C8545 Developmental Biology
Lesson 3

Early Development of Amphibians and Amniotes

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INVESTICE DO ROZVOJE VZDĚLÁVÁNÍ
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Evropským sociálním fondem
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Outline of Lesson 3

Early Development of Amphibians and Amniotes

- Oogenesis in amphibians
- Blastula formation and dorsoventral axis fomation in amphibians
  - cleavage of *Xenopus* zygote (video)
- Gastrulation
  - gastrulation of amphibians (video)
- Neurulation
  - neurulation in *Xenopus* (video)
- Oogenesis in amniotes - chicken
- Gastrulation in amniotes – chicken
  - early and late gastrulation in chicken (video)

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- Gastrulation in amniotes – chicken
  - early and late gastrulation in chicken (video)
- Formation of extraembryonic tissues in amniotes – chicken

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- Oogenesis in amphibians

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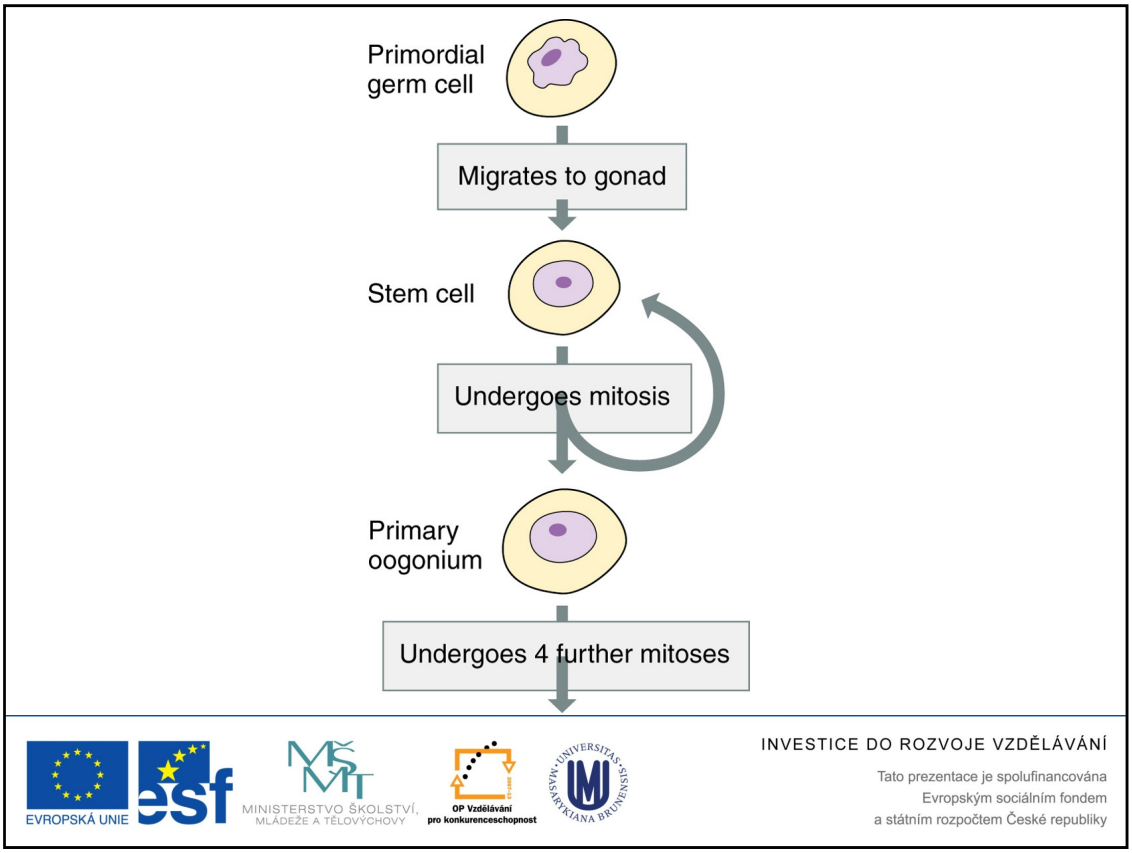
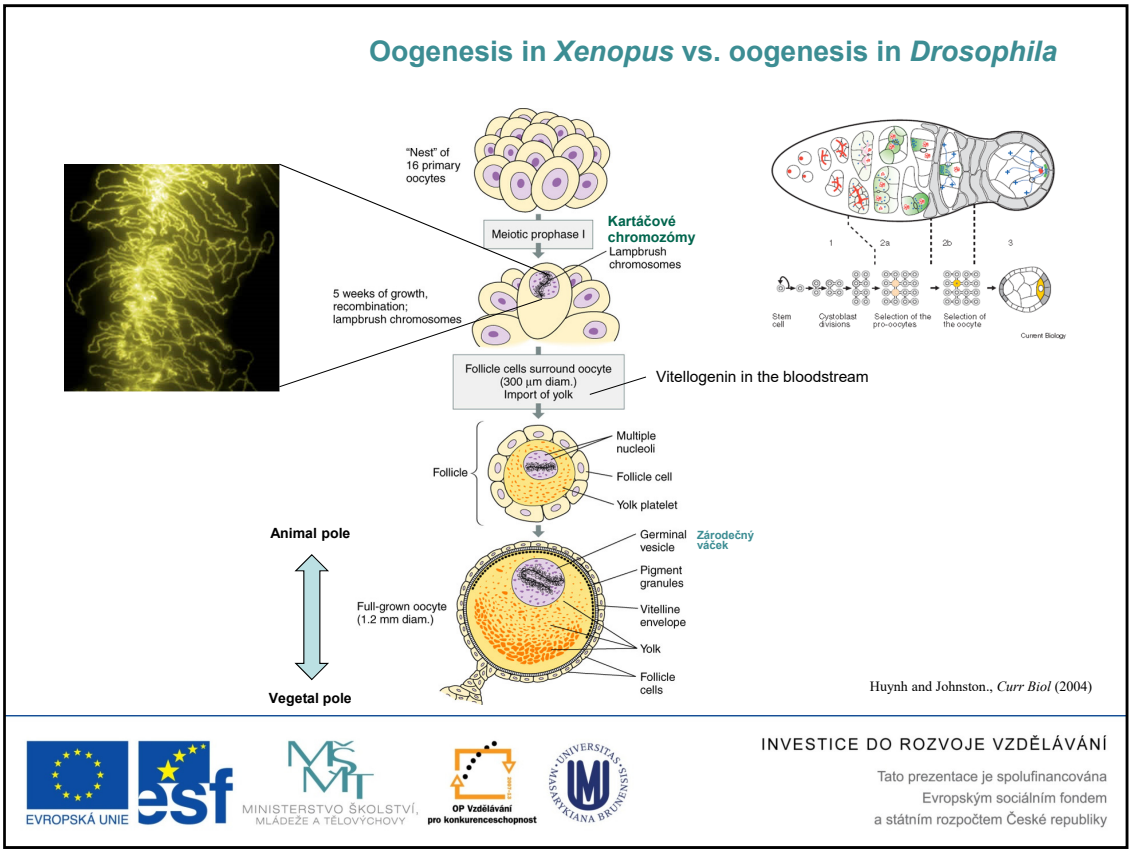


Oogonia, the germ cells in the ovary of amphibians, undergo mitosis, allowing to increase the cell number around 10.000 times.

In humans, the oogonia form limited population that does not undergo mitosis, while in frogs, the oogonia divide, allowing thus formation of many thousands of eggs during annual breeding season. Thus, the frogs oogonia are real ***stem cells*** that is not the case in humans

Primary oogonium undergoes 4 additional rounds of mitosis, leading to formation of nest of 16 cells, connected via cytoplasmic bridges.



These cells start to grow, enter meiosis and are called *primary oocytes*. In contrast to *Drosophila*, where only one of the oogonium progeny (oocyte) will undergo meiosis (see the inset on the right-hand side and the Lesson 02), here all 16 cells will develop into complete egg. The nucleus of oocytes is called *germinal vesicle* (similarly to *Drosophila)*.

During extended prophase I (about 2 weeks) the recombination occurs.

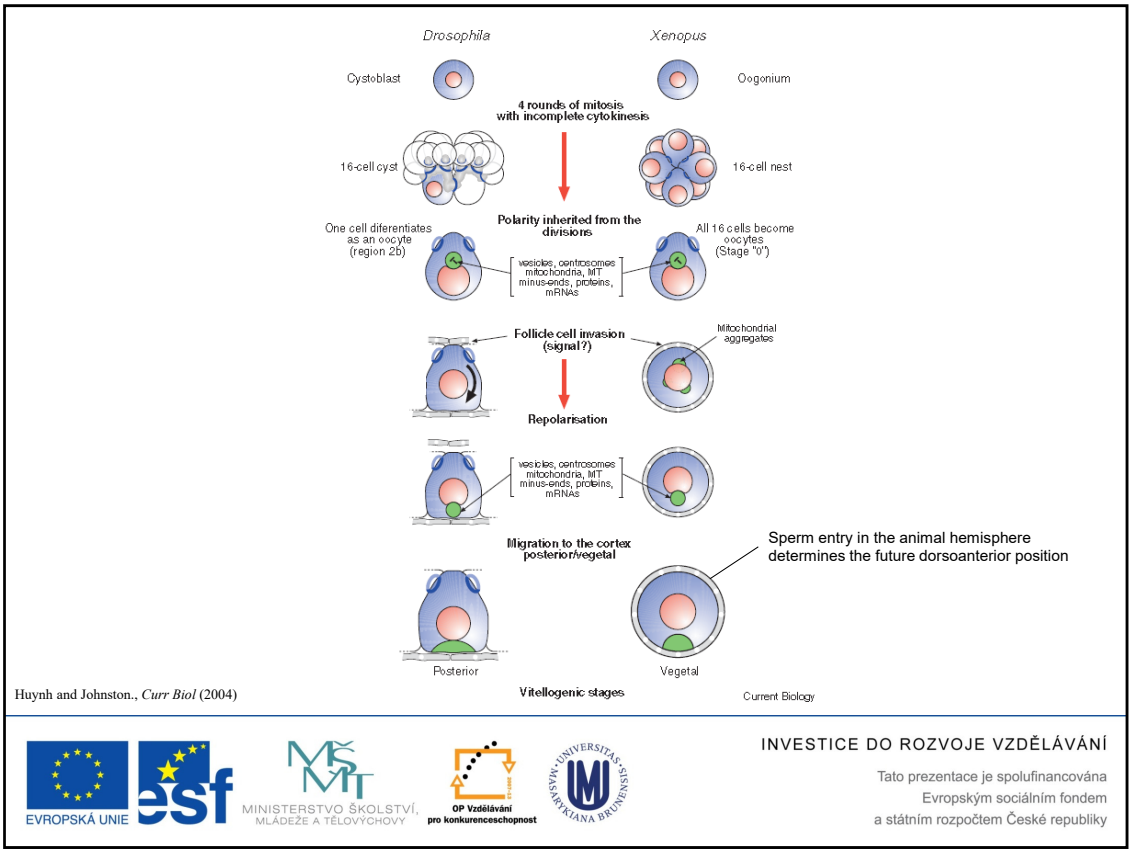
Chromosomes get uncoiled and will develop into brush-like form - they are called the *lampbrush chromosomes*. These uncoiled chromosome regions contain the transcriptionally active DNA that allows high level of RNA production needed for oocyte growth (see also later).

Each primary oocyte becomes surrounded by follicle cells, the chromosomes recompact and the yolk becomes stored. Yolk is produced in the liver and yolk precursor *vitellogenin* is transported by bloodstream.

In the oocyte, vitellogenin is processed to the yolk platelets.

There is apparent polarity in the oocyte. The nucleus is located in the hemisphere containing more pigment granules, at the **animal pole**, while yolk accumulates at the opposite, **vegetal pole**.

There is no anterioposterior axis formed yet, however, there is apparent animal-vegetal pole asymmetry. The vegetal pole corresponds to the position of previously formed cytoplasmic bridge.



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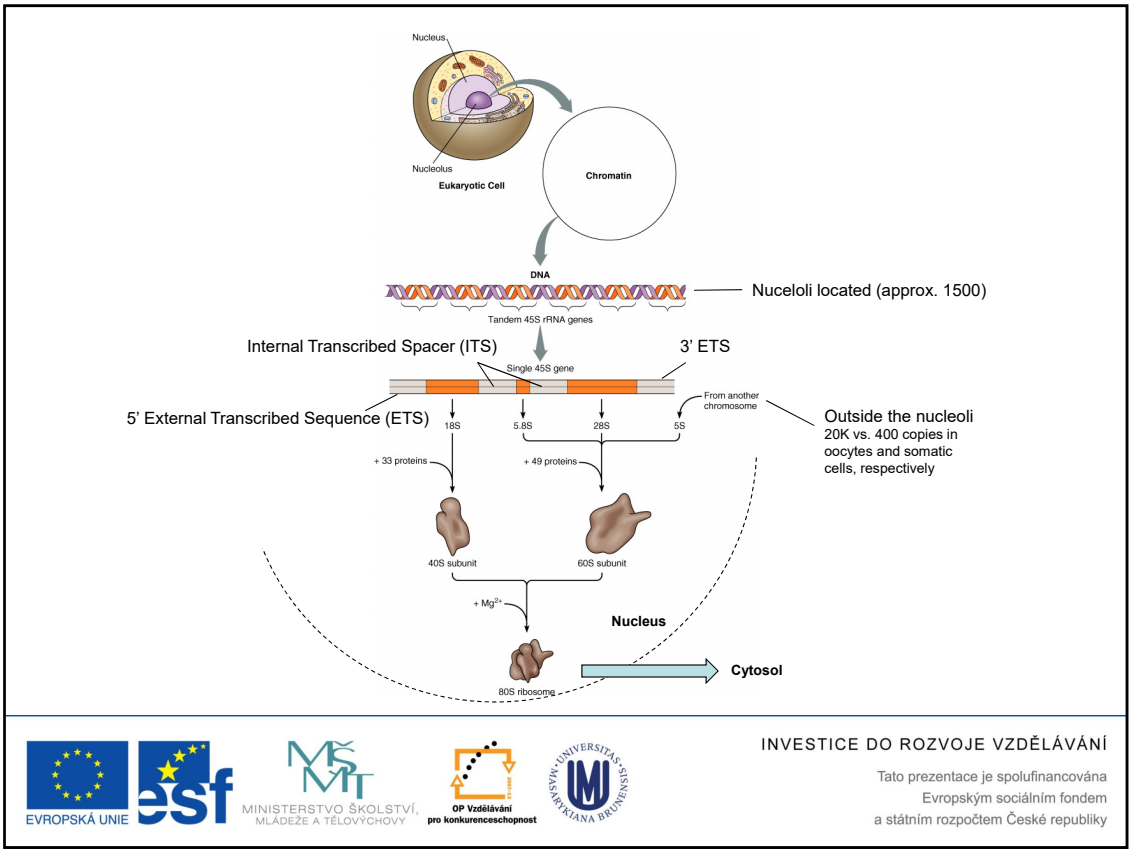
The mechanisms of the oocyte polarization and early axis formatioon are conserved in *Drosophila* and vertebrates as discussed in the previous lesson. The figure above shows similarities between the early steps of *Drosophila* and *Xenopus* oogenesis.

In both *Drosophila* and *Xenopus*, the oocyte inherits an anterior–posterior axis of symmetry from the cyst divisions.

Specific cytoplasmic components (green) accumulate in a depression above the nucleus (red). The oocyte then polarises along this axis when the somatic follicle cells surround it. It is suggested that a signal coming from the follicle cells may trigger this polarisation.

This polarisation is clearly seen in *Drosophila* with the translocation of specific cytoplasmic proteins, mRNAs and the centrosomes to the posterior of the oocyte (black arrow). The situation is less clear in *Xenopus*, as the cell rounds up and seems to lose any polarity. However, it is proposed that the same components that were located above the nucleus after the cyst division, are now part of the Balbiani body on the vegetal side (green sphere).

At the following stage, these components migrate to the posterior/vegetal cortex of the oocyte. This has been clearly demonstrated in *Xenopus*, and is here hypothesized for *Drosophila* . Both oocytes then enter the vitellogenic stages (Huynh and Johnston., *Curr Biol* , 2004).



The tremendous growth of the amphibian egg (1,3 mm in *Xenopus*) is ensured by the synthesis of the proteins that are produced on multiple ribosomes (thus, not imported from nurse cells like is the case of *Drosophila*).

