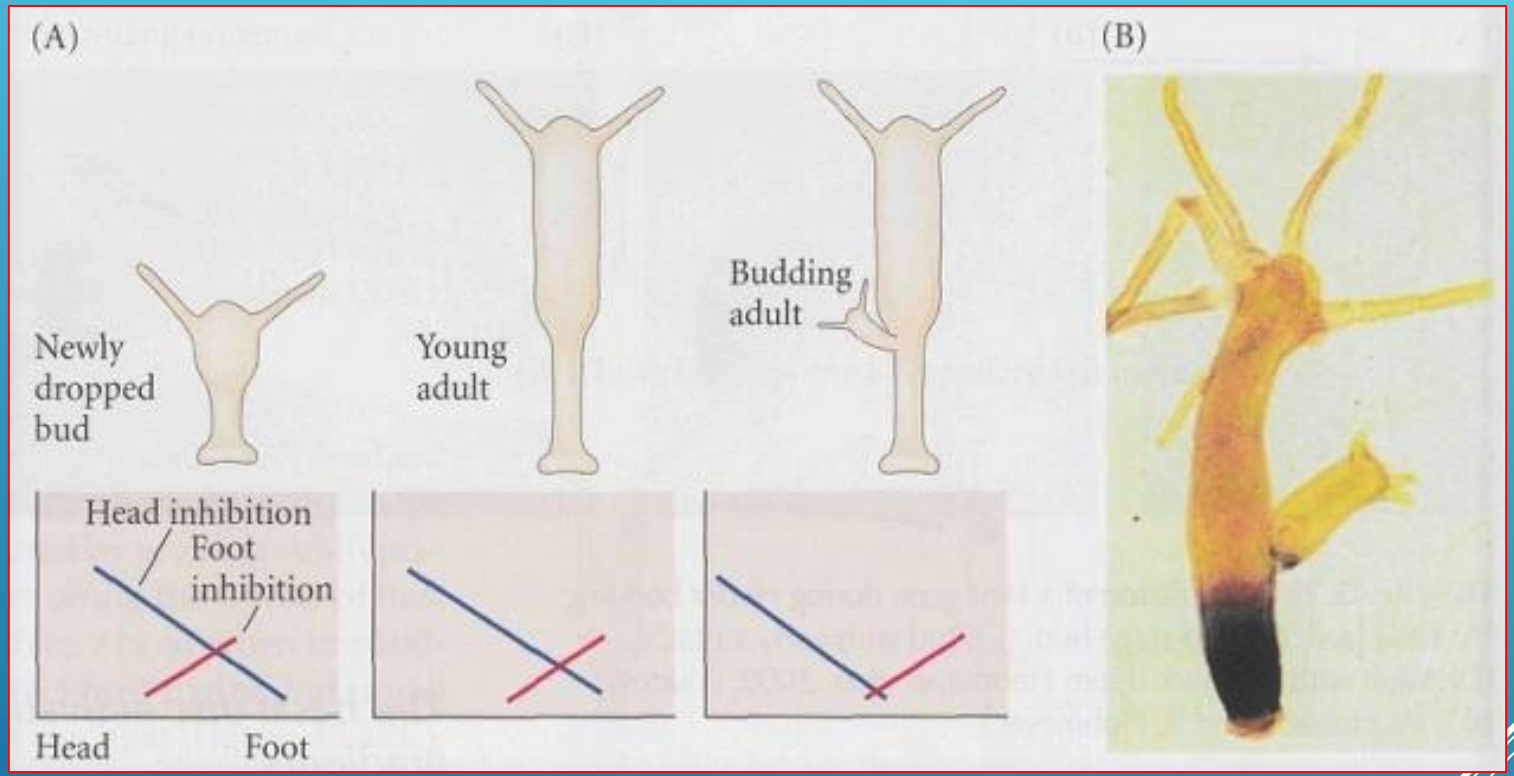

(A)
(B)
(C)
(D)

Foot activation and foot inhibition gradients

Certain properties of the basal disc suggest that it is the source of both a foot activation gradient and a foot inhibition gradient. The inhibition gradients for the head and the foot may be important in determining where and when a bud can form. In young hydra, the gradients of head and foot inhibitors appear to block bud formation. However, as the hydra grows, the sources of these labile substances grow farther apart, creating a region of tissue about two-thirds down the trunk where the levels of both inhibitors are minimal. This region is where the bud forms.

Molecular gradient that establishes the foot formation

Several small peptides have been found to activate foot formation and researchers are just beginning to sort out the mechanisms by which these proteins arise and function. However, the specification of cells as they migrate from the basal region through the body column may be mediated by a gradient of tyrosine kinase. The product of the shinguard gene is a tyrosine kinase that extends in a gradient from the ectoderm just above the basal disc through the lower region of the trunk. Buds appear to form where this gradient fades. The shinguard gene appears to be activated through the product of the manacle gene, a putative TF that is expressed earlier in the basal disc ectoderm.


(A)
Newly dropped bud
Young adult
Budding adult
Head inhibition
Foot inhibition
Head
Foot
(B)