C8545 Developmental Biology

Lesson 1

Introduction into the Study of Development

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Outline of Lesson 1

- The course at a glance and literature
- Repetitorium of basic terms
  - Major body directions
  - Mitosis vs. Meiosis
- Overview of development
  - Asymmetrical cell division as a major force of the development
  - Genetic integrity of the differentiated cells
  - Concept of stem cells
- Gametogenesis, fertilization and lineage tracing

The Course at a Glance

- **Lesson 1**
  - Introduction into the Study of Development
    - Repetitorium of Basic Terms
    - Overview of Development
    - Gametogenesis, Fertilization and Lineage Tracing
- **Lesson 2**
  - Oogenesis and Early Development of *Drosophila*
- **Lesson 3**
  - Early Development of Amphibians and Amniotes
- **Lesson 4**
  - Vertebrate Organogenesis
    - Development of Ectodermal Derivatives

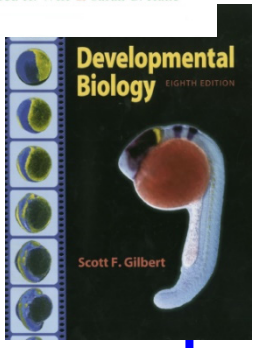
The Course at a Glance

- **Lesson 5**
  - Vertebrate Organogenesis
    - Development of Mesodermal and Endodermal Derivatives
- **Lesson 6**
  - Plant Reproduction
- **Lesson 7**
  - Plant Embryogenesis
- **Lesson 8**
  - Postembryonic Plant Development

The Course at a Glance

- **Lesson 9**
  - Morphogenesis in Animals and in Plants
- **Lesson 10**
  - Regulation of Gene Expression in the Development

Literature



- **Fred H. Wilt and Sarah Hake, Principles of Developmental Biology** (W.W. Norton & Company, New York, London, 2004)
- **Scott F. Gilbert, Developmental Biology,** eighth edition (Sinauer Associates, Inc., Publishers Sunderland, Massachusetts, USA, 2006)
- Zdeněk Vacek, Embryologie (Grada Publishing, 2006)
- Dubová J., Hejátko J., Friml J. (2005) Reproduction of Plants, in Encyclopedia of Molecular Cell Biology and Molecular Medicine (ed, R. A. Meyers), pp. 249 – 295. Wiley-VCH, Weinheim, Germany
- Selected original papers in scientific journals

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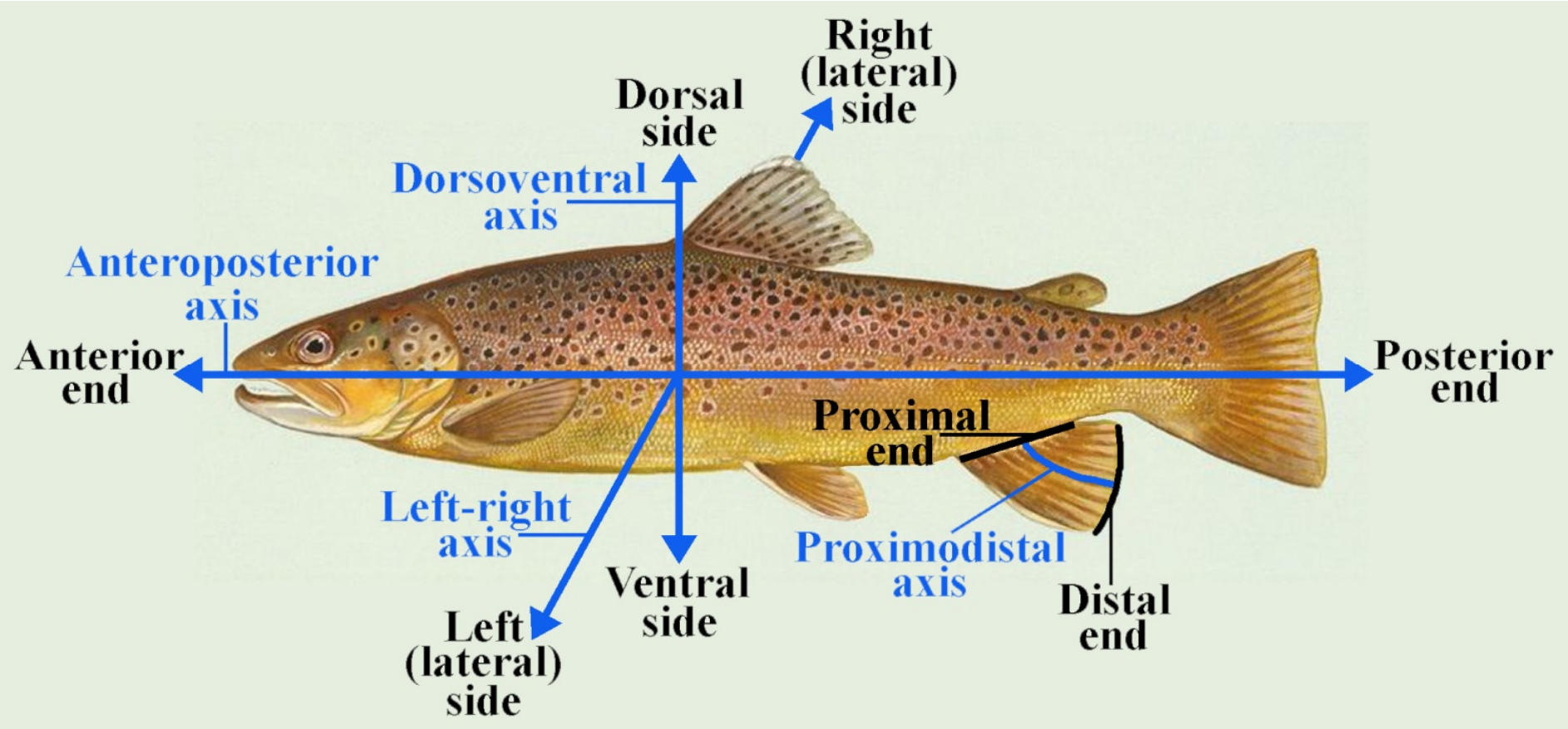
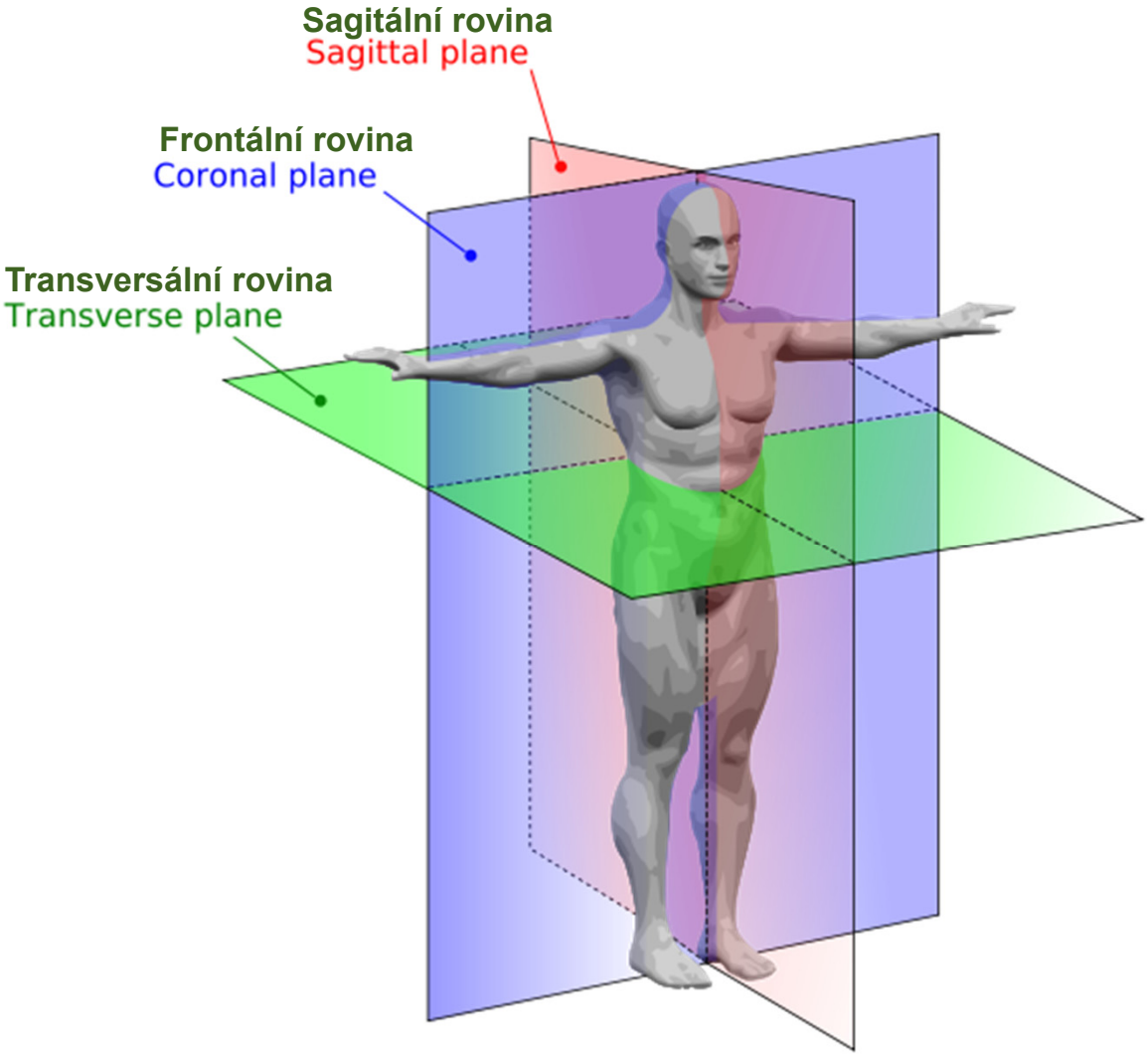
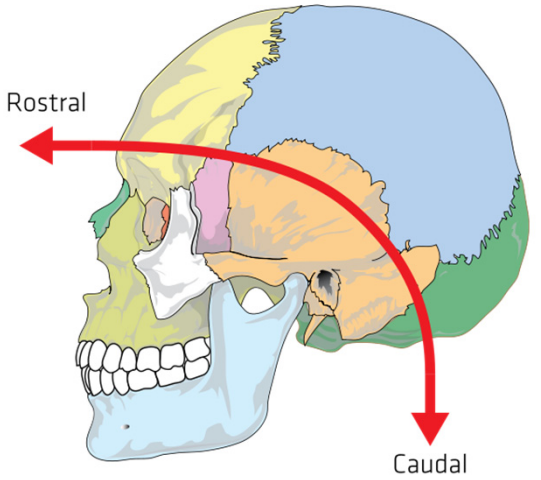
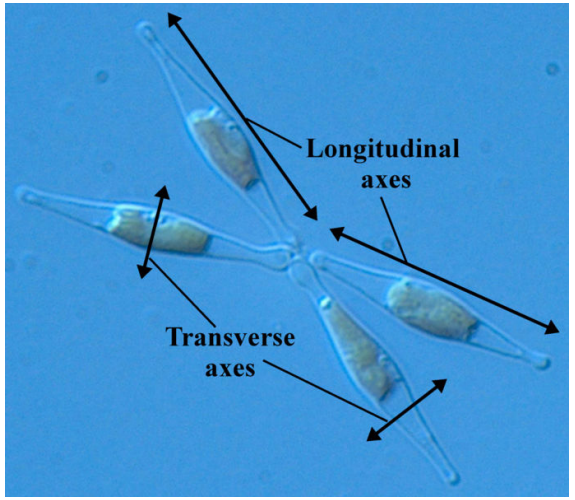