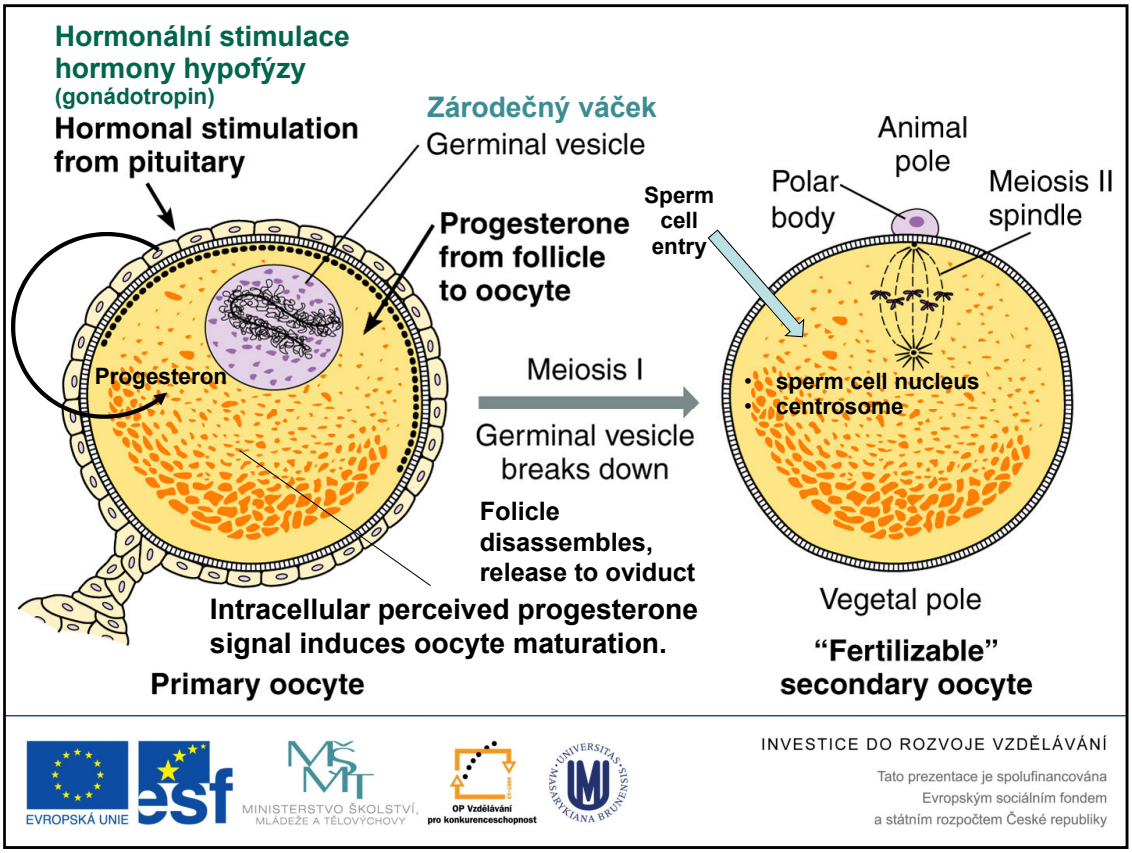
For that purpose, the genes encoding ribosomal RNA (rRNA) are amplified specifically in the egg (genes for 28S,18S and 5.8S rRNA are located in1500 extra nucleoli in the egg).

28S,18S and 5.8S rRNA are encoded by single 45S rRNA gene. 45S rRNA contains **ITS** (for **I**nternal **T**ranscribed **S**pacer) that refers to a piece of non-functional RNA situated between structural ribosomal RNAs (rRNA) on a common precursor transcript.

Read from 5' to 3', this polycistronic rRNA precursor transcript contains the 5' external transcribed sequence (5' ETS), 18S rRNA, ITS1, 5.8S rRNA, ITS2, 26S rRNA and finally the 3'ETS. During rRNA maturation, ETS and ITS pieces are excised and as non-functional maturation by-products rapidly degraded.

In case of 5s rRNA (which are not located in nucleoli), specific genes for 5sRNA are activated in the egg (there is a specific sequence of those egg-specific 5s RNAs, which are of 19,600 copies in comparison to approx. 400 copies of somatic cell 5s rRNA genes.

The number of nucleoli increases. In nucleoli, the ribozomal RNA genes are located, transcribed, new ribozomes are assembled and transported to the cytosol.



The fully grown oocyte resides in the ovary. External conditions affect production of pituitary gonadotropins, which induce production of progesterone by the follicle cells.

Progesterone signal is sensed by the specific receptors in the oocyte and induces **oocyte maturation.**

Germinal vesicle breaks down, the nucleolema disintegrates and meiosis I proceeds.

Follicle disassembles and mature oocyte is released to the oviduct, transported to cloaca and spawned. In *Xenopus*, the fertlization takes place in the prophase of meiosis II.

Spermatogenesis takes place in the seminiferous tubules of the male. Spermatogonia act as stem cells, mitotic descendants differentiate and enter meiosis, forming thus four haploid spermatids.

Most of the information at the time of fertlization resides in the cytoplasm of the egg. Besides its DNA, sperm cell contributes centrosome.

Acquiring of centrosome is sufficient to activate further development events in the haploid egg. However, amphibian eggs are easy to activate even via pricking with the pin.

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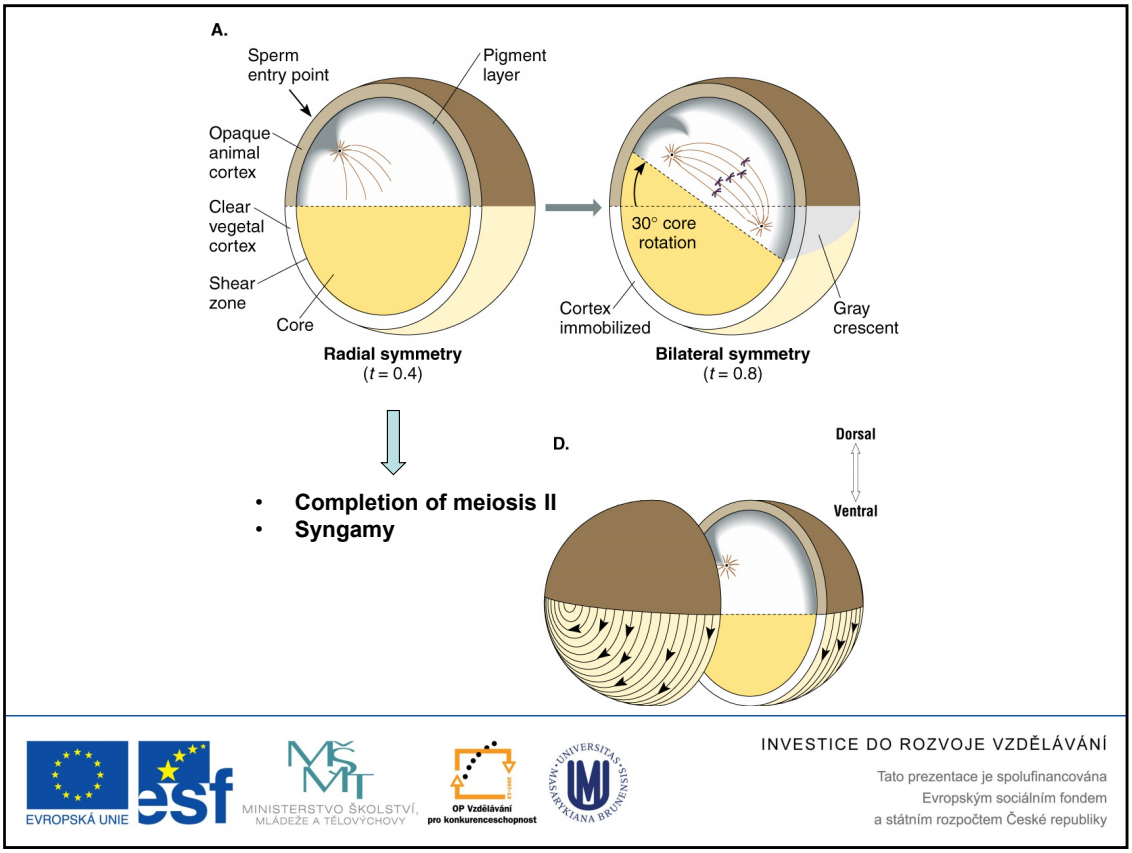
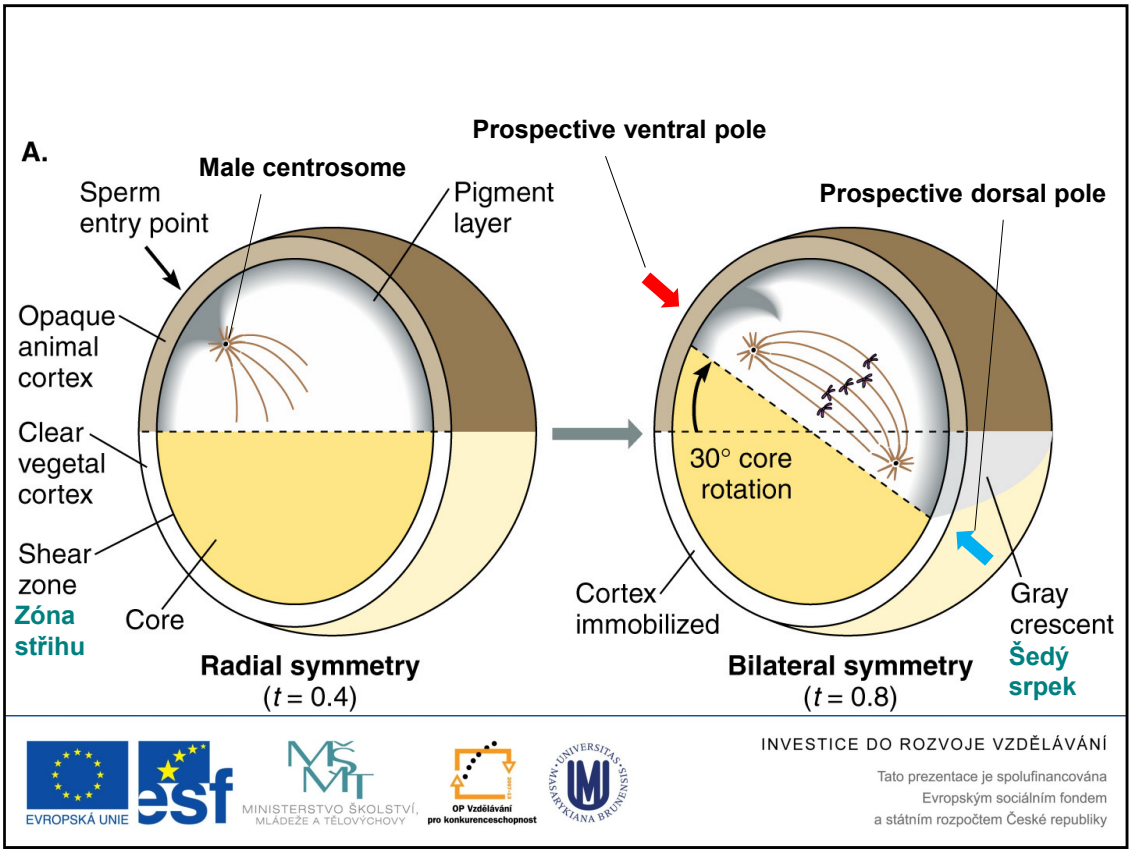


Just before fertlization, sperm accumulates preferentially at the animal cortex. However, the sperm might enter the egg anywhere in the animal hemisphere.

After the sperm cell and centrozome gets inside the egg cell, male centrozome becomes an organizing centre of female tubulin that will form a growing *sperm aster*.

Oocyte completes meiosis II and syngamy occurs.



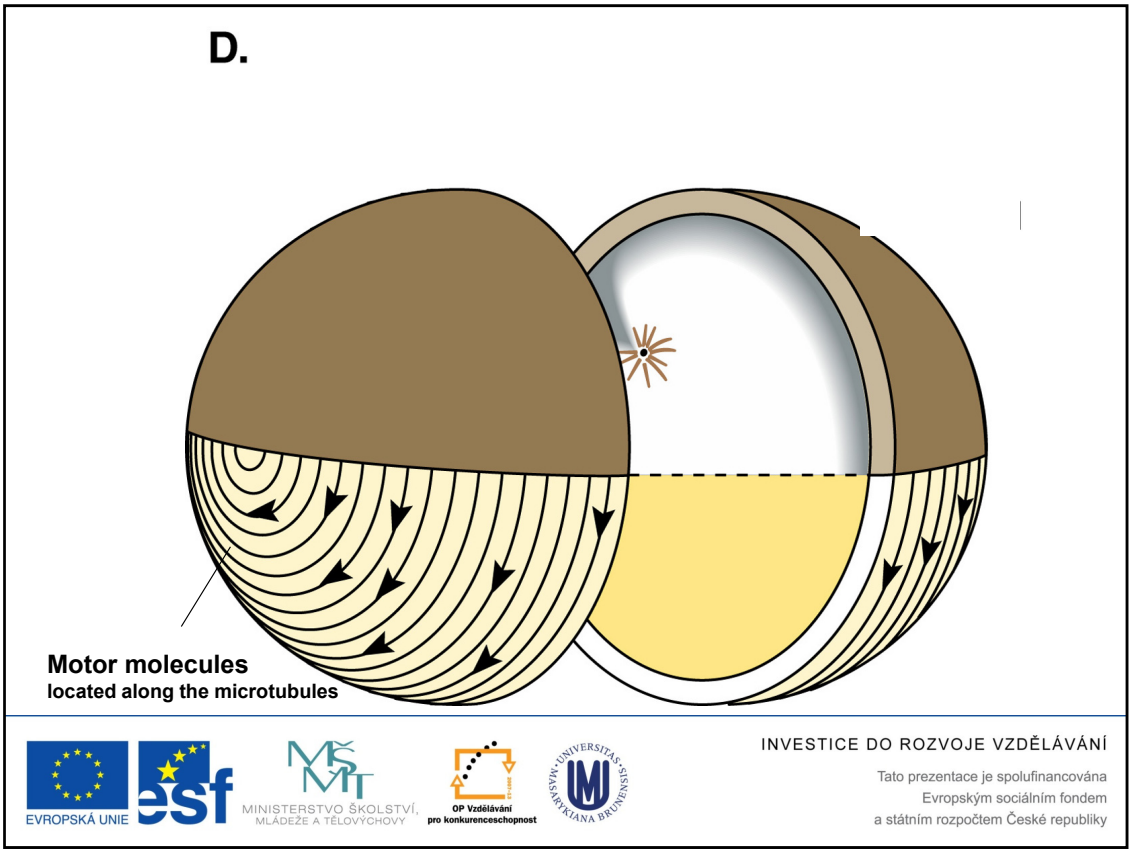
At the moment of fertilization, there is still no asymmetry, no dorsoventral or anteroposterior axis as is the case of egg in *Drospohila*, but only animal and vegetal poles could be distinguished.

However, the fertilization breaks this radial symmetry and via the sperm aster formation it induces acquisition of the bilateral symmetry. Fertilization also starts the aligning of the microtubules in a shear zone in a direction necessary for the cortex cytoplasm rotation. The sperm entry point defines the plane of rotation (the meridian) that goes through the sperm entry point and the animal and vegetal poles.

In the case of parthenogenesis, the movement starts in random meridian to induce the bilateral symmetry.

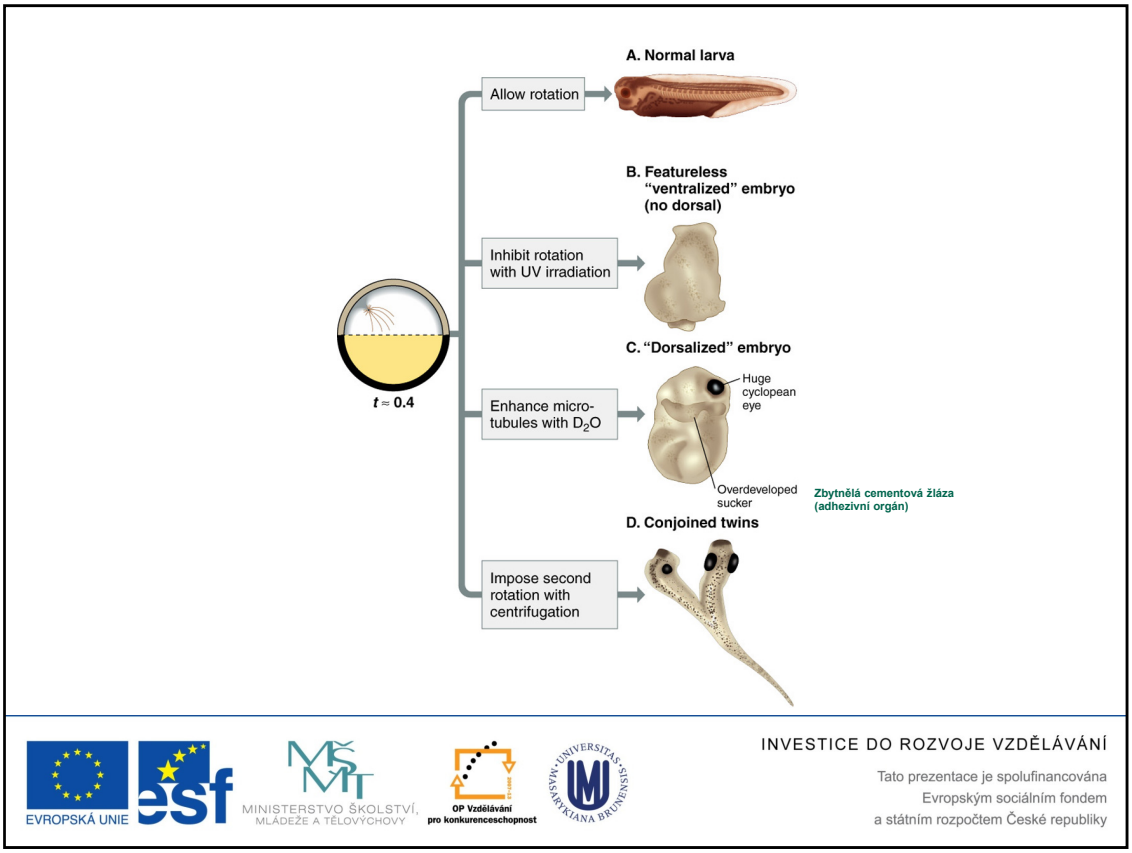
For the future formation of dorsoventral axis, the movement of the egg cortex with regard to the core is critical. The movement of the cortex (about 4 um thick layer at the egg periphery) starts at about 0,4t-0,8t, where t is the time between fertilization and first cleavage of the egg.

