DSE-1BT: Developmental aspects of embryo

Gastrulation:

❖ Gastrulation

Gastrulation is the process during embryonic development that changes the embryo from a blastula with a single layer of cells to a gastrula containing multiple layers of cells. Gastrulation typically involves the blastula folding in upon itself or dividing, which creates two layers of cells. Organisms that do not form a third layer are known as *diploblastic* organisms. These include the jellyfish and related animals. Triploblastic organisms contain a third layer, the **mesoderm**, which is created from one of the first two layers. Triploblastic organisms account for the majority of higher animals.

The layers created by gastrulation become germ layers, or special tissues that give rise to specific parts of the organism. These germ layers always give rise to the same types of tissues. The **endoderm** will give rise to the gut and associated organs. The **ectoderm** is the outermost layer, and will create the skin and the nervous system. Between them lies the mesoderm, which will created the connective tissues and musculature in most organisms.

❖ Concept of induction

Organs are complex structures composed of numerous types of tissues. In the vertebrate eye, for example, light is transmitted through the transparent corneal tissue and focused by the lens tissue (the diameter of which is controlled by muscle tissue), eventually impinging on the tissue of the neural retina. The precise arrangement of tissues in this organ cannot be disturbed without impairing its function. Such coordination in the construction of organs is accomplished by one group of cells changing the behavior of an adjacent set of cells, thereby causing them to change their shape, mitotic rate, or fate. This kind

of interaction at close range between two or more cells or tissues of different history and properties is called proximate interaction, or **induction**. There are at least two components to every inductive interaction. The first component is the inducer: the tissue that produces a signal (or signals) that changes the cellular behavior of the other tissue. The second component, the tissue being induced, is the responder.

Not all tissues can respond to the signal being produced by the inducer. For instance, if the optic vesicle (presumptive retina) of *Xenopus laevis* is placed in an ectopic location (i.e., in a different place from where it normally forms) underneath the head ectoderm, it will induce that ectoderm to form lens tissue. Only the optic vesicle appears to be able to do this; therefore, it is an inducer. However, if the optic vesicle is placed beneath ectoderm in the flank or abdomen of the same organism, that ectoderm will not be able to respond. Only the head ectoderm is competent to respond to the signals from the optic vesicle by producing a lens.

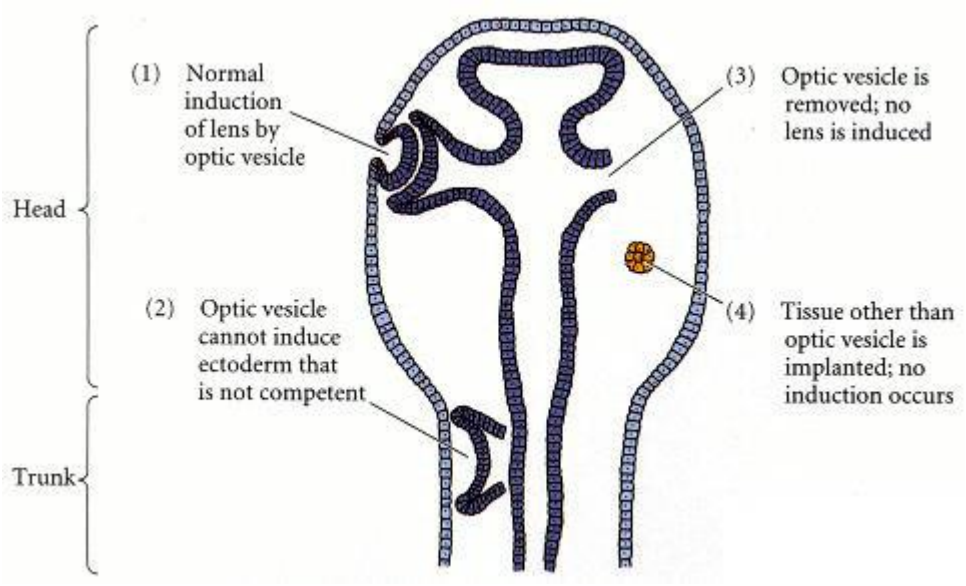

Figure: Ectodermal competence and the ability to respond to the optic vesicle inducer in *Xenopus.* (1) The optic vesicle is able to induce lenses in the anterior portion of the ectoderm, but not in the presumptive trunk and abdomen (2). If the optic vesicle is removed (3), the surface ectoderm forms either an abnormal lens or no lens at all. (4) Most other tissues are not able to substitute for the optic vesicle.

Thus, there is no single inducer of the lens. Studies on amphibians suggest that the first inducers may be the pharyngeal endoderm and heart-forming mesoderm that underlie the lens-forming ectoderm during the early- and mid-gastrula stages. The anterior neural plate may produce the next signals, including a signal that promotes the synthesis of Pax6 in the anterior ectoderm. Thus, the optic vesicle appears to be *the* inducer, but the anterior ectoderm has already been induced by at least two other factors. (The situation is like that of the player who kicks *the* "winning goal" of a soccer match.) The optic vesicle appears to secrete two induction factors, one of which is BMP4, a protein that induces the transcription of the Sox2 and Sox3 transcription factors (and another, as yet unidentified, signal that induces the appearance of the L-Maf transcription factor. The combination of Pax6, Sox2, Sox3, and L-Maf ensures the production of the lens.