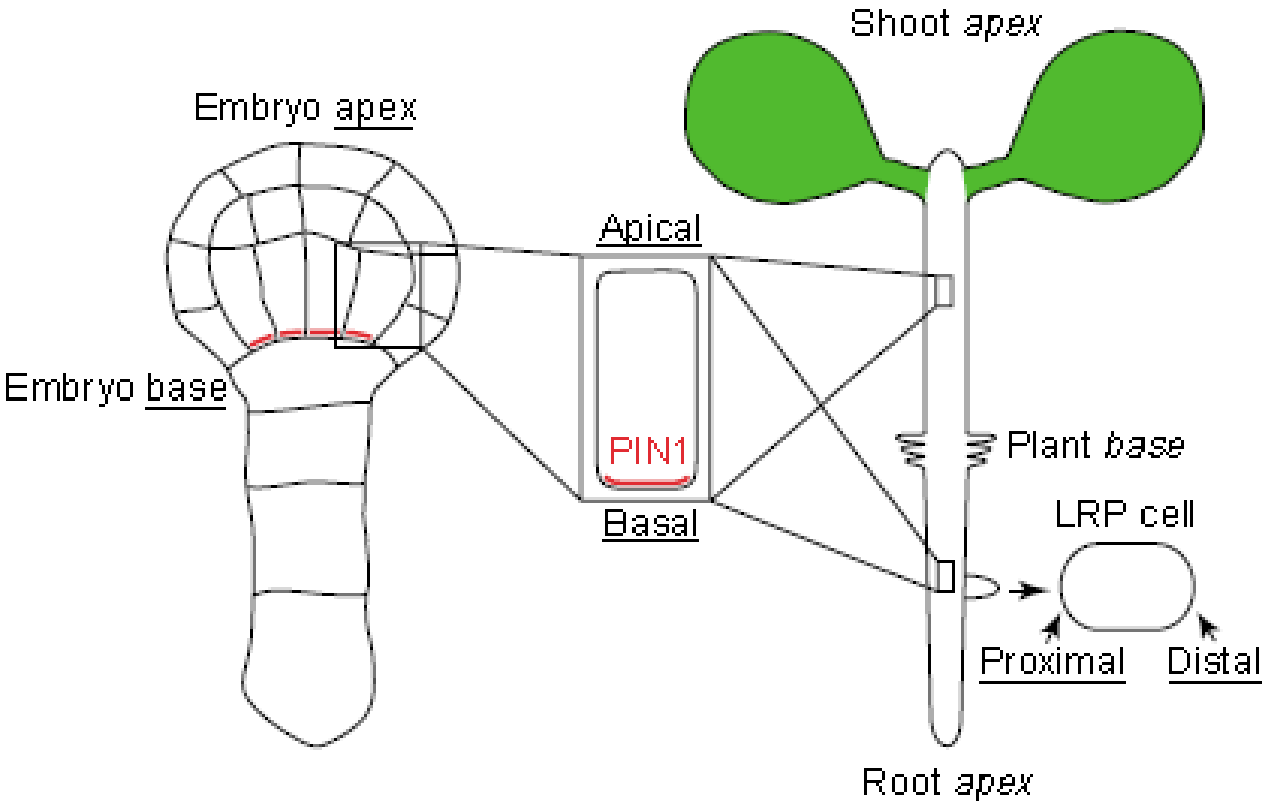
http://en.wikipedia.org/wiki/Anatomical_terms_of_location



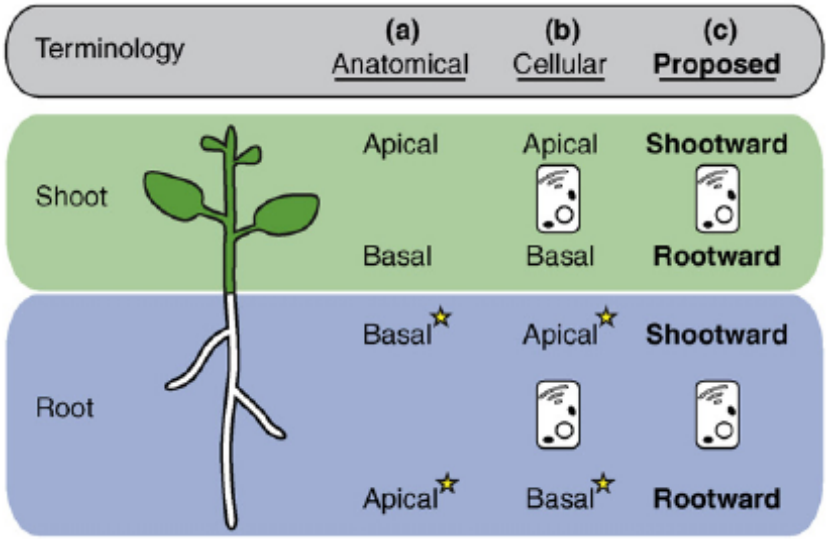
http://en.wikipedia.org/wiki/Anatomical_terms_of_location