The gray crescent zone gets cross dissected by the first cleavage (see the video) and it will became the place of high gastrulation activity (see later).



The movement is facilitated by the arrays of microtubules that are oriented in parallel with the egg surface and located at the interface between cortex and the core.

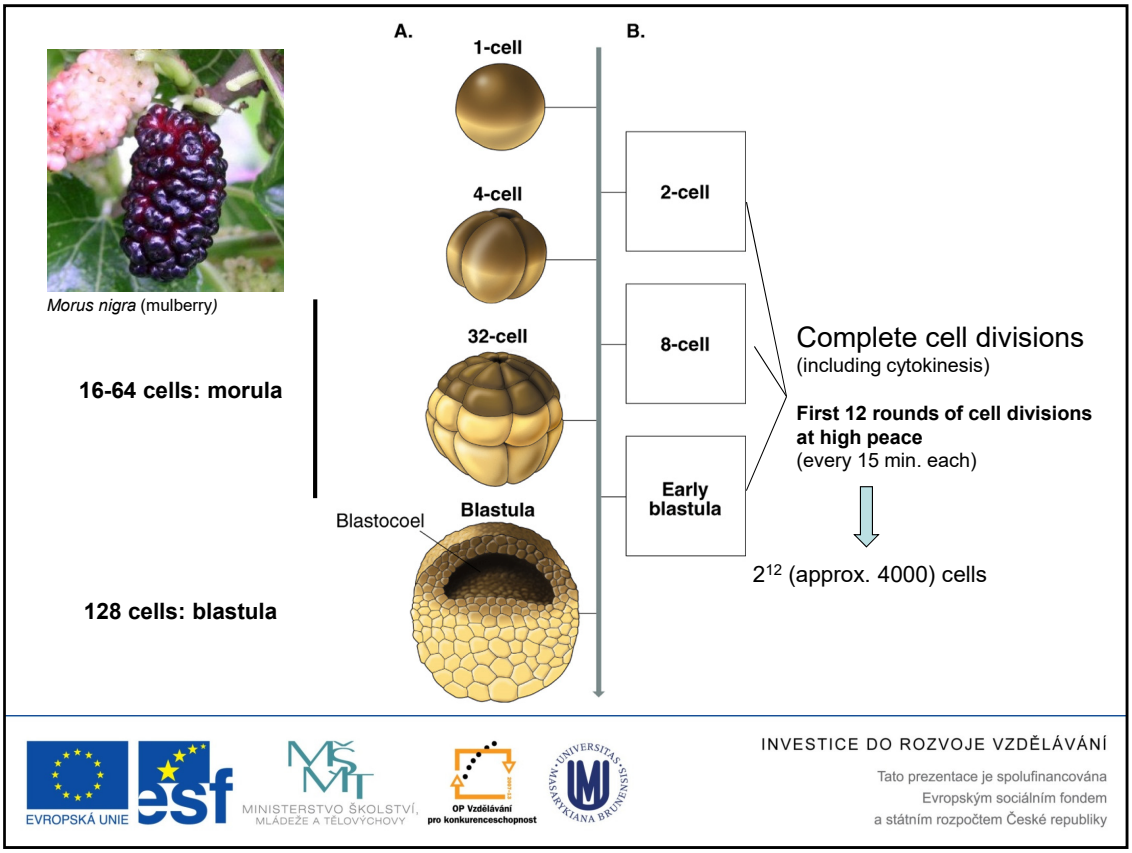
There are motor molecules associated with the microtubules that are responsible for the movement. The movement is oriented towards the positive pole of microotubules, which point towards the future dorsal pole of the embryo.



If the rotation is disturbed (via e.g. UV light, which prevents microtubule polymerization), there is no dorsal structures development (the embryo will contain a gut and blood cells, but no muscles or nervous system.

Vice versa, if the movement is stimulated by heavy water, hyperdorsalized embryos are formed.

Finally, modification of the movement via e.g. centrifugal forces, extra cortical rotation could be imposed, leading to Siamese twins formation.



Early after fertilization, the cleavage of the egg starts.

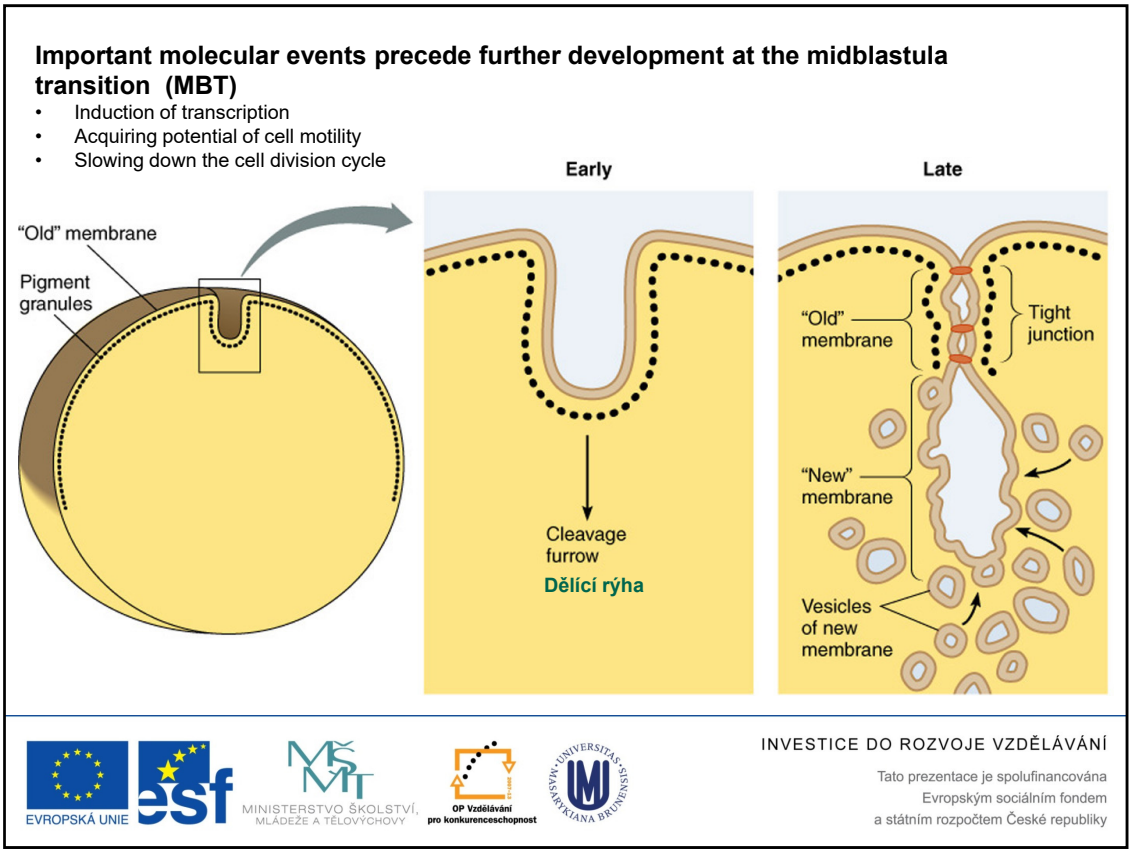
In the stage between 16-64 cells the embryo resembles the fruit of mulberry, therefore it's being called **morul**a (from Latin "morus").

In the stage of 128 cells *blastocoel* appears and the embryo is called **blastula**.

During this stage, egg becomes a "DNA factory" that produces DNA, proteins and plasma membrane components at a very high speed.

In comparison to *Drosophila*, where syncitium is formed followed by cellularization, in amphibians the complete cell division (i.e. including cytokinesis) takes place. DNA polymerases, histone mRNA and membrane precursors are stockpiled in the egg during oogenesis.

First 12 rounds of cell divisions occurs at a high peace, every 15 minutes each, leading to formation of 2^{12} cells (approx. 4000 cells).



Newly formed cells are divided by cleavage furrows that introduce part of the "old" plasma membrane into the cell-to-cell interfaces. At the position of the old membrane, the cells are connected with what is called "tight junctions" (for the underlying molecular mechanisms see in later chapters).

At the stage of **midblastula transition (MBT),** substantial molecular changes occur that precede the following developmental events (i.e. developmental potential specification of different blastula portions).

First, there is an **induction of transcription**, second, some cells acquire **potential of motility** and third, the **cell division cycle slows** down (G1 and G2 phases become a part of the cell cycle).

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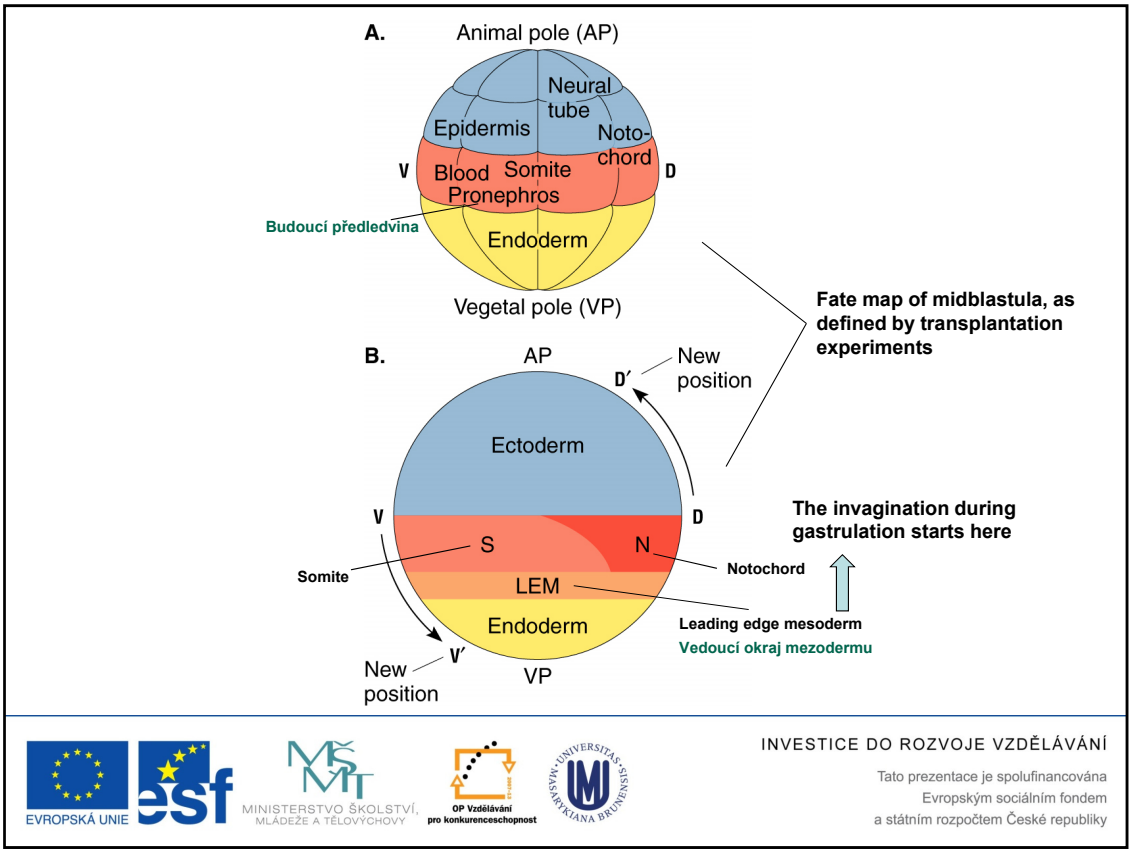


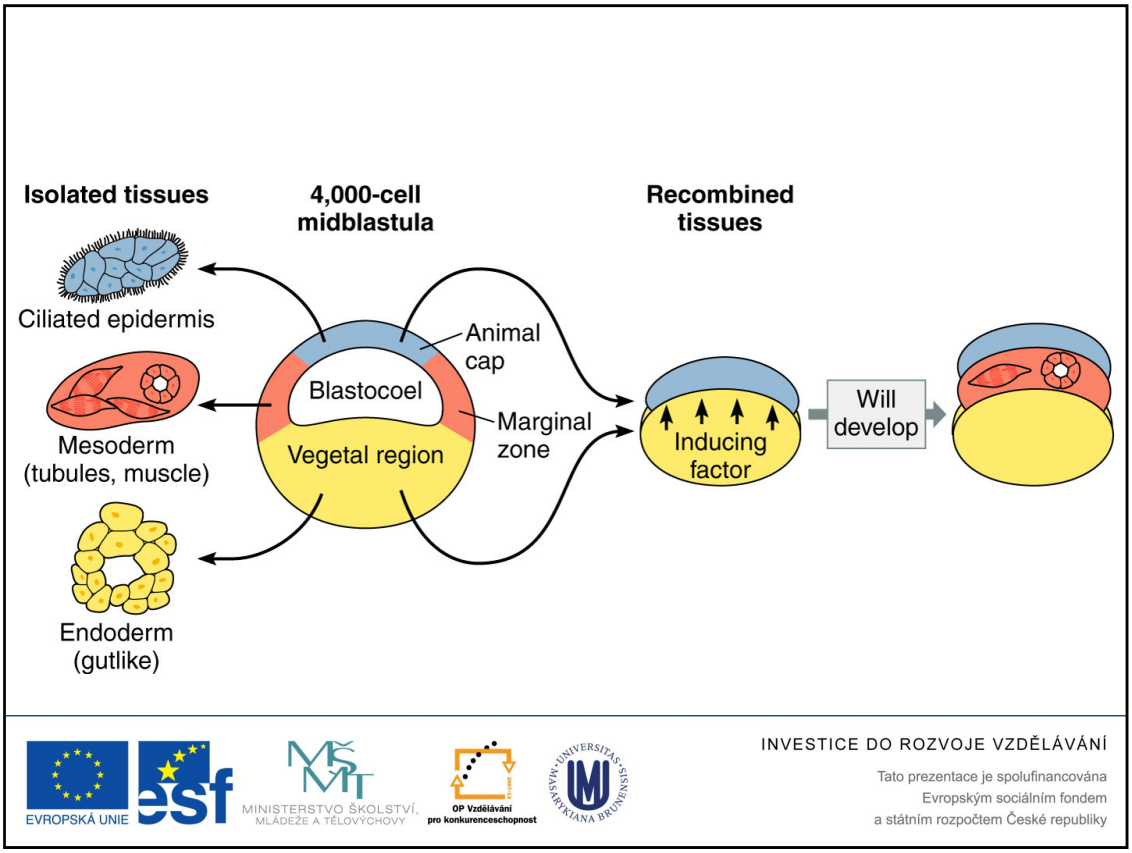
At the stage of midblastula, the **fate map** (i.e. the developmental fate of differently stained blastula cells) correspond to the egg, as there are no cell movements yet.

Originally defined fate map of *Xenopus* (above) has recently been updated, with slight modifications of the prospective ventral and dorsal poles (below).

The **specification map** (or also **competence map**) is obtained by explantation experiments, i.e. pieces of the blastula are transferred to other embryos or to the tissue culture medium and allowed to develop into pre-specified tissue. However, the competence of cells to form specific tissue after excision from embryo might differ in comparison to the intact embryo (see next slide).

Leading edge mezoderm (LEM) starts the invagination during gastrulation (see later).

Experiments by Connie Lane and Bill Smith suggest that the prospect ventral and dorsal poles are located closer to the vegetal and animal poles, respectively (shown by arrows pointing to these new positions designated as V' and D').



When the cells from the animal pole (animal cap cells) are removed, they are able to from ciliated epidermis in the tissue culture medium.

The cells originating from the vegetal pole form gutlike endoderm cells.

When the cells are combined, however, they will produce mesodermal structures.

These findings let to a hypothesis that vegetal pole cells are source of graded inducing factor, which induces mesoderm formation. Recent findings suggest that this is more complex with generalized induction of mesoderm and anterior endoderm followed by secondary induced signal that allows dorsal mesoderm formation.

This concept of induction signals, however, does not exclude predetermination based on the egg deposited signaling molecules. This seems to be the case, at least partially.