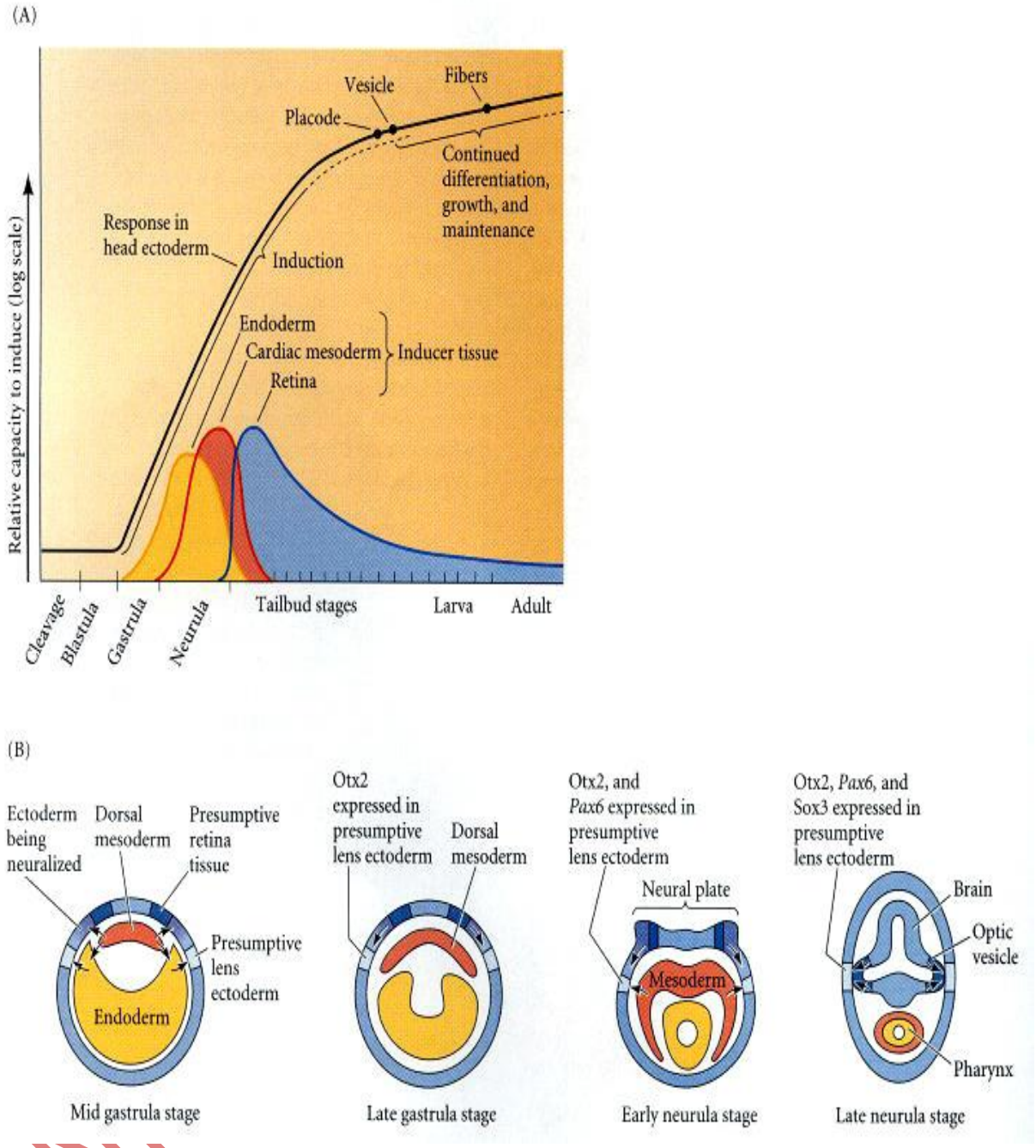

Figure: Lens induction in embryonic amphibians. (A) The additive effects of inducers, as shown by transplantation and extirpation (removal) experiments on the salamander *Tarichosa torosa*. The ability to produce lens tissue is first induced by pharyngeal endoderm, then by cardiac mesoderm, and finally by the optic vesicle. The competence of the lens ectoderm to respond to these inducers increases logarithmically from the early gastrula through the tailbud larval stages. (B) Sequence of induction postulated by similar experiments performed on embryos of the frog *Xenopus laevis*. Unidentified inducers (possibly from the pharyngeal endoderm and heart-forming mesoderm) cause the synthesis of the Otx-2 transcription factor in the head ectoderm during the late gastrula stage. As the neural folds rise, inducers from the anterior neural plate

(including the region that will form the retina) induce *Pax6* expression in the anterior ectoderm that can form lens tissue. Expression of the Pax6 transcription factor may constitute the competence of the surface ectoderm to respond to the optic vesicle during the late neurula stage. The optic vesicle secretes factors (probably of the BMP family) that induce the synthesis of the Sox transcription factors and initiate observable lens formation.