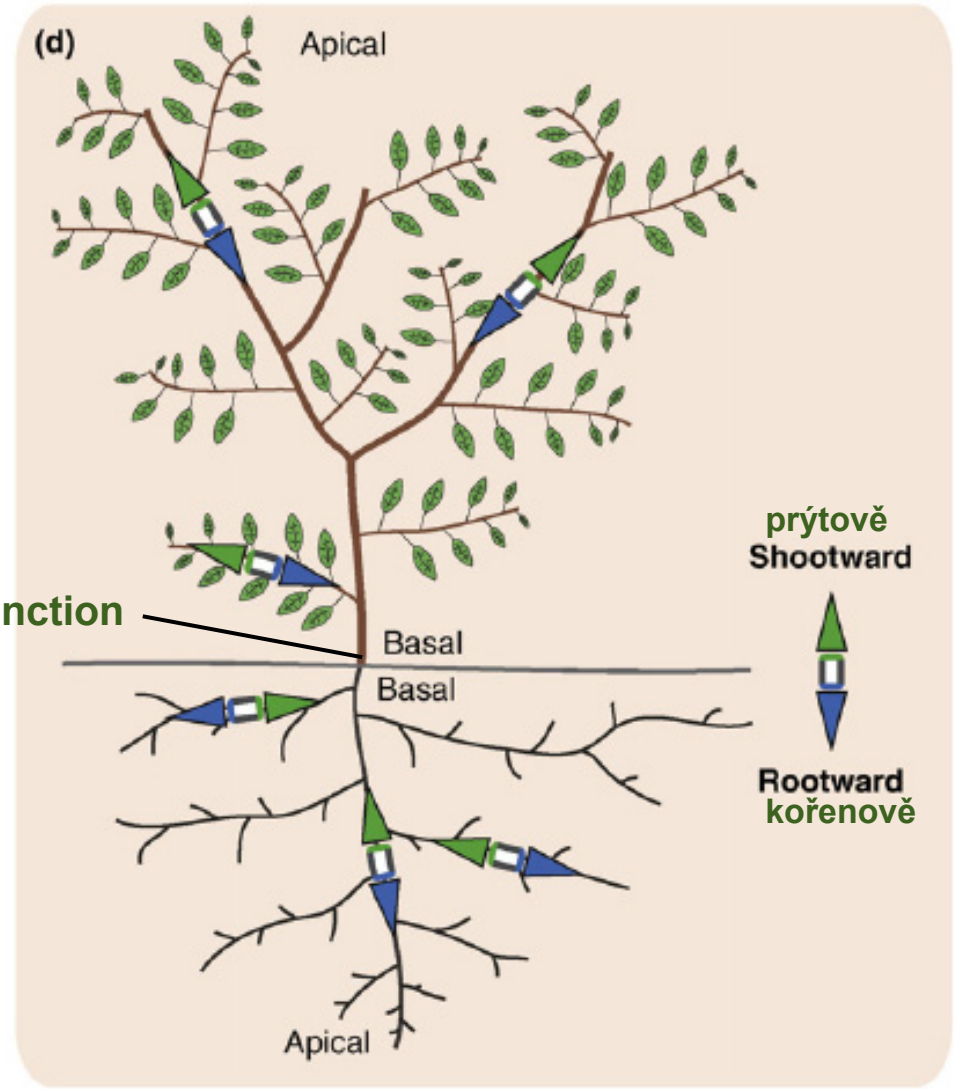






Friml et al., *Trends Plant Sci* (2006)





Baskin et al., *Trends Plant Sci* (2010)