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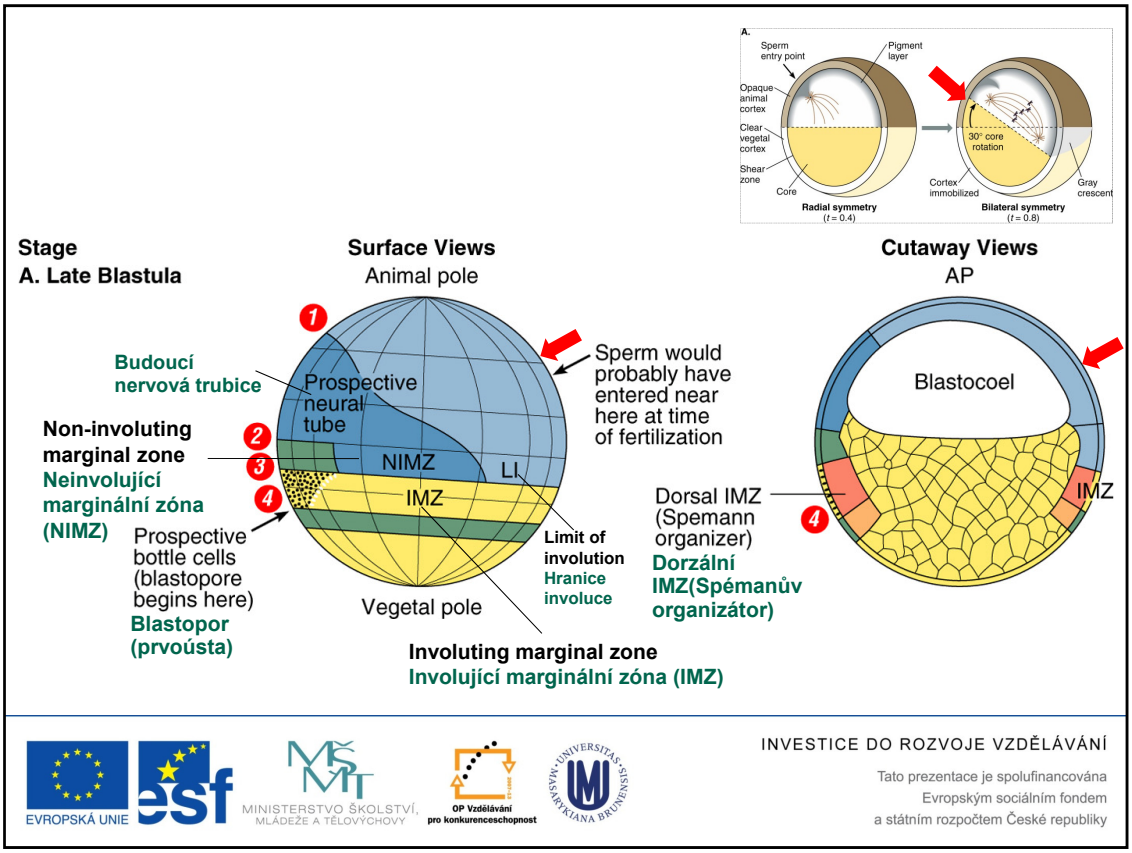
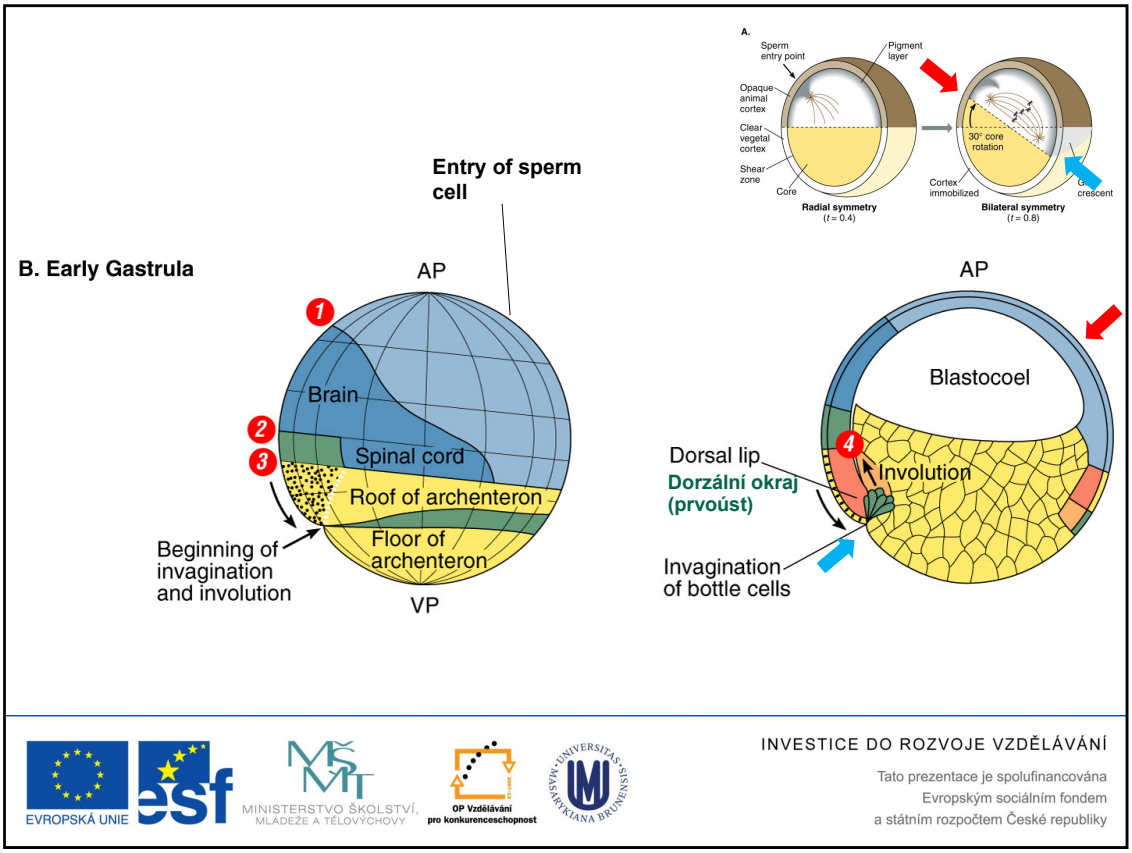


Gastrulation starts in the position that is approximately opposite to the sperm entry and where the vegetal cortex got over the original animal pole (see the red arrow in the inset).

Then, the so called bottle cells start invaginate, leading to the blastopore formation that is delimited by the blastopore lip.

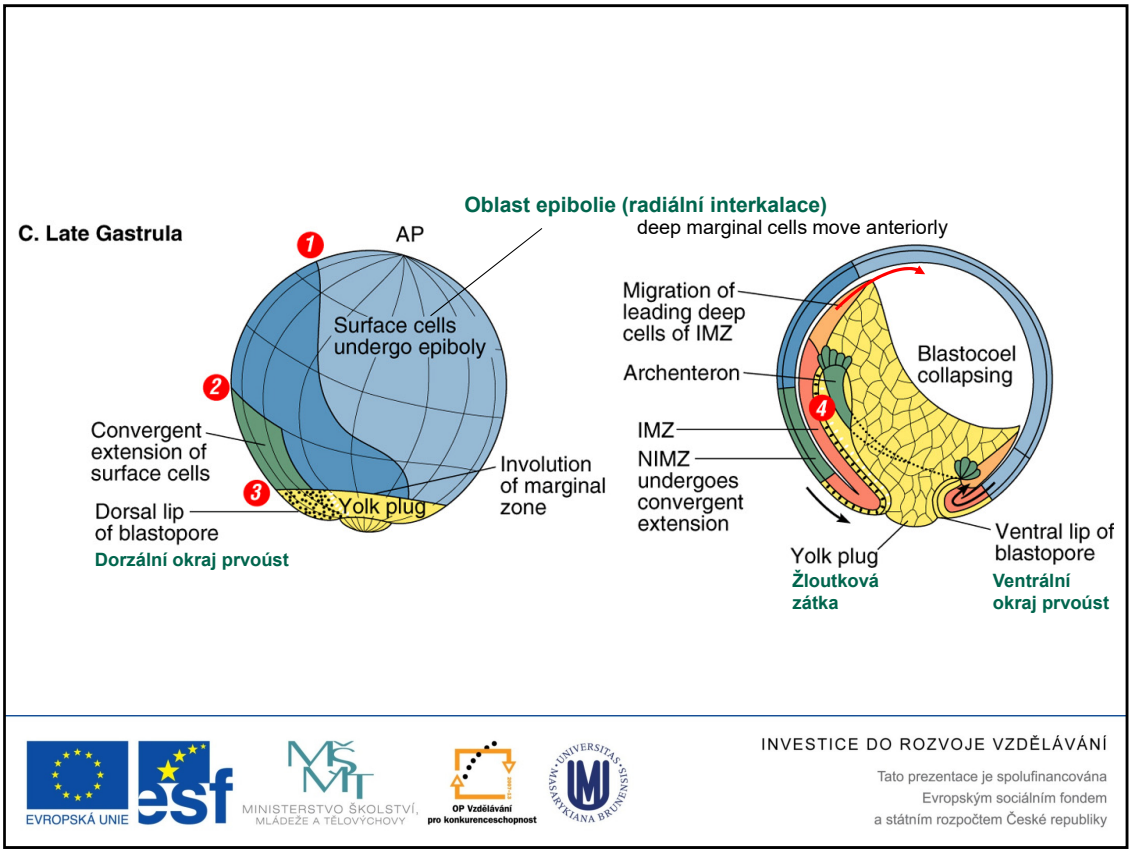


The bottle cells at the dorsal lip become narrow and attenuated, which allows their ingression deeper into the other cell layers. Thanks to the pressure of surrounding cells the bottle cells appear to pull on their thin cell “necks”.

The anatomical structure arising from this invagination is known as **blastopore**. The beginning dimple is called the **dorsal lip of the blastopore** and it occurs in the position where due to the rotation of the cortex, the interface between original vegetal and animal portions of the egg get opposed to each other (see the red and blue arrows, respectively).

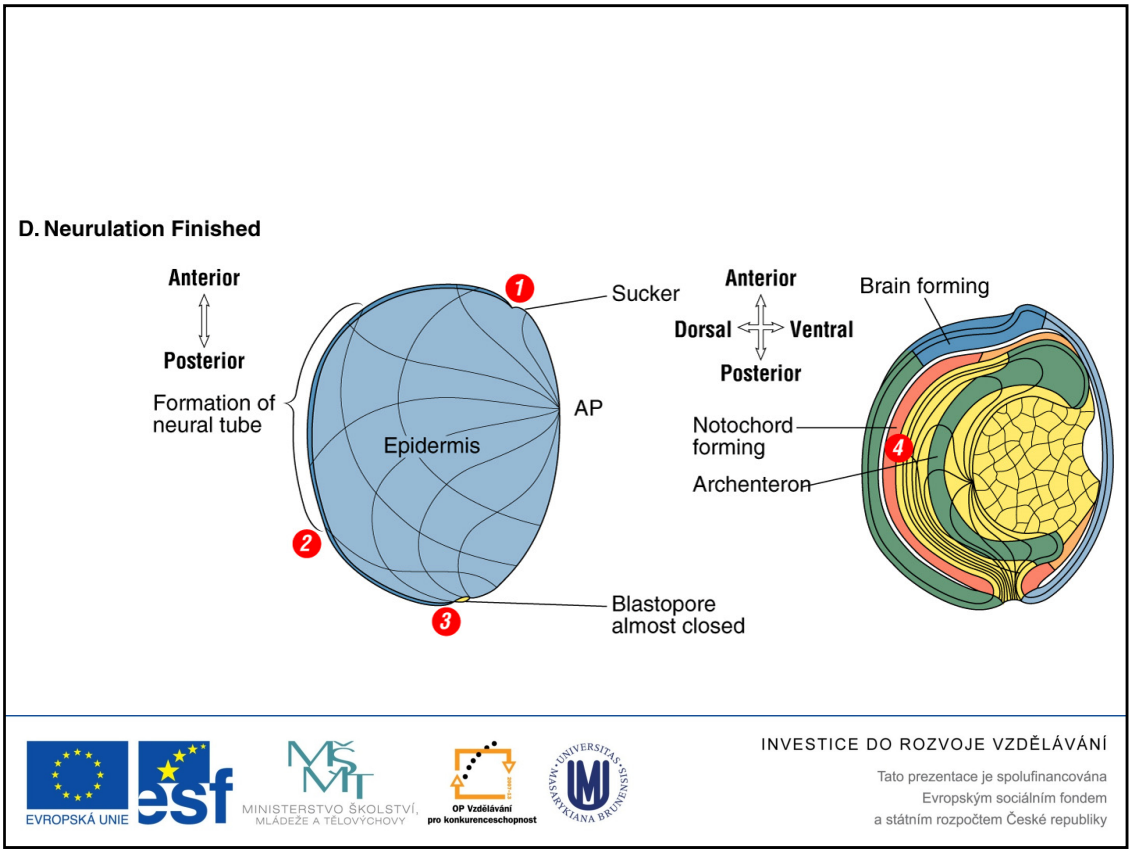
Once involuted, the deep marginal zone cells actively migrate, moving the archenteron anteriorly.

The invaginating cells of the **dorsal and ventral lip** develop into **mesoderm**, **surface cells** of the **majority of the former animal pole** develop into **epidermal and neural ectoderm** and the cells developing from the **majority of the former vegetal pole** will develop into **endoderm**.



The invagination of the vegetal pole cells leads to the tensions that result into extension of the portion of the embryo surface, a process called **epiboly**.

The movement of deep marginal cells anteriorly leads to the collapse of the blastocoel, while new interior cavity called **archenteron** is formed.



Complex movement of the cells precedes the invagination, leading to abortion of the blastocoel and new interior cavity formation, the **archenteron.**

Dorsal portion of the embryo undergoes epiboly and neurulation is finished (for the more detailed description of neurulation see later text).

At the end of gastrulation in amphibians, similarly to *Drosophila* there is an internal cavity, lumen of the future gut surrounded by endoderm. In contrast to *Drosophila*, the internal cavity is blind ended, with the future mouth being developed on the closed pole.

The surface is created by epidermal and neural ectoderm and between them there is remaining intermediate mesodermal layer.