❖ Competence

This ability to respond to a specific inductive signal is called **competence**. Competence is not a passive state, but an actively acquired condition. For example, in the developing chick and mammalian eye, the Pax6 protein appears to be important in making the ectoderm competent to respond to the inductive signal from the optic vesicle. Pax6 expression is seen in the head ectoderm, which can respond to the optic vesicle by forming lenses, and it is not seen in other regions of the surface ectoderm. Moreover, the importance of Pax6 as a **competence factor** was demonstrated by recombination experiments using embryonic rat eye tissue. The homozygous Pax6-mutant rat has a phenotype similar to the homozygous Pax6-mutant mouse, lacking eyes and nose. It has been shown that part of this phenotype is due to the failure of lens induction. But which is the defective component—the optic vesicle or the surface ectoderm? When head ectoderm from Pax6-mutant rat embryos was combined with a wild-type optic vesicle, no lenses were formed. However, when the head ectoderm from wild-type rat embryos was combined with a Pax6-mutant optic vesicle, lenses formed normally. Therefore, Pax6 is needed for the surface ectoderm to respond to the inductive signal from the optic vesicle. The inducing tissue does not need it. It is not known how Pax6 becomes expressed in the anterior ectoderm of the embryo, although it is thought that its expression is induced by the anterior regions of the neural plate. Competence to respond to the optic vesicle inducer can be conferred on ectodermal tissue by incubating it next to anterior neural plate tissue.

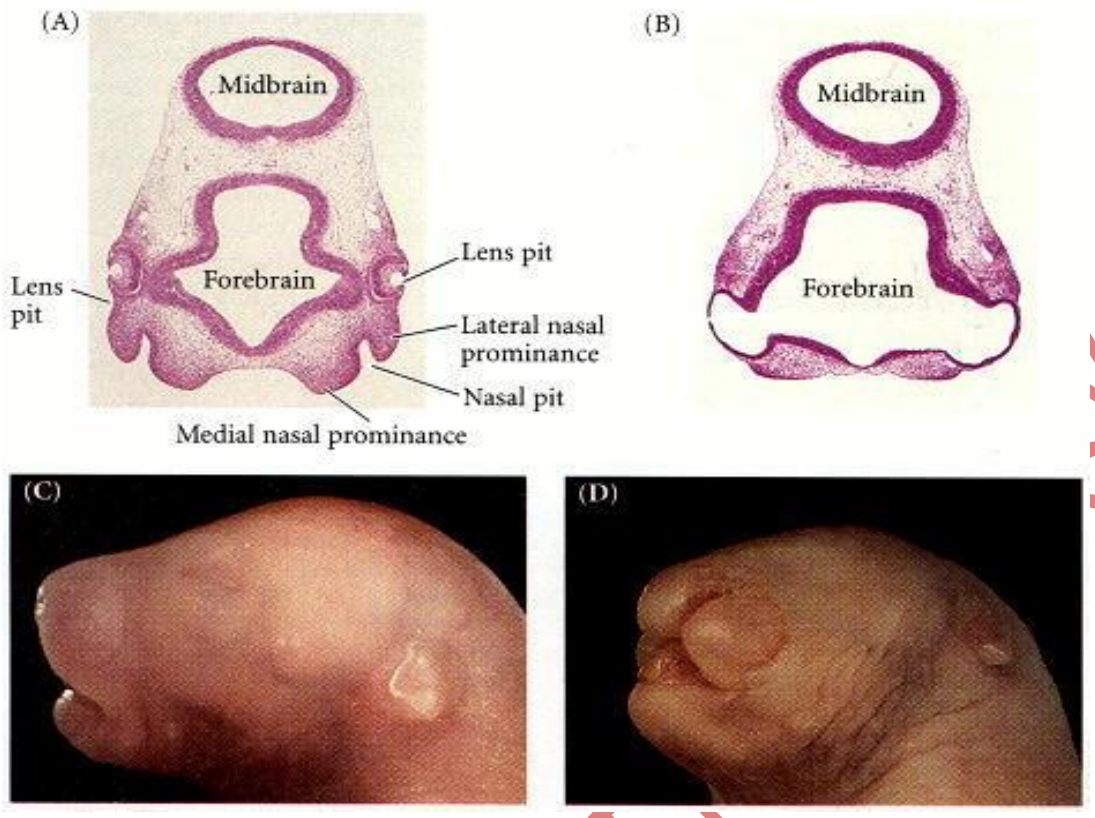

Figure: Induction of optic and nasal structures by Pax6 in the rat embryo. (A, B) Histology of wild-type (A) and homozygous *Pax6* mutant (B) embryos at day 12 of gestation shows induction of lenses and retinal development in the wild-type embryo, but neither lens nor retina in the mutant. Similarly, neither the nasal pit nor the medial nasal prominence is induced in the mutant rats. (C) Newborn wild-type rats show prominent nose as well as (closed) eyes. (D) Newborn *Pax6* mutant rats show neither eyes nor nose.