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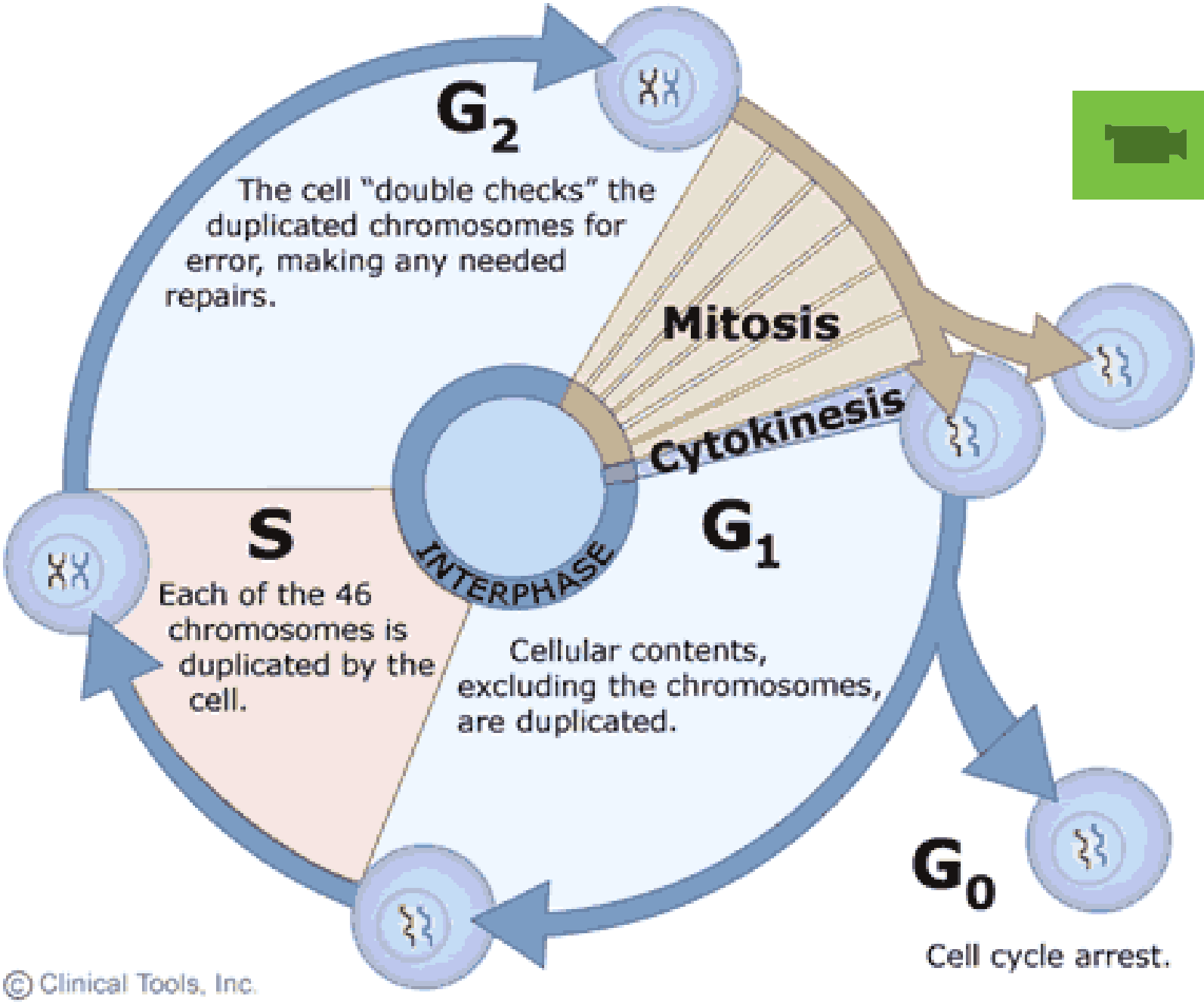
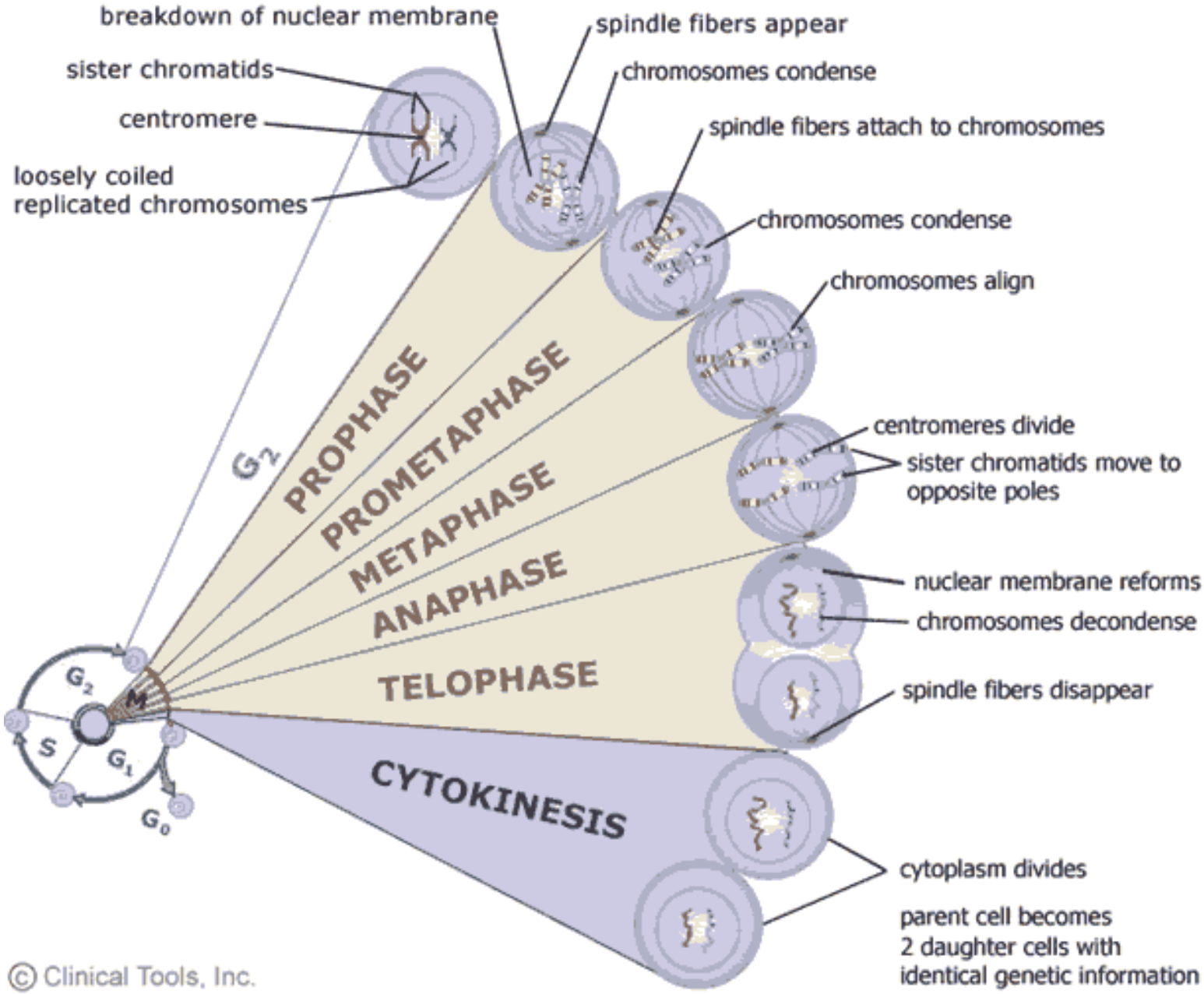
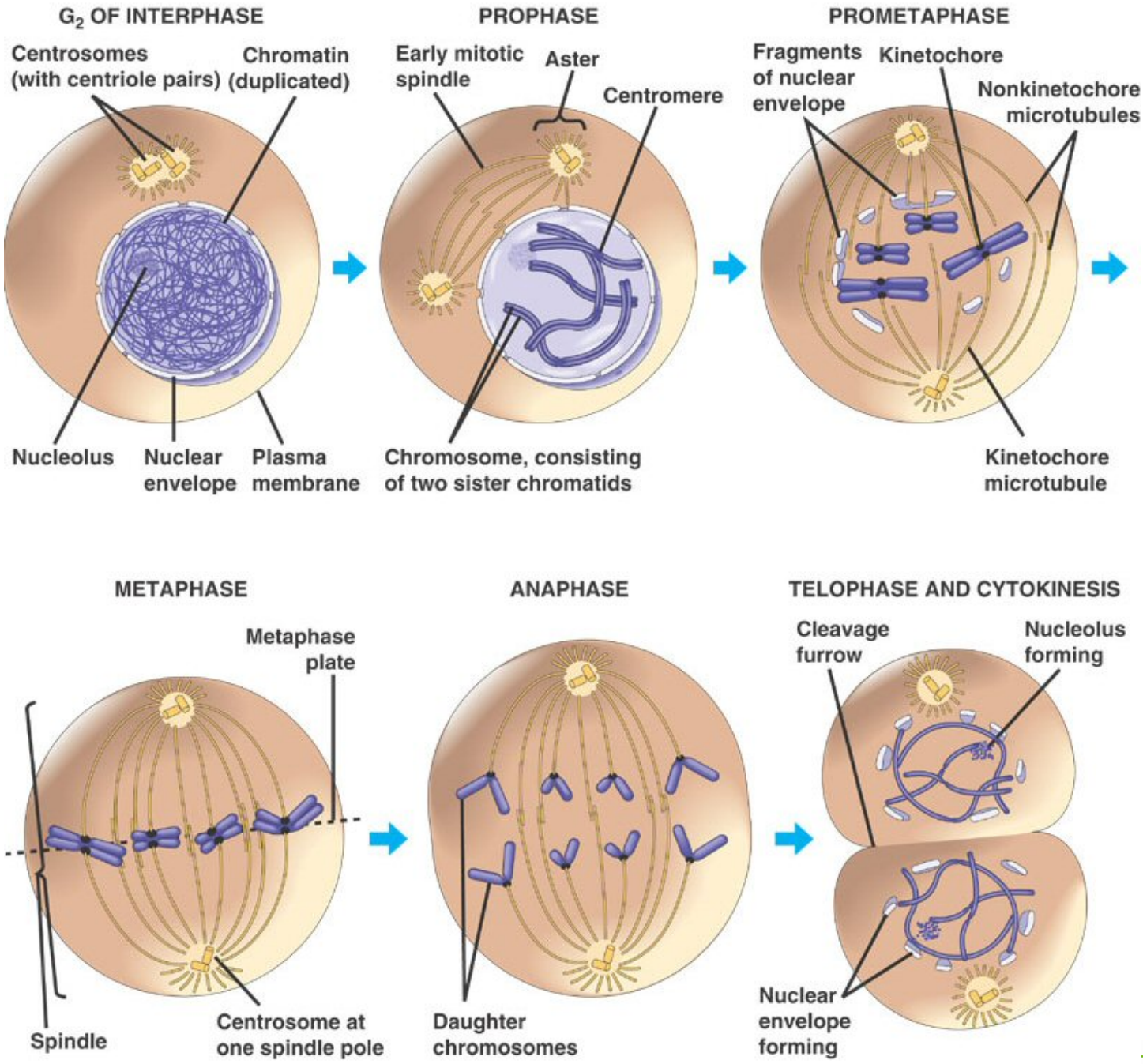
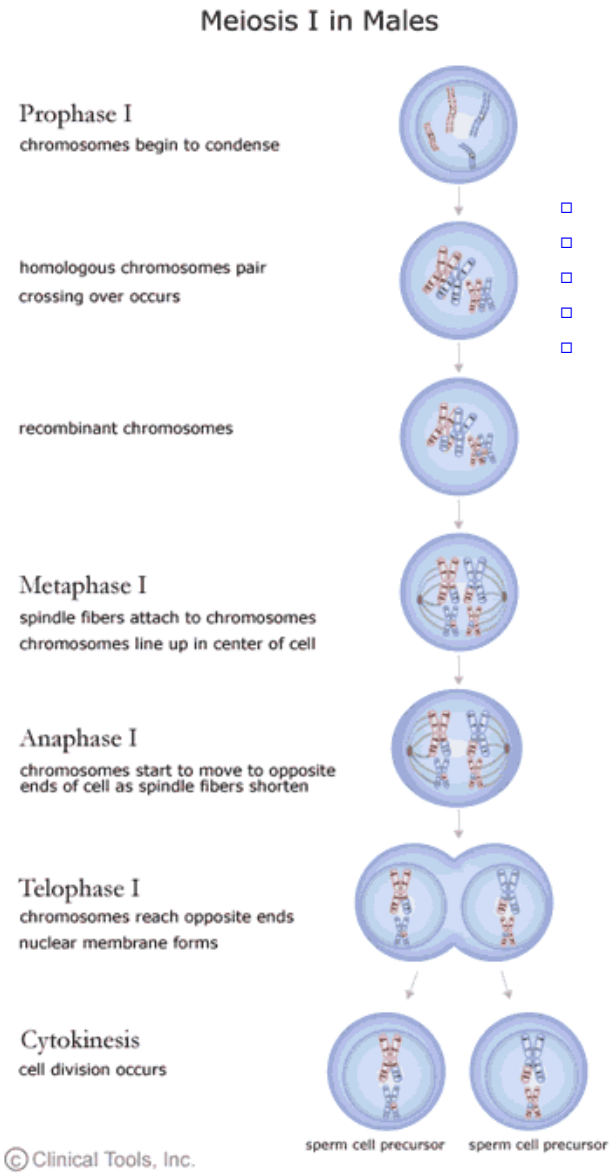
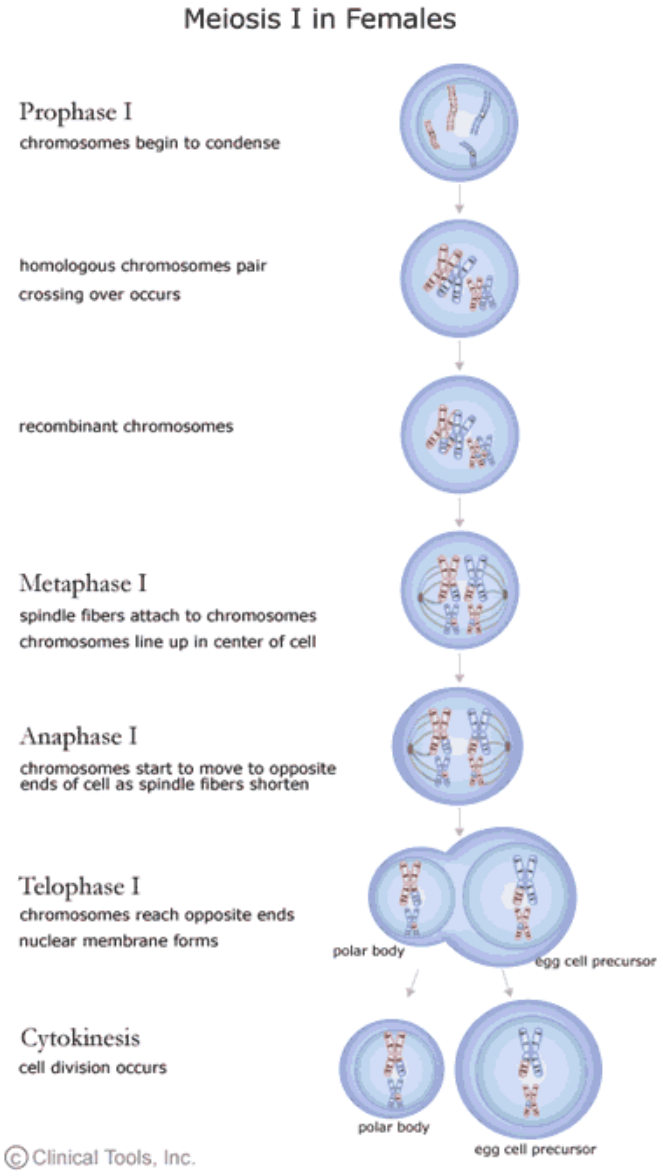

G2
The cell "double checks" the duplicated chromosomes for error, making any needed repairs.
Mitosis
Cytokinesis
INTERPHASE
G1
Cellular contents, excluding the chromosomes, are duplicated.
S
Each of the 46 chromosomes is duplicated by the cell.
G0
Cell cycle arrest.
© Clinical Tools, Inc.