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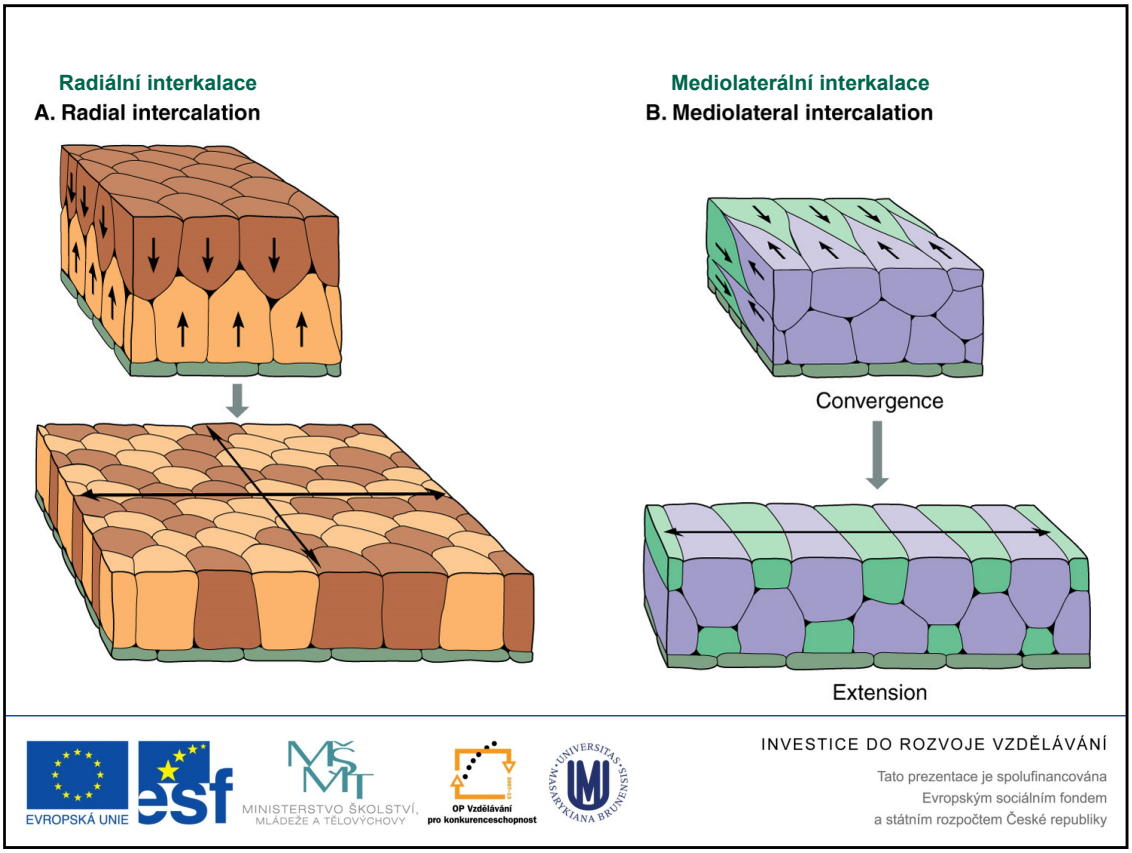
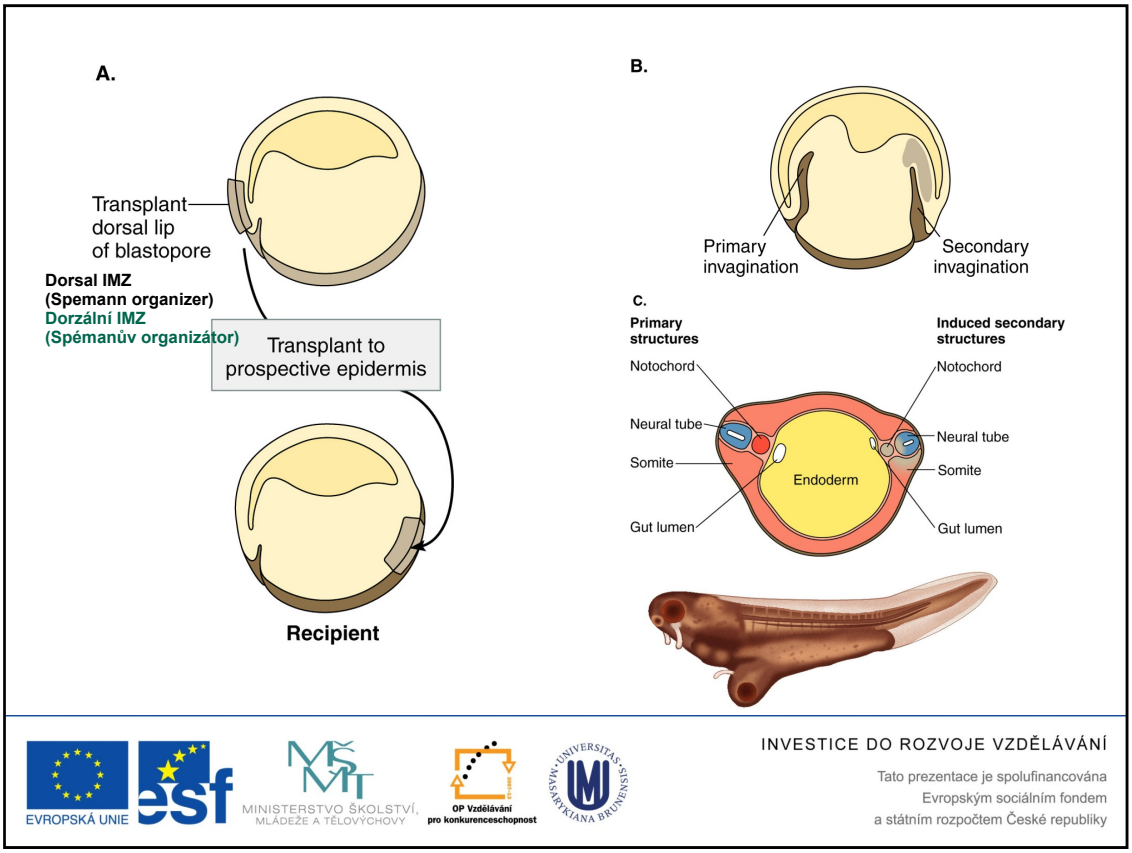


The process of epiboly is connected with the surface extension. This is allowed by cell layers intercalation, leading to the reduction of the cell layer thickness, but increasing its surface. There is radial and mesodermal intercalation.

The **radial intercalation** leads to the intercalation of surface cells into the deeper cell layers, while the **mediolateral intercalation** allows convergence of the cells from the same layer leading thus to both narrowing of the cell layers in the mediolateral direction and their extension



Cells adjacent to the dorsal lip of the blastopore act as a so called **Speman organizer**.

When the cells of the Speman organizer are transplanted to other embryo, they are able to induce secondary invagination, leading to the second axis formation with secondary neural tube and adjacent muscles and some other structures, finally resulting into conjoined twin embryo.

As shown in experiments with distinctly pigmented embryos, most of the secondary axis tissue originates from the host. Thus, the Speman organizer is able to induce change of the developmental fate in the neighbouring tissue.

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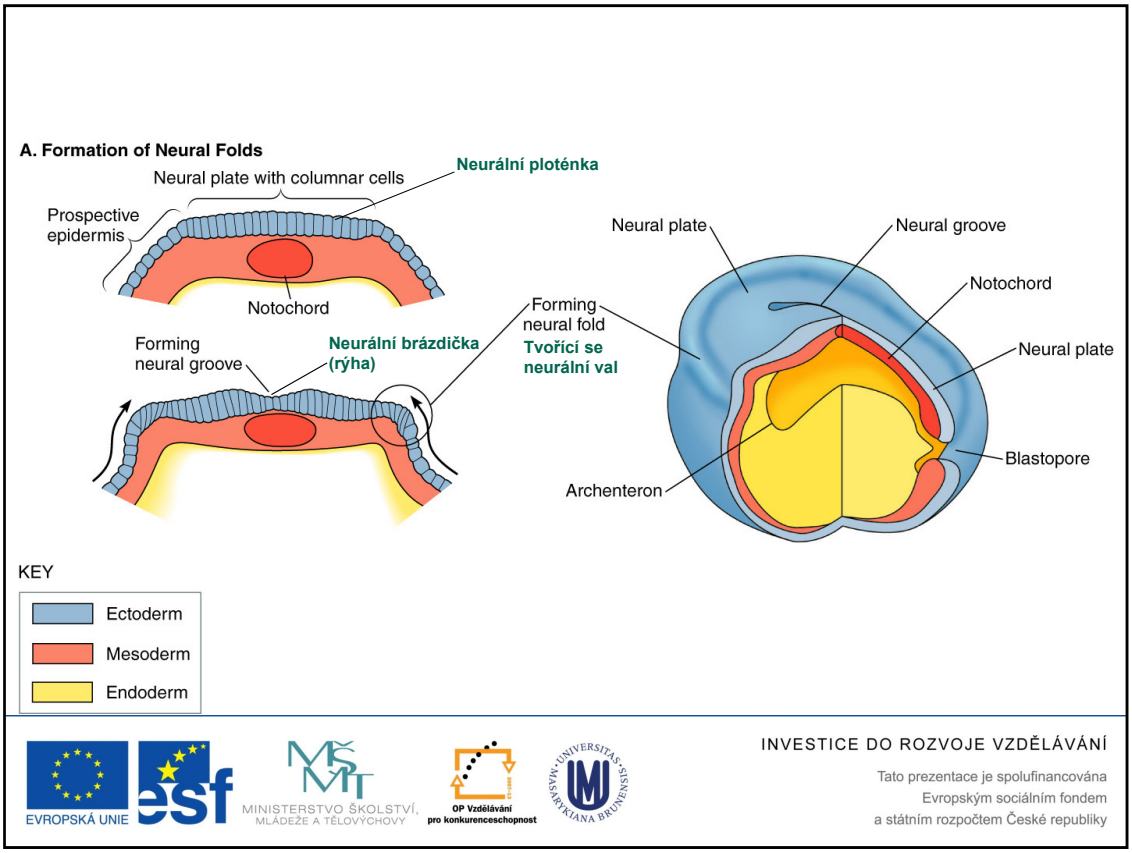
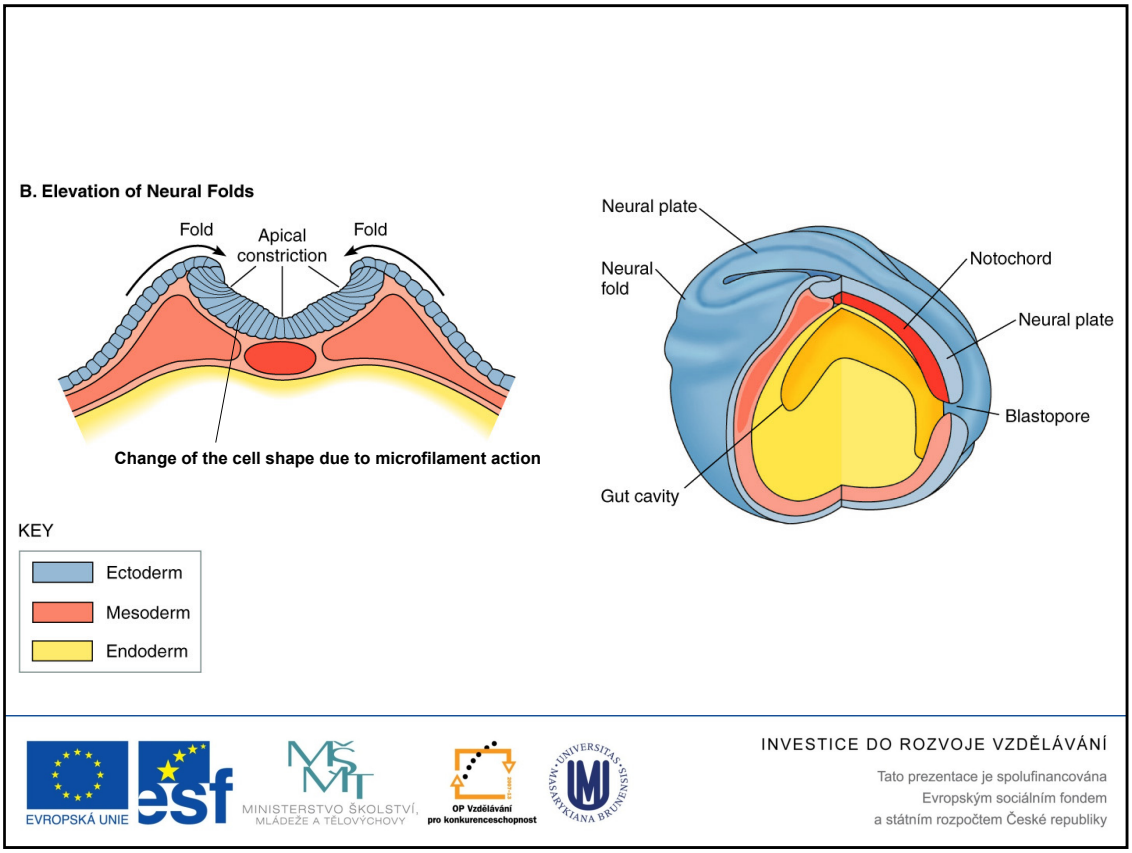
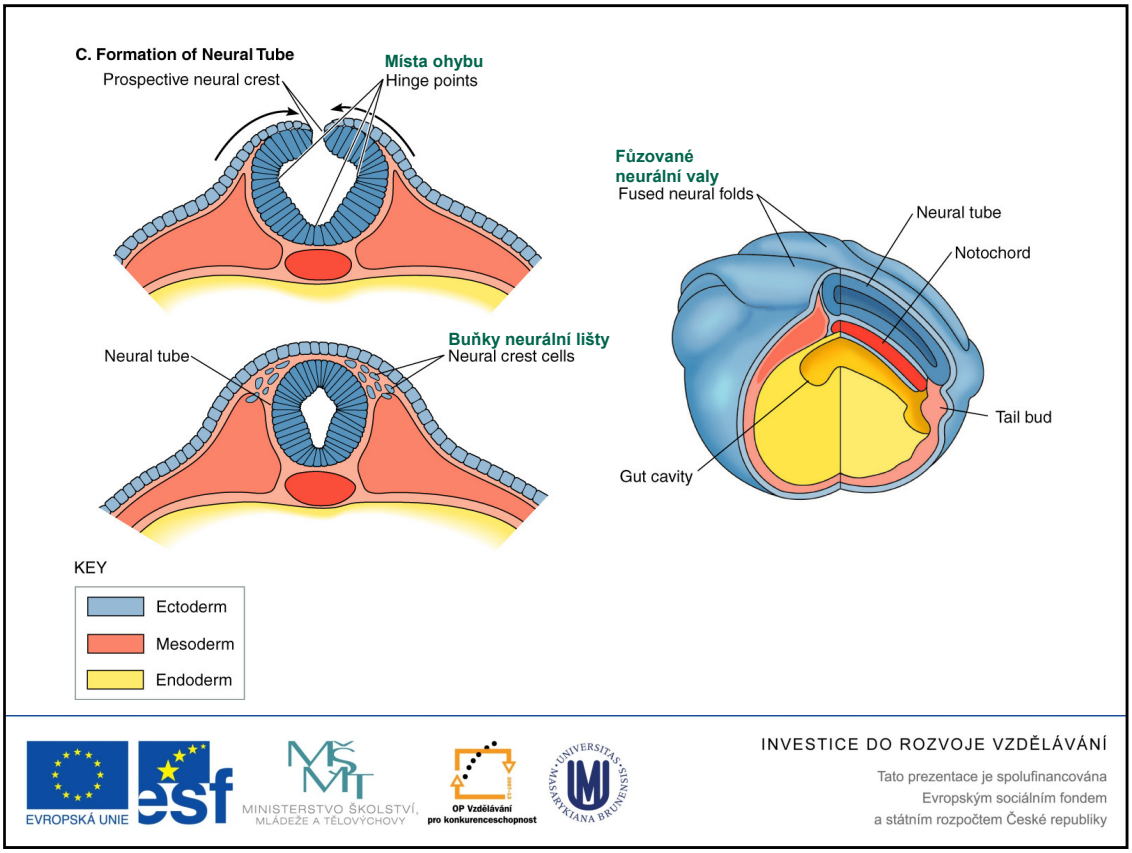


Dorsal mesoderm acts as an inductor of the dorsal ectoderm formation that turns into neural tube, the process called **neurulation**. The molecular mechanism of this process will be discussed later.

The cells of the dorsal ectoderm are induced by the notochordal mesoderm to change their shape from square to rectangular, forming what is called *neural plate*.



Due to microfilament action, the neural plate cells change their shape that is one of the processes necessary for the rolling of the plate into *neural tube*. The two outer edges of the plate approach one other in the dorsal midline.



Finally the two “lips” of the plate meet and fuse.

In some other vertebrates, e.g. in fishes, the neural tube is formed in a different way-the chord cells form a rod, which then becomes whole in the center.

Outline of Lesson 3

Early Development of Amphibians and Amniotes

- Oogenesis in amphibians
- Blastula formation and dorsoventral axis fomation in amphibians
  - cleavage of *Xenopus* zygote (video)
- Gastrulation
  - gastrulation of amphibians (video)
- Neurulation
  - neurulation in *Xenopus* (video)

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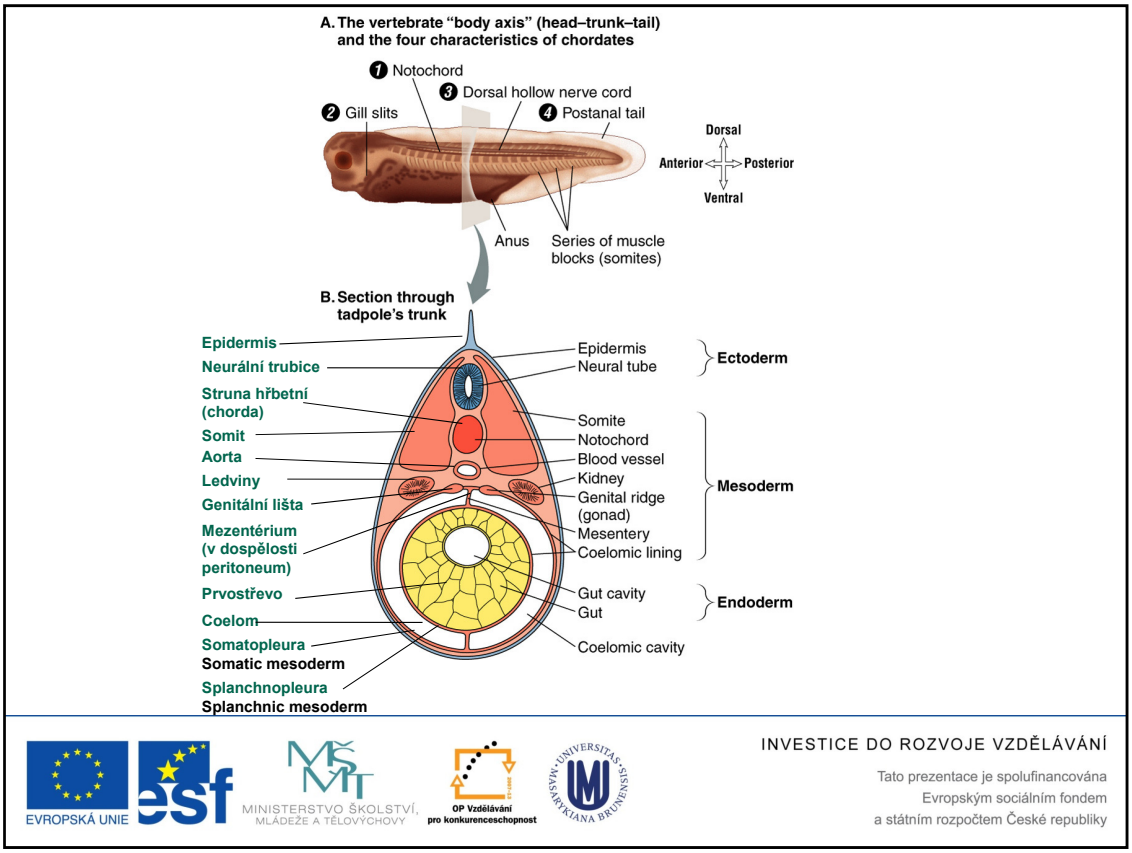

Mesoderm and endoderm will form many organs. The pattern of transforming an epithelial sheet into a tube or sphere is repeated in the formation of many organs of the body.