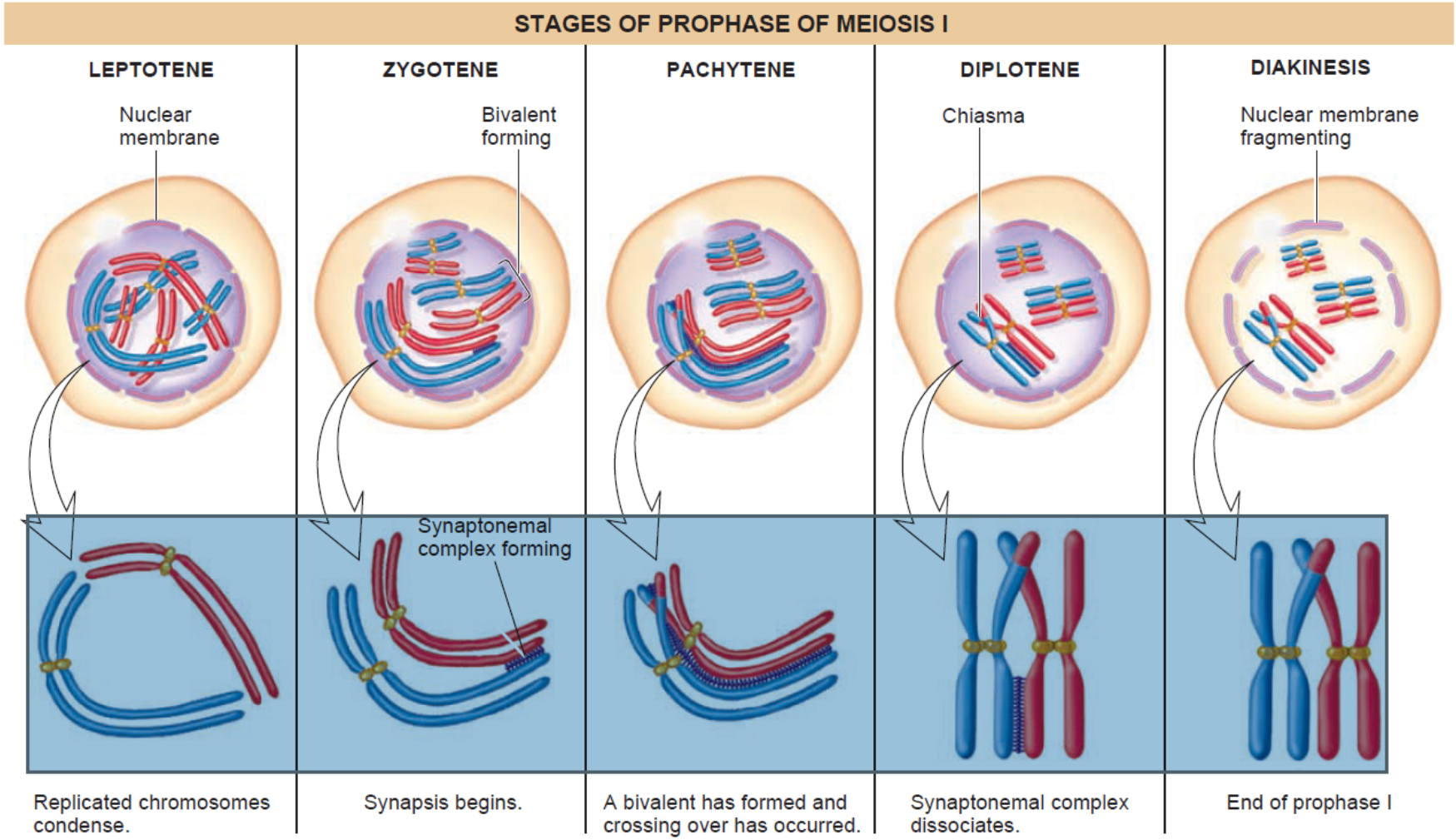

breakdown of nuclear membrane
spindle fibers appear
sister chromatids
chromosomes condense
centromere
spindle fibers attach to chromosomes
loosely coiled
replicated chromosomes
chromosomes condense
chromosomes align
centromeres divide
sister chromatids move to
opposite poles
nuclear membrane reforms
chromosomes decondense
spindle fibers disappear
cytoplasm divides
parent cell becomes
2 daughter cells with
identical genetic information
PROPHASE
PROMETAPHASE
METAPHASE
ANAPHASE
TELOPHASE
CYTOKINESIS
G2
G2
M
S
G1
G0
© Clinical Tools, Inc.


G2 OF INTERPHASE
Centrosomes (with centriole pairs)
Chromatin (duplicated)
Nucleolus
Nuclear envelope
Plasma membrane
PROPHASE
Early mitotic spindle
Aster
Centromere
Chromosome, consisting of two sister chromatids
PROMETAPHASE
Fragments of nuclear envelope
Kinetochore
Nonkinetochore microtubules
Kinetochore microtubule
METAPHASE
Metaphase plate
Spindle
Centrosome at one spindle pole
ANAPHASE
Daughter chromosomes
TELOPHASE AND CYTOKINESIS
Cleavage furrow
Nucleolus forming
Nuclear envelope forming

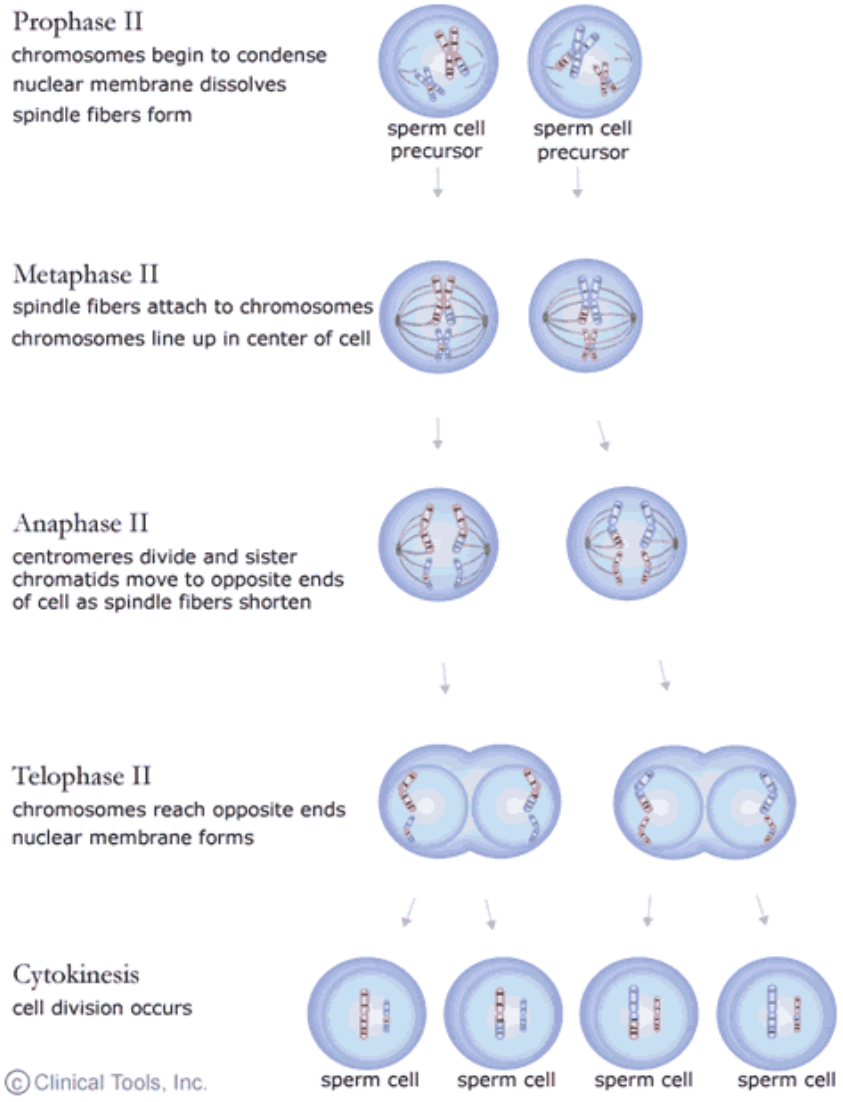


- **Leptotene**
- **Zygotene**
- **Pachytene**
- **Diplotene**
- **Diakinesis**

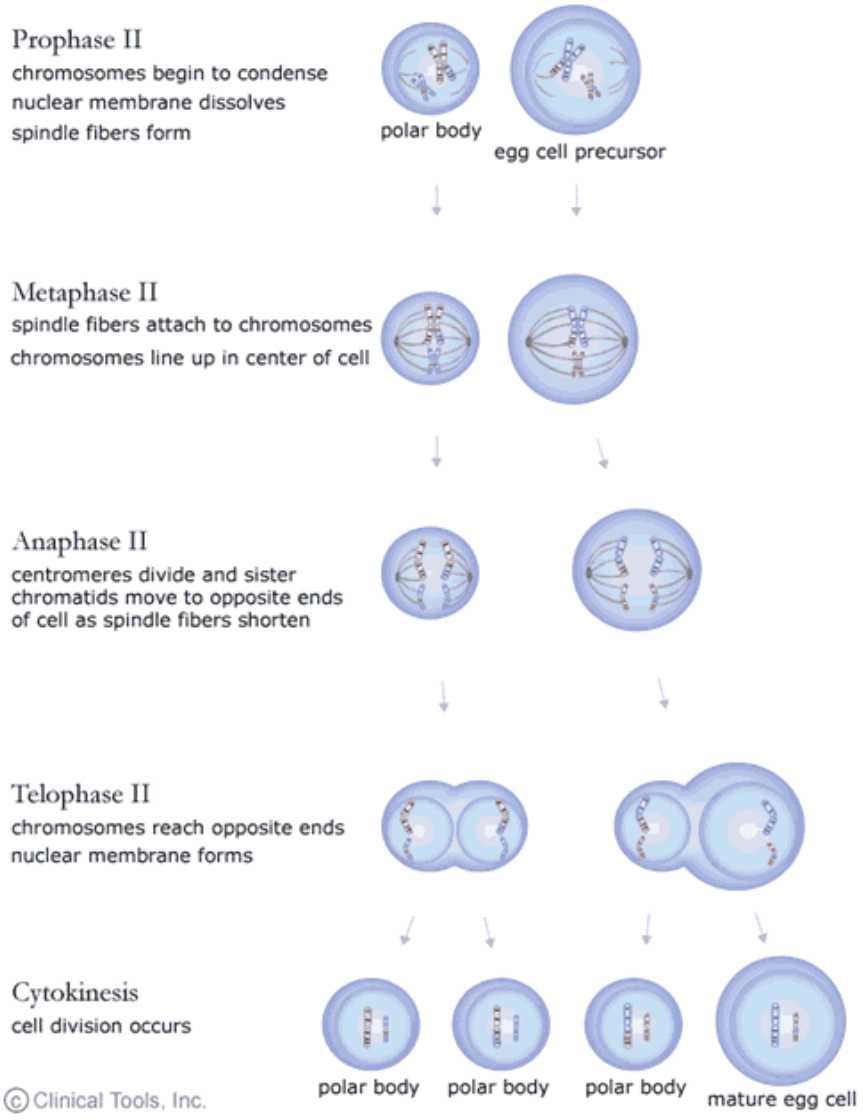


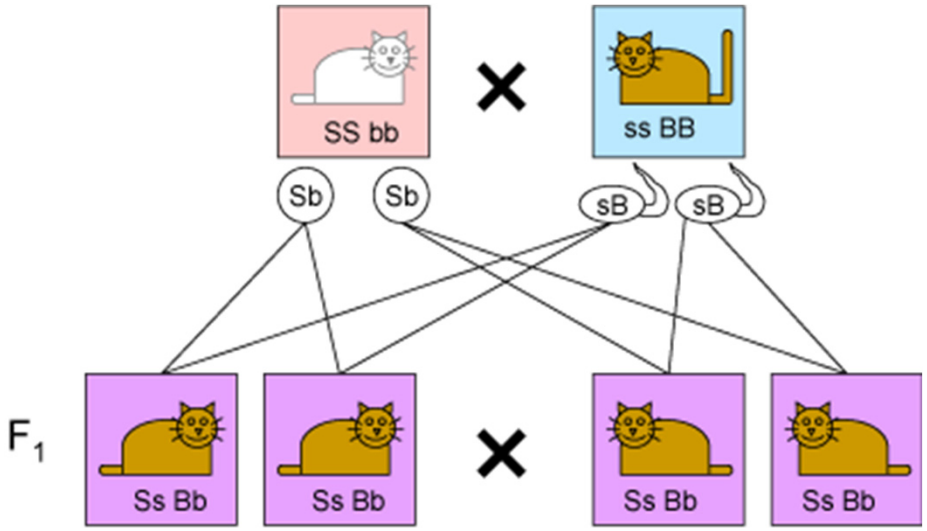

STAGES OF PROPHASE OF MEIOSIS I
LEPTOTENE
ZYGOTENE
PACHYTENE
DIPLOTENE
DIAKINESIS
Nuclear membrane
Bivalent forming
Chiasma
Nuclear membrane fragmenting
Synaptonemal complex forming
Replicated chromosomes condense.
Synapsis begins.
A bivalent has formed and crossing over has occurred.
Synaptonemal complex dissociates.
End of prophase I

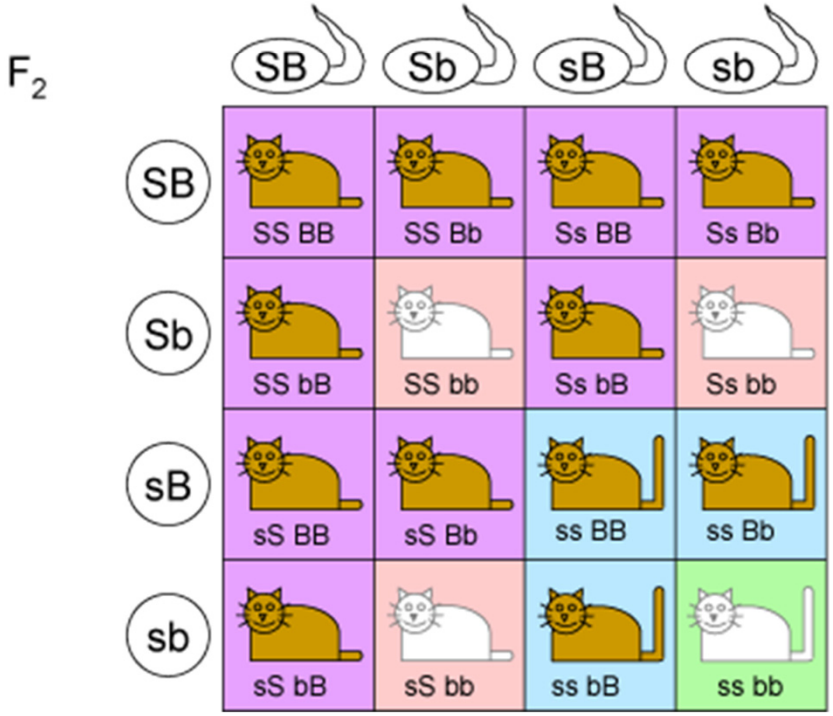
Meiosis II in Males



Meiosis II in Females




SS bb
ss BB
Sb
Sb
sB
sB
F1
Ss Bb
Ss Bb
Ss Bb
Ss Bb


F2
SB
Sb
sB
sb
SB
SS BB
SS Bb
Ss BB
Ss Bb
Sb
SS bB
SS bb
Ss bB
Ss bb
sB
sS BB
sS Bb
ss BB
ss Bb
sb
sS bB
sS bb
ss bB
ss bb