The endoderm of the archenteron (epithelium) will bulge out (evaginate) in various places along its length into the adjacent mesoderm and will form salivary glands, lung, liver, pancreas and thyroid.

The dorsal most mesoderm subjacent to the midline of the neural plate undergoes intercalation, stack of cells swell and form what is called **notochord**. Notochord structure is typical for vertebrates, it is significant skeletal structure in lower vertebrates but becomes calcified and buried within the bony spinal column of terrestrial vertebrates.

On each side of the notochord, mesoderm will develop into bilaterally symmetric blocks called **somites**. Many other structures derive from somites, e.g. most of the skeletal muscle, all dermis and cartilage surrounding the spinal chord.

More ventrolateral mesoderm will splits into two layers, the more peripheral that associates with the outer ectoderm forms **somatic mesoderm** layer, the other mesoderm layer covers endoderm of the developing gut, forming thus **splanchnic mesoderm**. The space between these two layers is called *coelom*.

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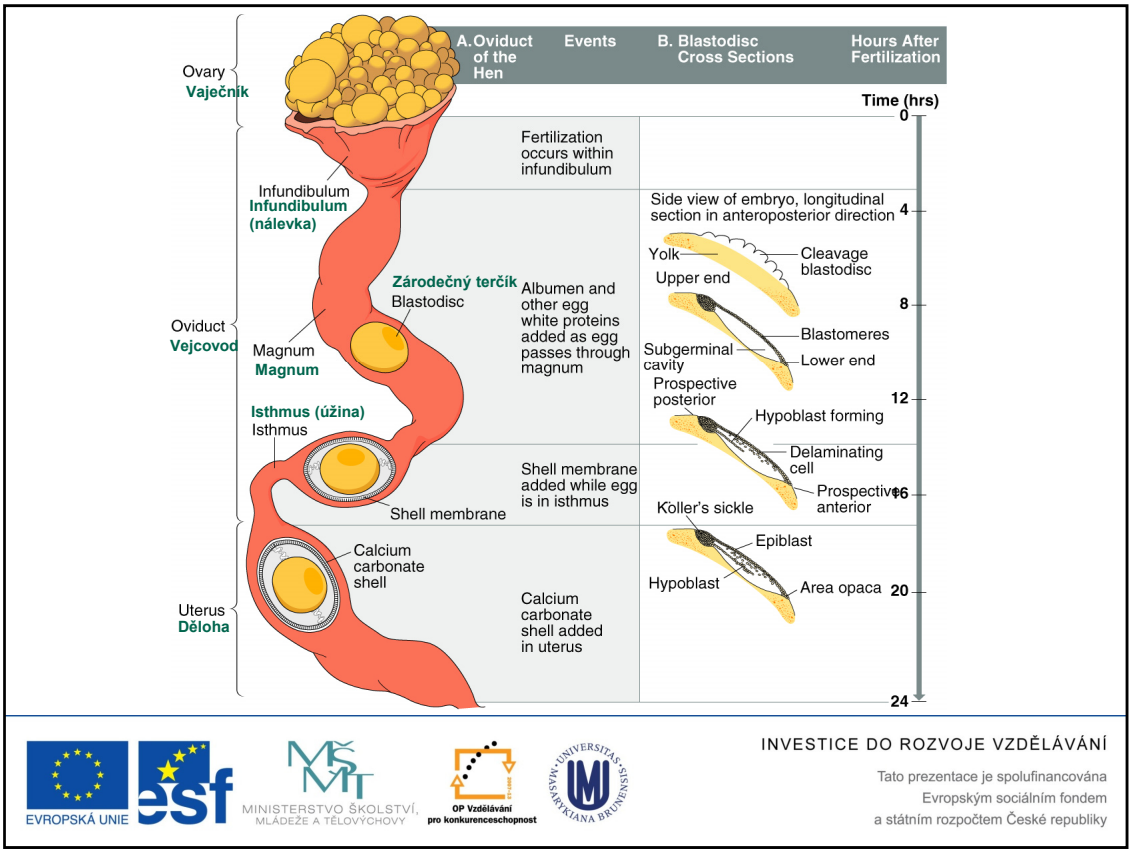

Oogenesis occurs in the specialized female reproductive tract. Ovary produces oocytes that undergoes meiosis and accumulates yolk that is produced in the liver. The cytoplasm is located aside as a small coherent disc.

Ones the oocyte is released from the ovary, it is fertlized and starts travel through the oviduct that contains specialized departments.

In the *magnum*, white is synthesized and **blastodisc**, another term of blastoderm that undergoes meroblastic or partial cleavage, is formed. White consists mainly of ovalbumin and lysozym that has antibacterial effects.

In the *isthmus*, the complex membrane constitutes around the white and in the *uterus*, and elaborate calcium carbonate shell is deposited around the egg.

Cells of the upper portion of blastodisc, called **epiblast** are divided from the remaining yolk by *subgerminal cavity*. During passing through the oviduct, some cells of the epiblast shed and are falling down to the cavity, where they die. That leads to the thinning of the central area, *area pelucida*.

The cells at the periphery of the blastodisc are syncitial and are called *marginal zone* (see also following slide).

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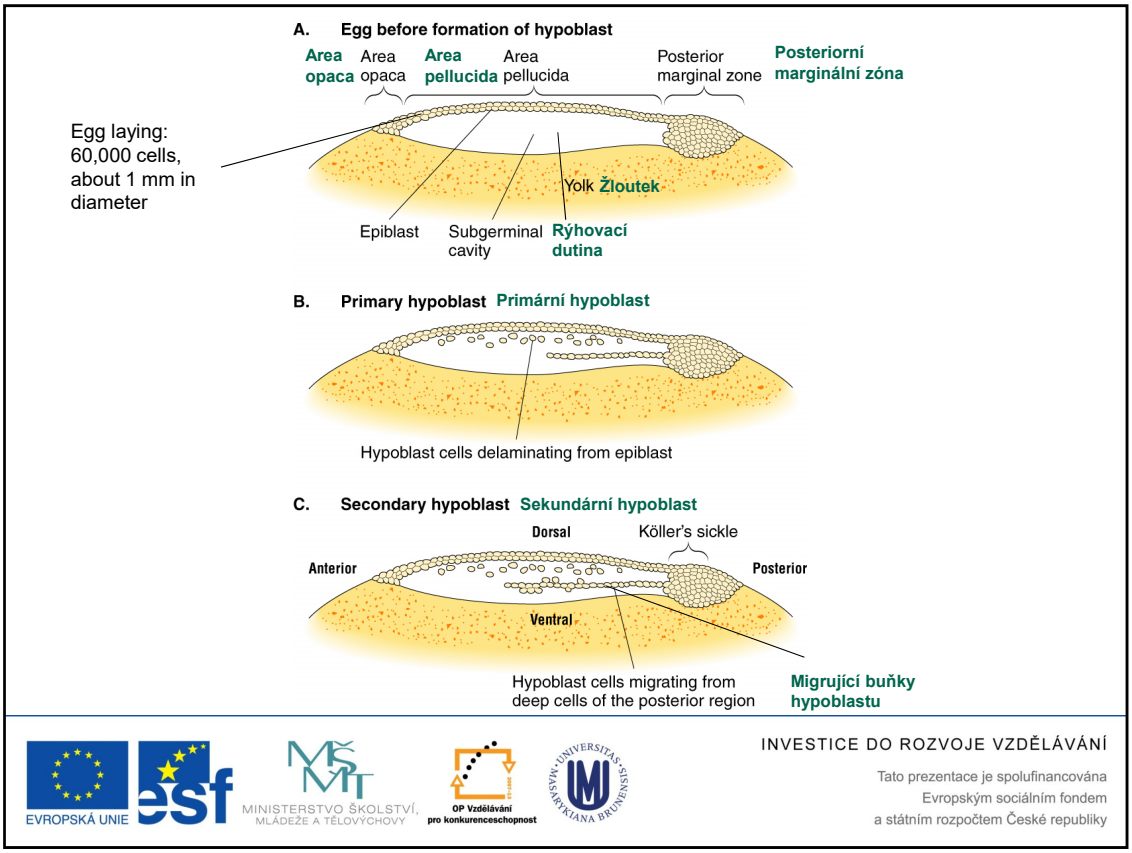
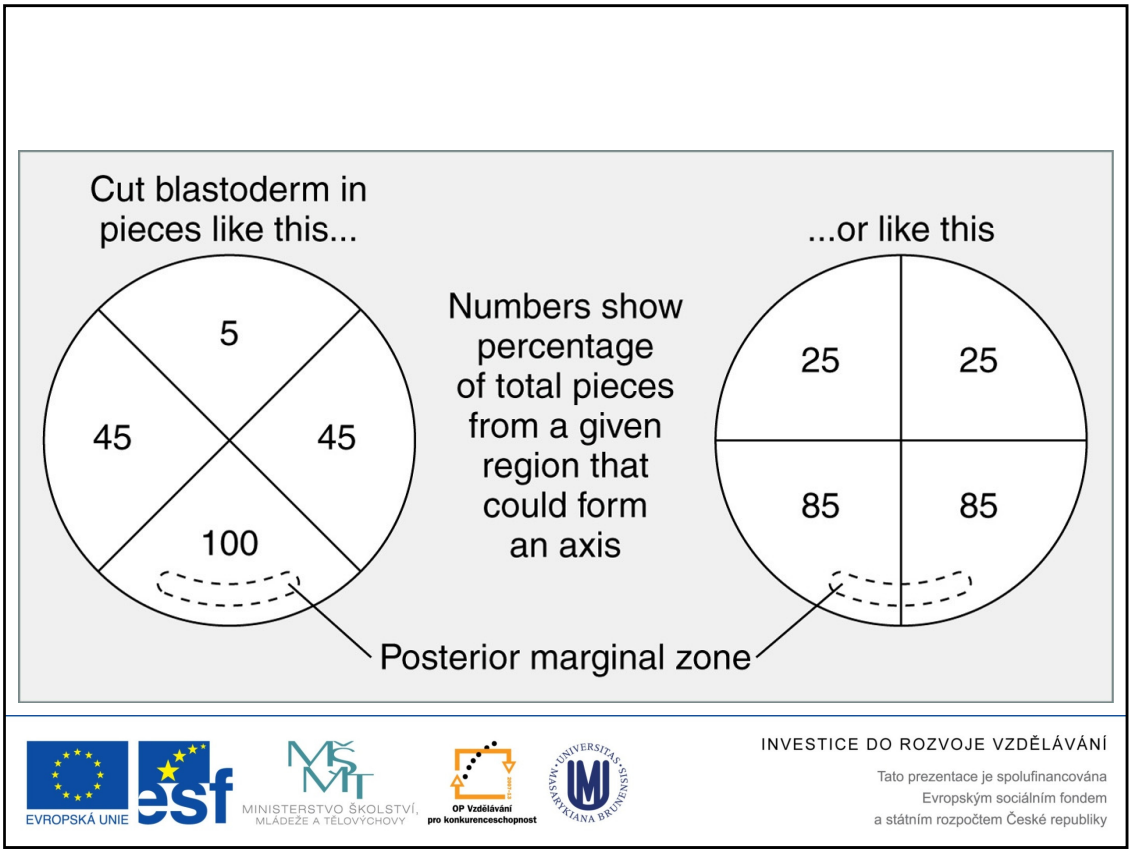


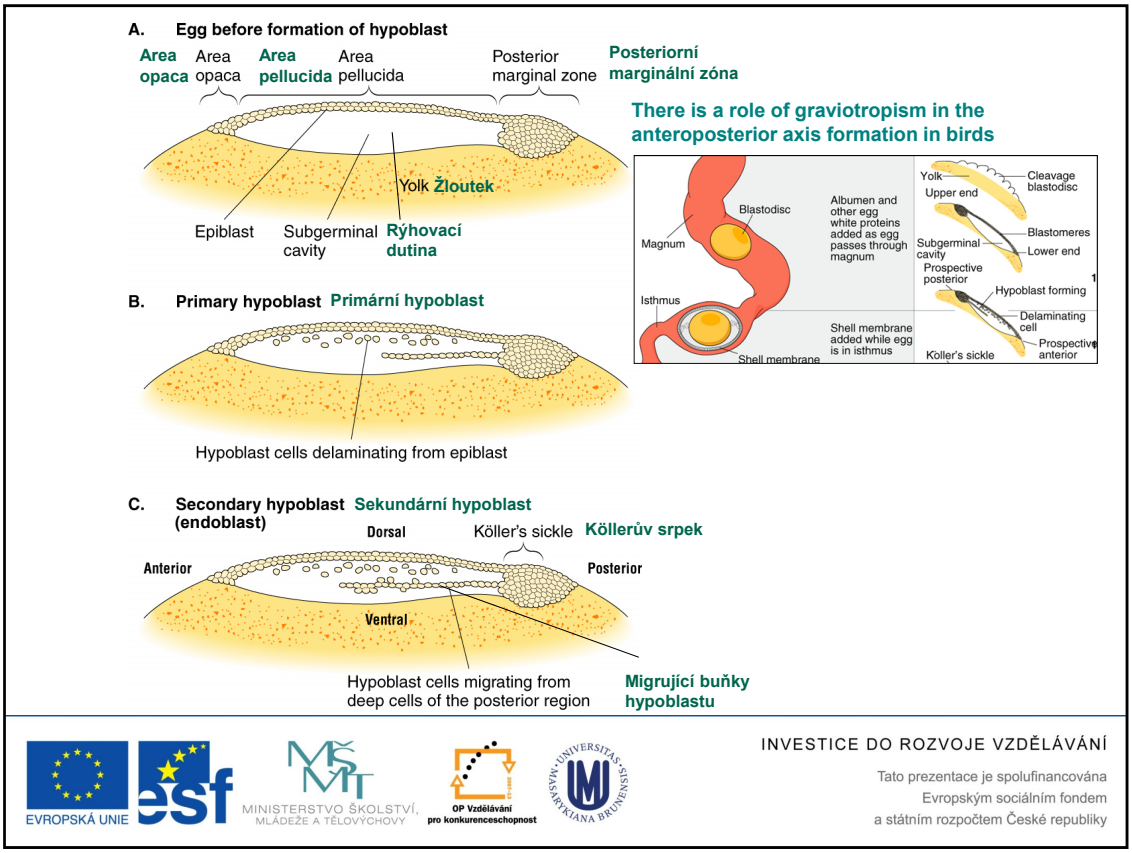
At the time of the egg laying, the blastodisc consists of about 60,000 cells and is about 1 mm in diameter. The central part of the blastodisc is more transparent, because its constituent cells have less yolk and it is called *area pelucida*. There are more yolky cells at the periphery, called *area opaca*.

Though mostly radial symmetric, the developmental bias is already predetermined as shown by surgical experiments (see the next slide).



The future posterior pole could be morphologically recognized as a thickening at the periphery of blastodisc (in the marginal zone).

Then, the blastodisc was cutted in pieces and let to develop in the culture. The percentage of pieces that were able to form axis under these conditions was scored. These experiment have clearly shown that individual zones of blastodisc are already prespecificed at that developmental stage.