Wikipedia

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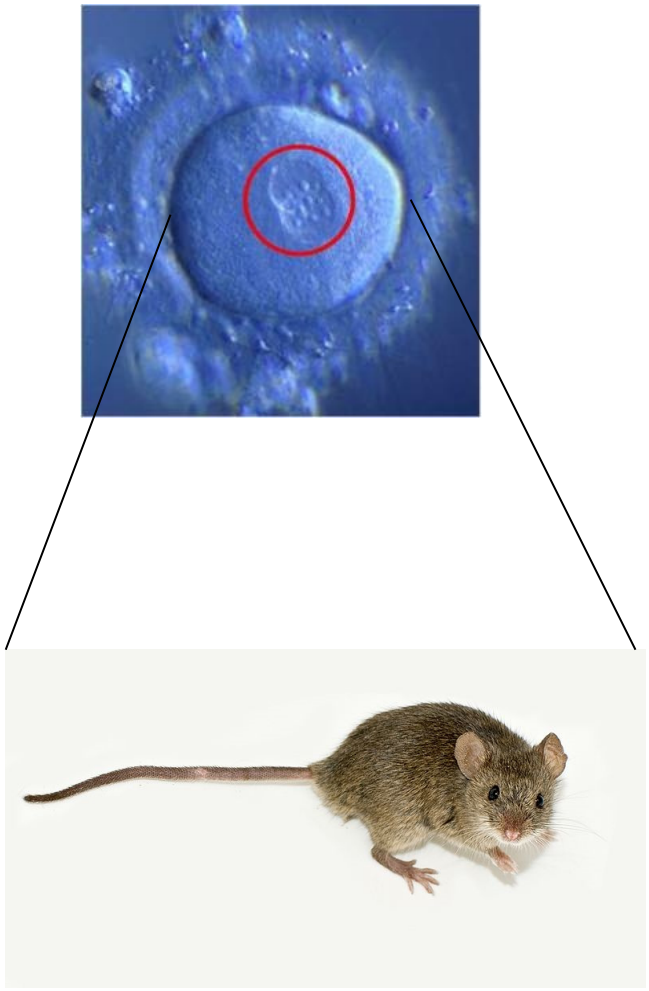
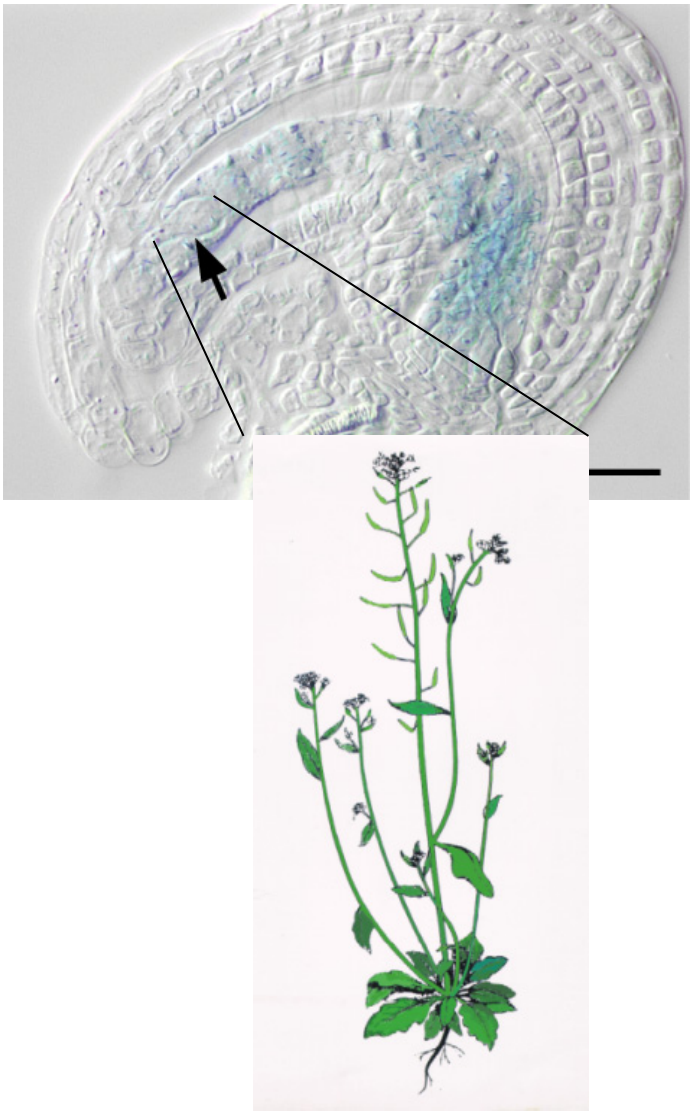
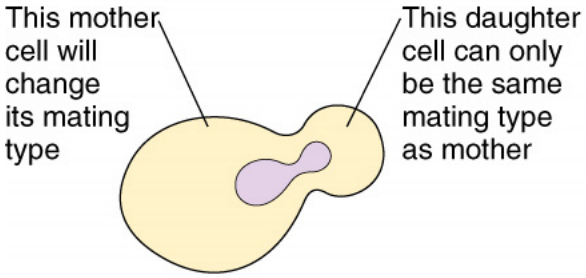


Wikipedia and Bio-Image

Hejátko et al., *Mol Genet Genomics* (2003)