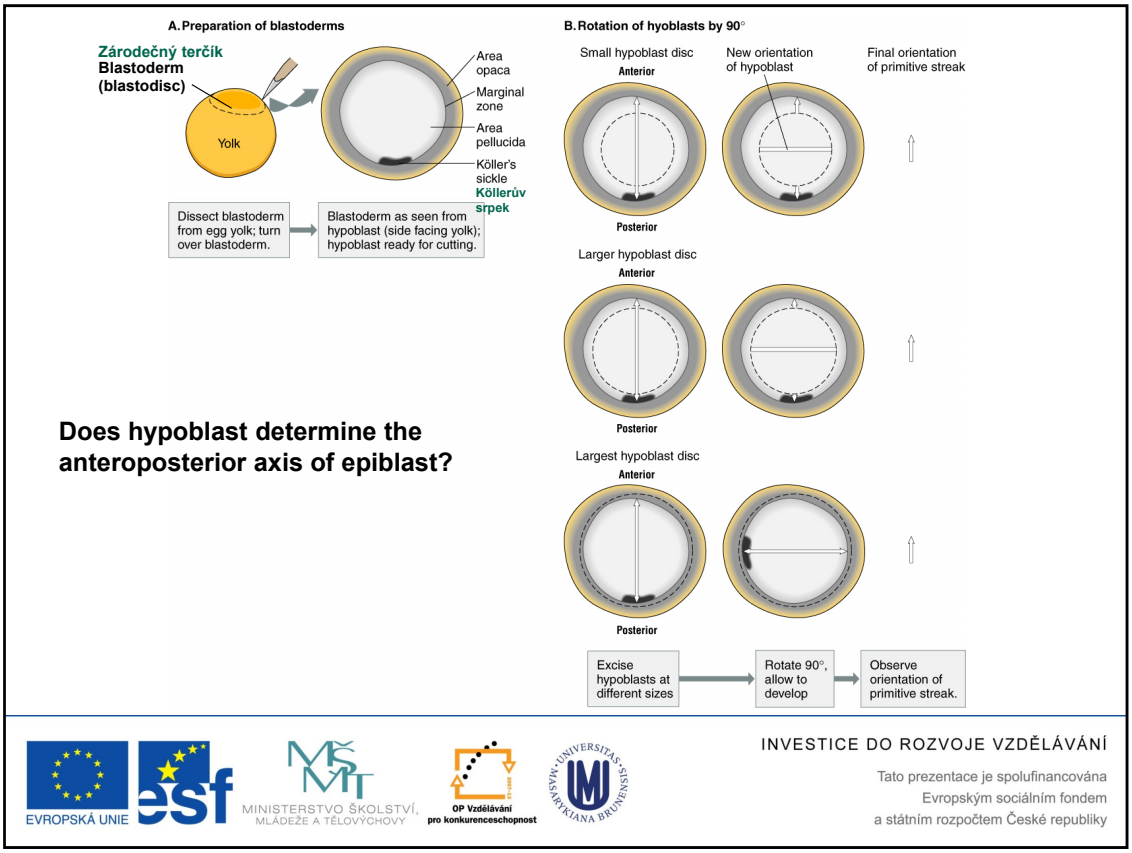
During development, the area pelucida becomes two-layered structure.

At the prospective posterior end, there is located proliferative tissue called **Köller's sickle**. From this region, a new cellular layer advances, forming thus a lower tissue layer, called **hypoblast**.

Cells detaching from the anterior portion of the area pelucida might be incorporated into the developing hypoblast (sometimes called also endoblast).

Gravitropism plays a role in the specification of the anteroposterior axis. In the oviduct, egg is always oriented with the posterior pole up (see the inset).

When the eggs were removed during that process and reoriented, the prospective posterior pole always appears at the upper side of the egg. The underlying molecular mechanism is still not clear. Possibly, the shading of cells from the epiblast might be somehow connected, as it always occurs at the prospective posterior end.



What is the type of inductive interaction between lower layers of the blastodisc and epiblast in the determination of the further development is not completely clear.

Recently, the original idea that hypoblast induces anteroposterior axis in the epiblast was challenged by the series of surgical experiments.

When the hypoblast region of different size was rotated towards developing epiblast and cultured, no changes were apparent in the primitive streak formation. This suggests that anteroposterior axis formation in epiblast is already predetermined at that developmental stage (see the slide).

However, other experiments support some level of communication between hypoblast and epiblast. When the hypoblast was removed together with marginal zone, axis formation failed. On the other hand, leaving either hypoblast or the marginal zone present allows axis formation to occur.

Thus, very probably, hypoblast and marginal zone are a source of the inductive signal, similarly to the situation of the mesoderm formation in amphibians. The molecular determinants are being recently identified and will be discussed in later lessons.

Outline of Lesson 3

Early Development of Amphibians and Amniotes

- Gastrulation in amniotes – chicken

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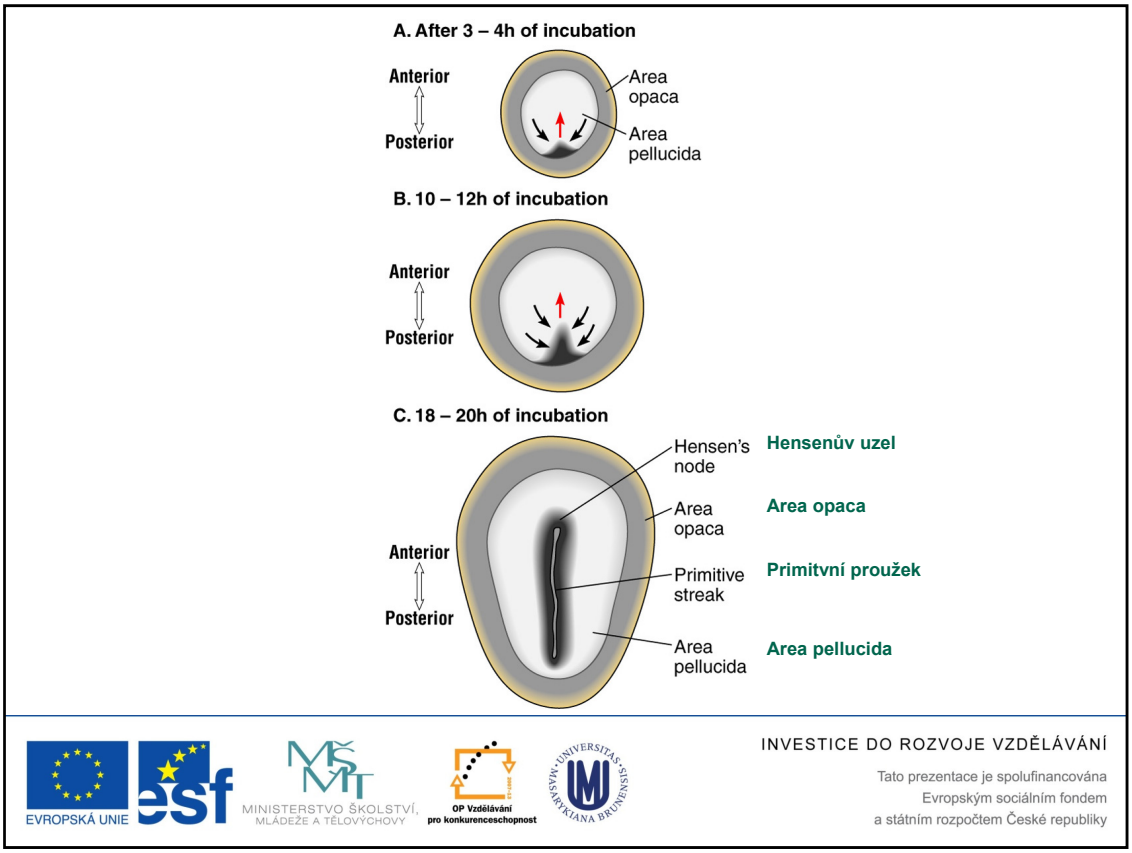
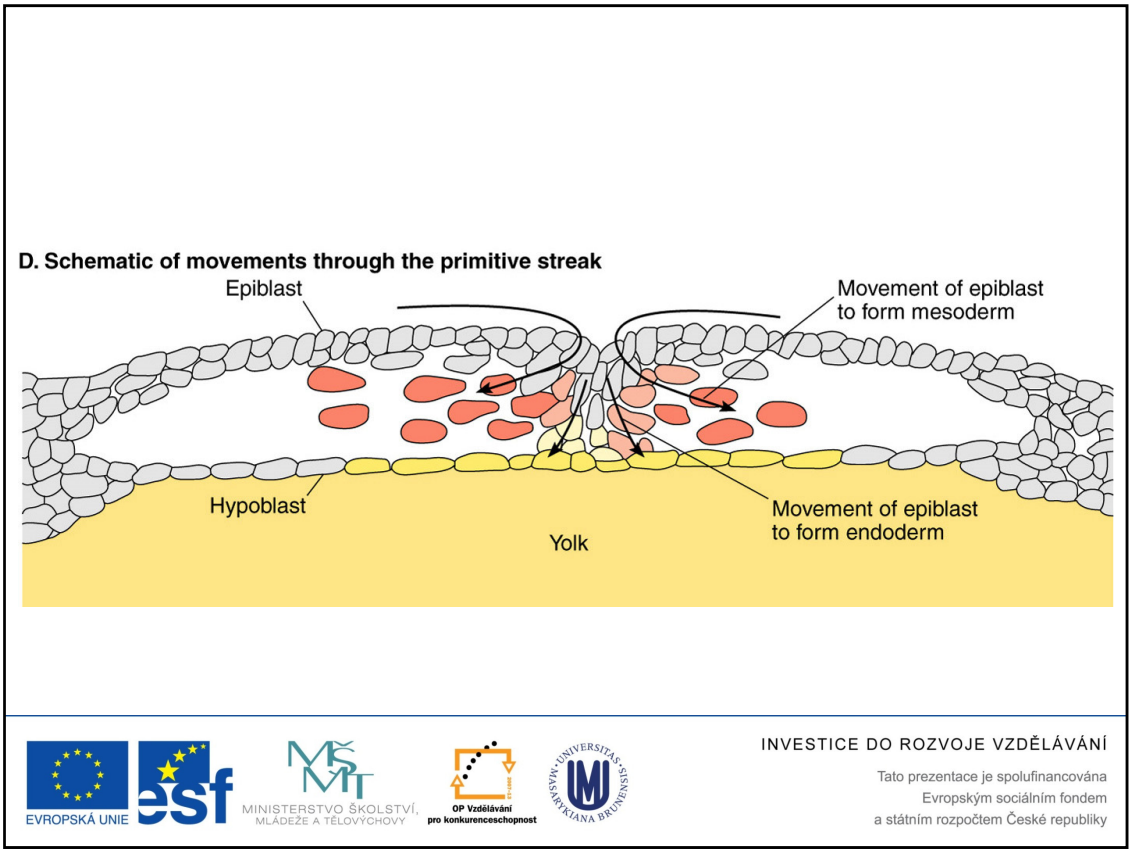


Gastrulation in birds starts by the oriented movement of cells from the lateral portions of the posterior epiblast towards the midline. That suggests that the individual cells have already predetermined whether they will move or not, in other words, they already *acquired they future identity* (see also the video).

The migrating cells create in the midline a thickening what is called **primitive streak**. The anterior end of the streak is called **Hensen's node** that plays an important organizing role (see later).



Primitive streak plays a similar role like the bottle cells in case of amniotes.

This is the place where gastrulation starts, and via complicated cell movements allowing to develop all three germ layers: ectoderm (the cells that will remain on the surface of epiblast), endoderm (the movement of these cells displaces hypoblast cells laterally) and mesoderm (the cells in between).

Importantly, notice that **all embryonic tissue originate from epiblast**. The epiblast cells migrating and diving into the hypoblast *displace the original hypoblast to the margins, where it develops into extraembryonic endoderm* (see below).

Cells at the margins of the the *area opaca* divide and blastoderm edges spread all over the enormous yolk. That allow future formation of extraembryonnic tissues that will become a fundament for the membranes surrounding the whole embryo-extraembryonic ectoderm (originating from marginal zone), extraembryonic endoderm (from original hypoblast) and extraembryonic mesoderm (from middle layer of cells).

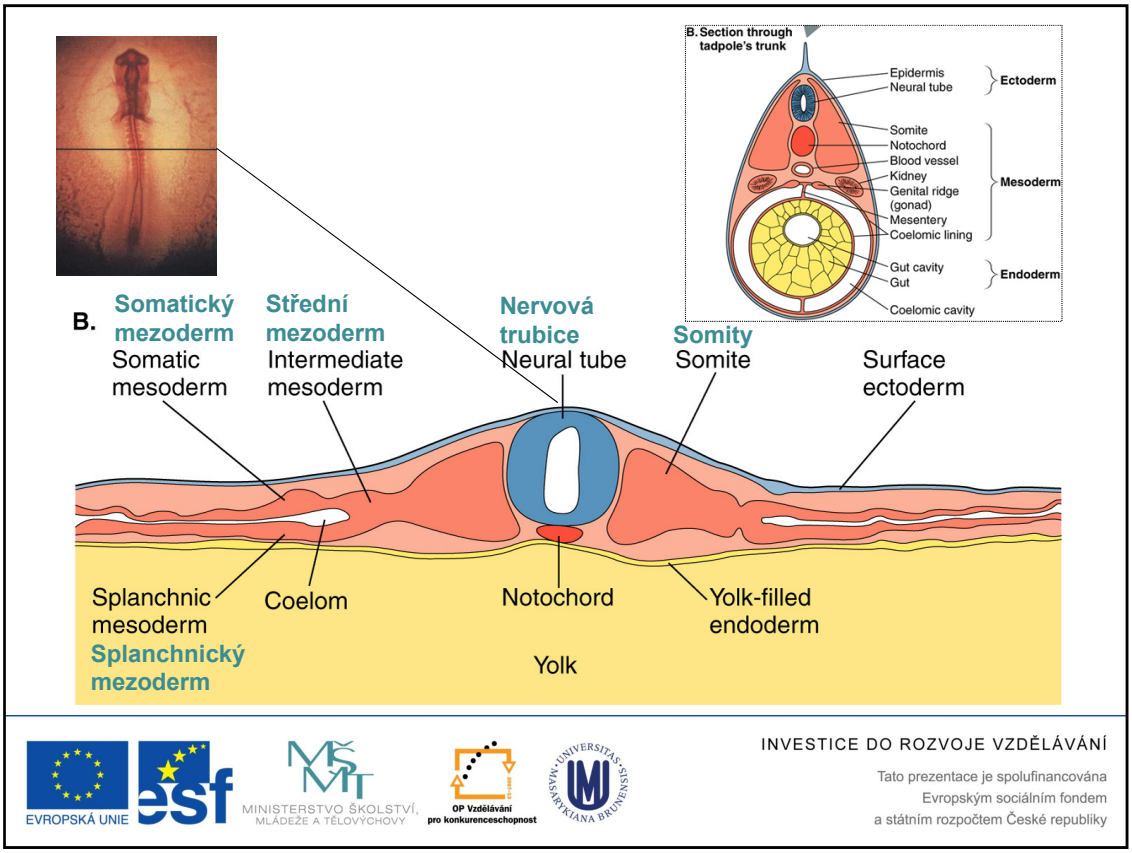
The **Hansen's node** is an *organizing center* of similar importance as is the Spemann organizer in amniotes.

It is a hub of complex morphogenic activties and cell interactions. E.g. it is a structural way station for passing cells and a centre of cell proliferation. The cells spread from here forming the notochord and brain (what is called a "head process").

The Hansen's node starts moving towards the posterior end of the primitive streak and leaves behind differentiated *neural plate, notochord* and the developing *somites*.

Hansen's node was shown to have similar function as have the cells of the dorsal lip in amniotes (Spemann organizer). Transplantation of the Hansen's node leads to the ectopic formation of neural tube and somites that are of host origin; thus, it is a *primary inducer*.

Hansen's node could be surgically extirpated (removed); however, ones the tissue heal, new node regenerates in a position where the tissues knit together. Thus, the **Hansen's node is a selforganizing morphogenic centre**, probably based on the interactions of surrounding tissues.



In a cross section of the developing chicken embryo, all the germ layers and *organ anlagen* (earliest beginnings of an organ, from German) are almost identical in comparison to *Xenopus* embryo:

Neural tube and *notochord* could be distinguished at the apical portion and bilateral *somites* are apparent.

More laterally, *intermediate mesoderm* forms that will develop into kidney.

Most laterally, the mesoderm forms thin spreading sheets that, again similarly to amphibians, form two layers, **somatic mesoderm** (fusion of the laterall mesoderm and ectoderm) and **splanchnic mesoderm** (fusion of the laterall mesoderm and entoderm). The space between them is **coelom**.

In comparison to amphibians (see the inset), the endodermal gut is missing and forms later.

The second major difference is the future formation of extraembryonic membranes that will enclose the embryo and that demonstrate an adaptation of terrestrial vertebrates.

Outline of Lesson 3

Early Development of Amphibians and Amniotes

- Gastrulation in amniotes – chicken
  - early and late gastrulation in chicken (video)

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Outline of Lesson 3

Early Development of Amphibians and Amniotes

- Gastrulation in amniotes – chicken
  - early and late gastrulation in chicken (video)
- Formation of extraembryonic tissues in amniotes - chicken

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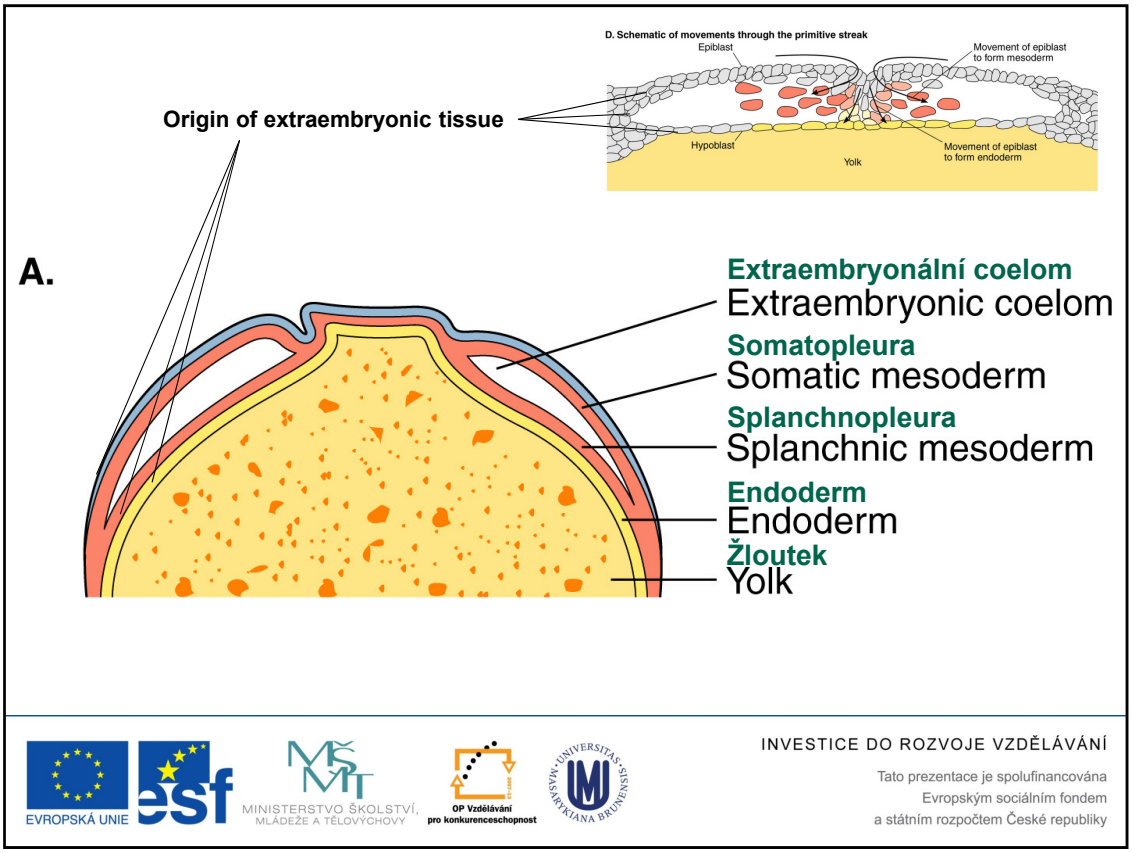
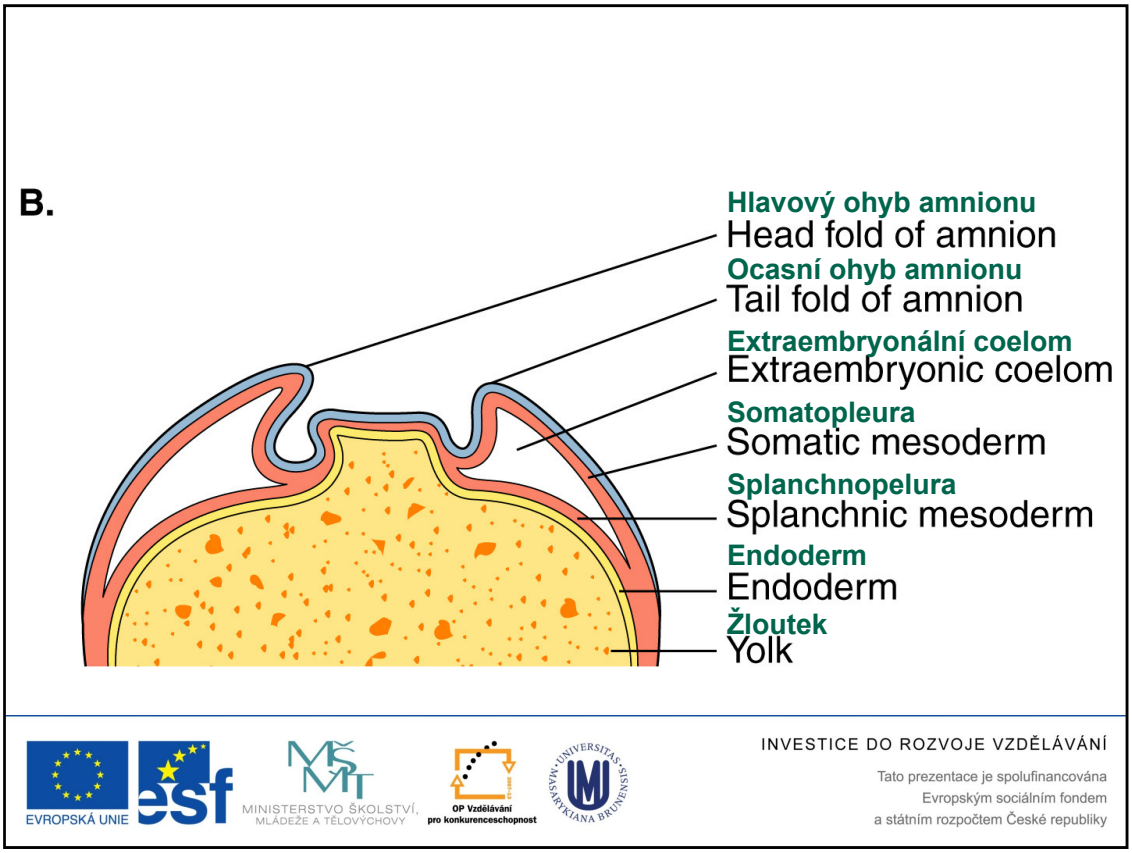
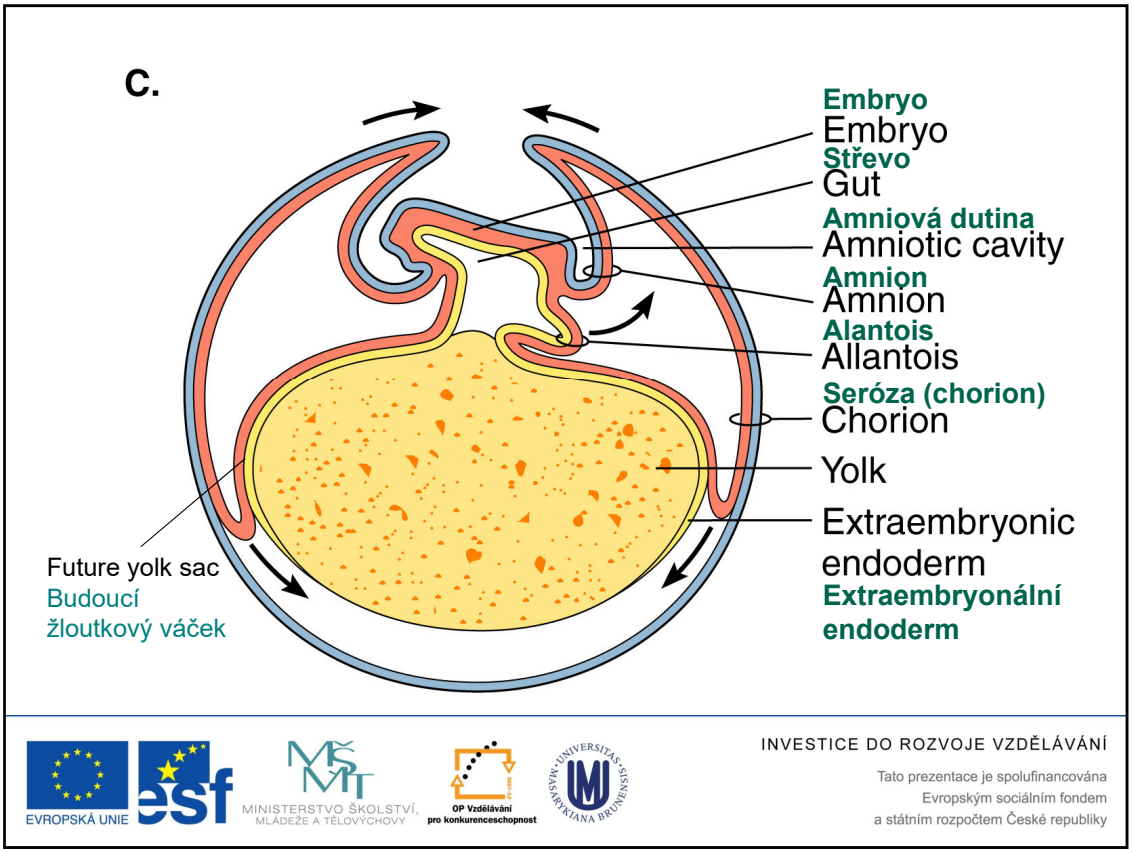


Via complicated invaginations and movements, four membrane sacs are formed of the extraembryonic tissue. The formation of the extraembryonic sacs represent adaptation for the terrestrial environment.

First, the double layered surroundings of the embryo are formed from the ectoderm-somatic mesoderm. The ectoderm-mesoderm layer in the zona pellucida region starts movements that undercut margins of the embryo and demarcate thus the extraembryuonic tissue from the embryo proper.



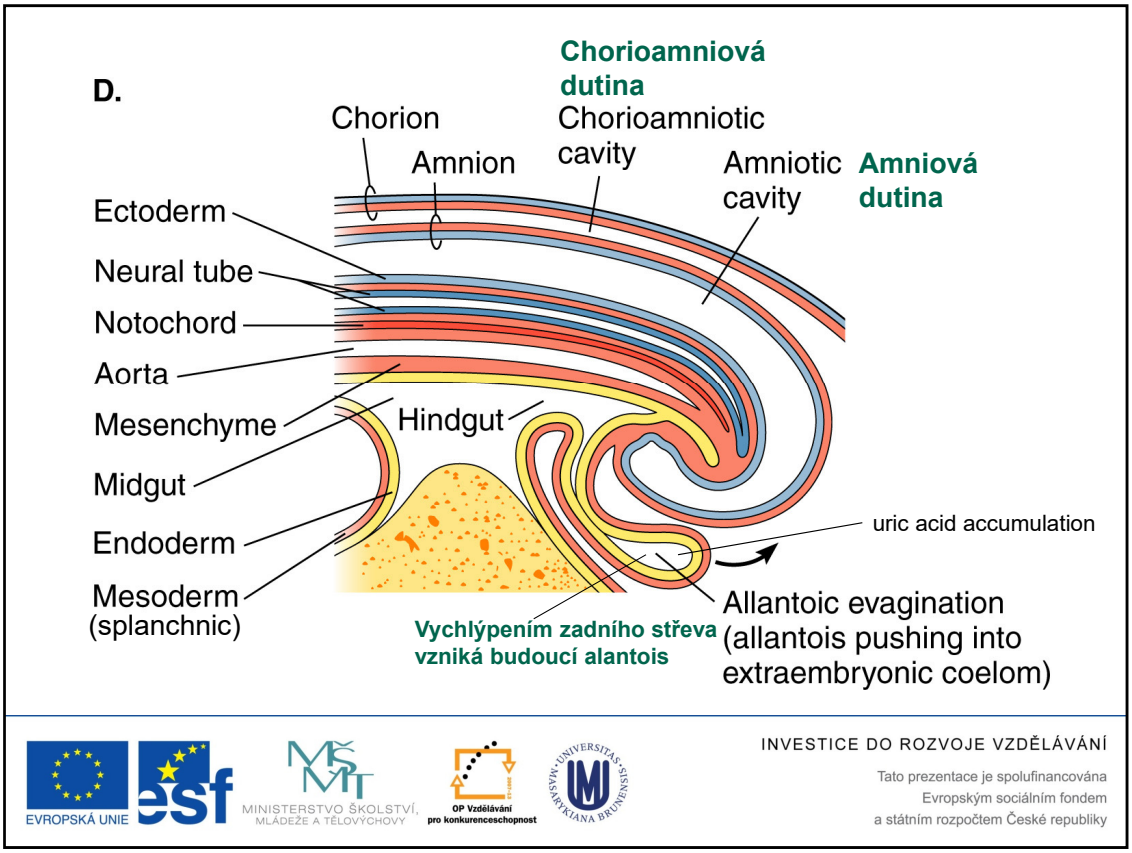
The extraembryonic tissue layers grow up and cover the embryo from both head and tail poles. The newly formed double ectoderm-mesoderm layer that starts to cover the embryo is called **amnion**.



Further growth of the head and tail folds of the amnion leads to the complete coverage of the embryo into what is called **amniotic cavity** and the double layers of the amnion eventually separate.

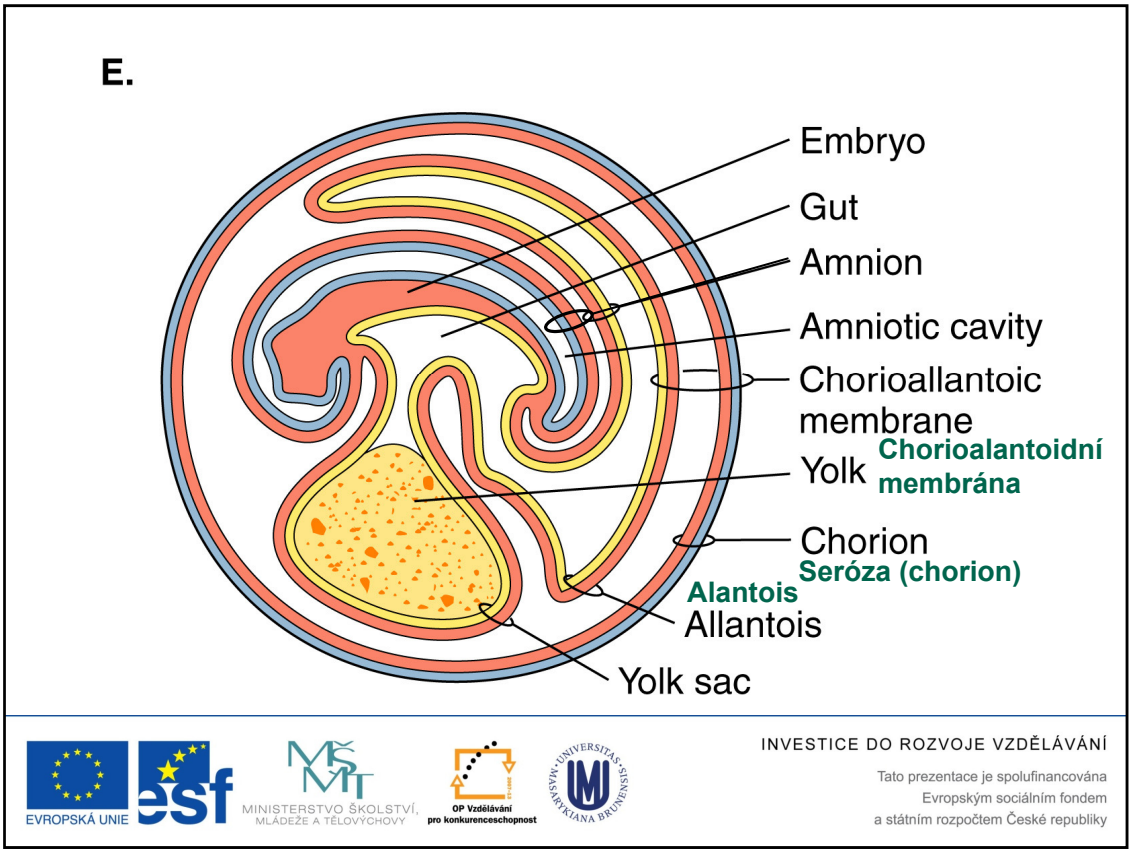
The outer ectoderm-mesoderm layer will eventually enclose the entire mass of the egg and become epithelial layer under the shell through which gas can exchange. This layer is called **chorion**.

The extraembryonic endoderm (originating from the hypoblast in the area opaca and area pellucida, see above) together with splanchnic mesoderm cover the yolk and become highly vascularized. The resulting structure is called **yolk sac**. The enzymes in the yolk sac allow mobilization of the enclosed yolk and via the blood stream the nutrients are supplied to the embryo.



The evagination of the hindgut that is composed of endoderm and splanchnic mesoderm into the space between yolk sac and chorion leads to the formation of another sac that is called **allantois**.

Allantois contains products of the embryo metabolism, the crystals of the uric acid. As the uric acid acummulates, the allantois expands but this is compensated by the reduction of the yolk sac.



In birds, the allantois becomes very large, fills the space between the chorion and yolk sac and fuses with chorion into singe *chorioallantoic membrane*. The mebrane is highly vascularized and allows gas exchange through the shell.

Key Concepts

- First source of **asymmetry originates from the oogenesis** both in *Drosophila* and *Xenopus*.
- In *Xenopus*, another **important source of asymmetry** leading to breaking of the virtual radial symmetry of the egg and **dorsoventral axis specification** is the **sperm entry** that induces **cytoplasm rotation**.
- These processes result into **Speman organizer differentiation** and allow **specification of the cell fate** during **blastula formation**.
- **Gastrulation** allows **further delimitation of the developmental fate**.
- **Amniotes** developed **terrestrial adaptations** that are of **extraembryonic origin**.

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