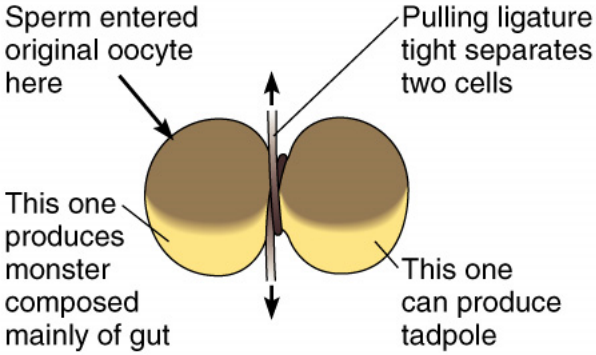


A. Yeast Mitosis (Budding)



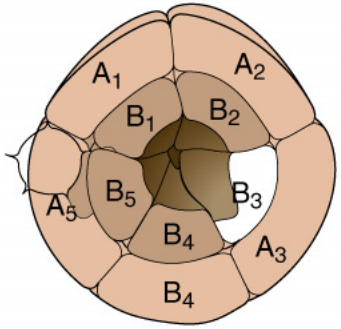
Scale: Mature yeast cell ≈ 10 μm

B. Amphibian Embryo (2-Cell Stage)



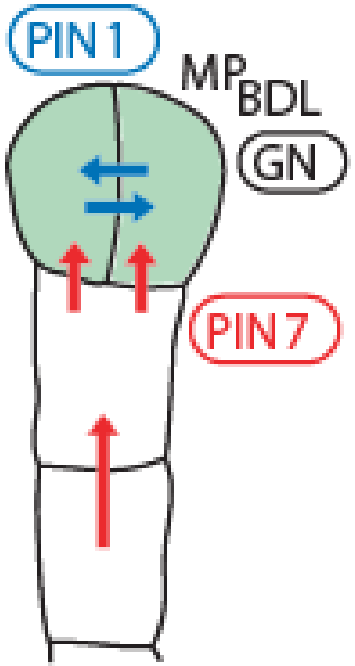
Scale: Entire egg ≈ 1 mm

C. Mouse Embryo (16-Cell Stage)

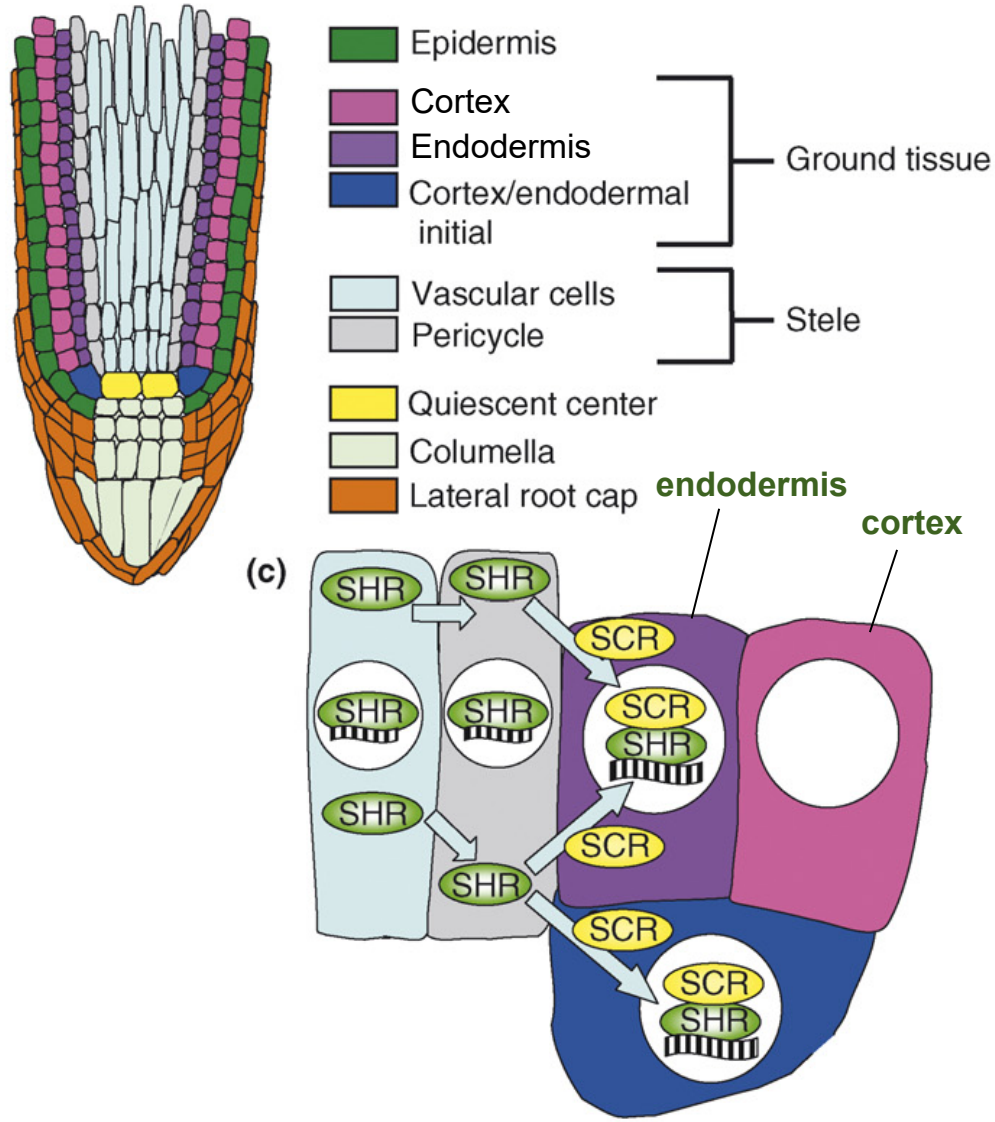


Each AB pair (A_1B_1, A_2B_2, etc.) arose from one mother cell. A cells can only form extra-embryonic tissues like placenta. B cell descendants may form the embryo proper.

Scale: Entire embryo ≈ 100 μm



Dubova, Hejatko, Friml (2005)



Petricka & Benfey, *Curr Opinion Genet Dev* (2008)

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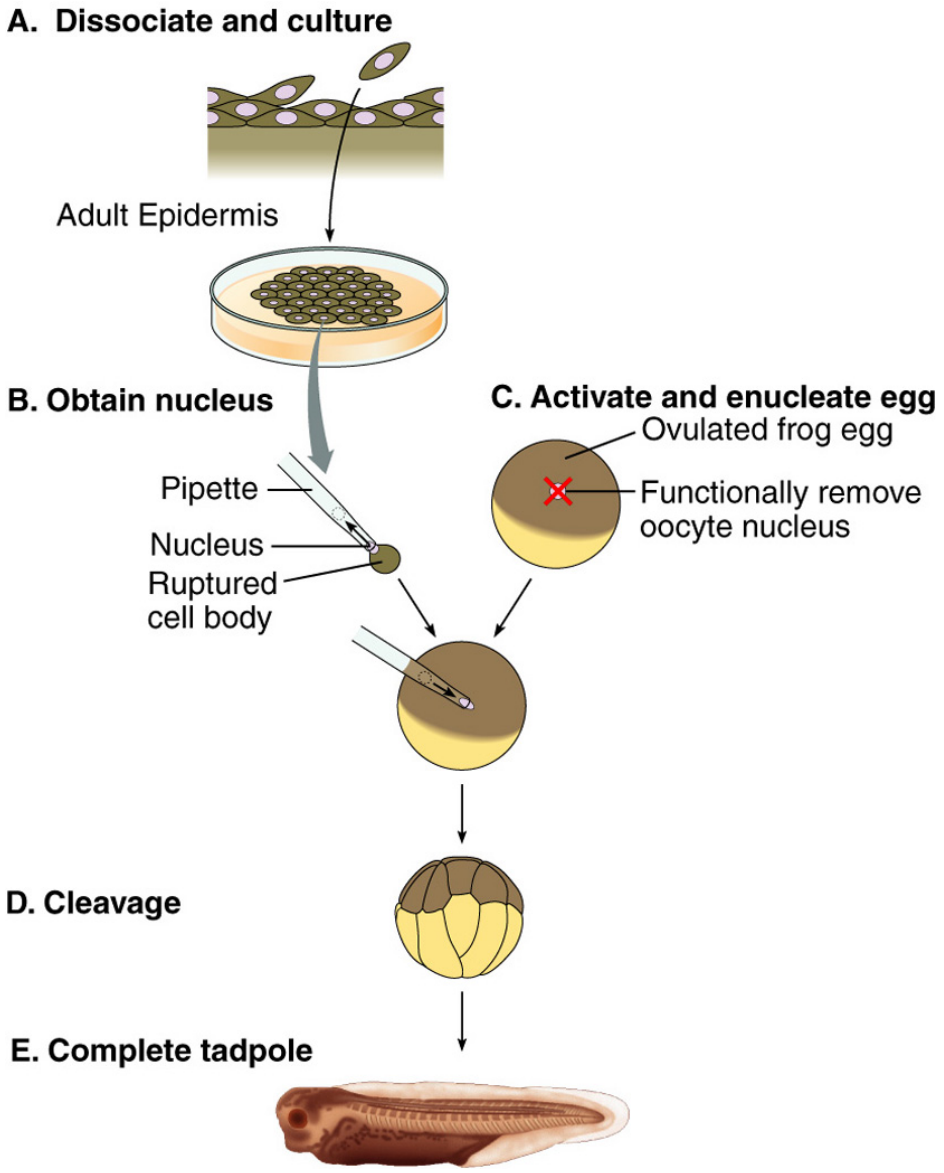
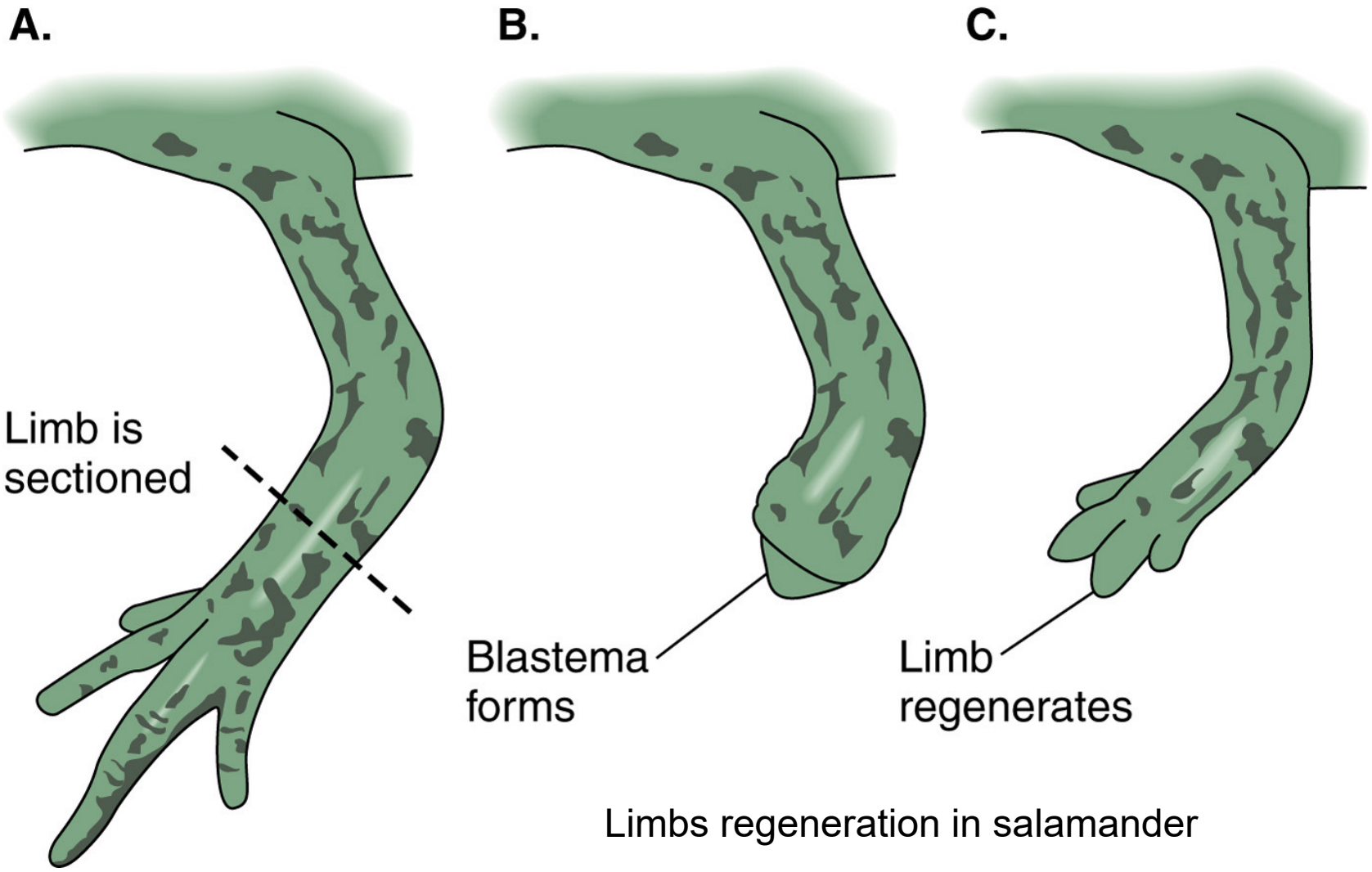
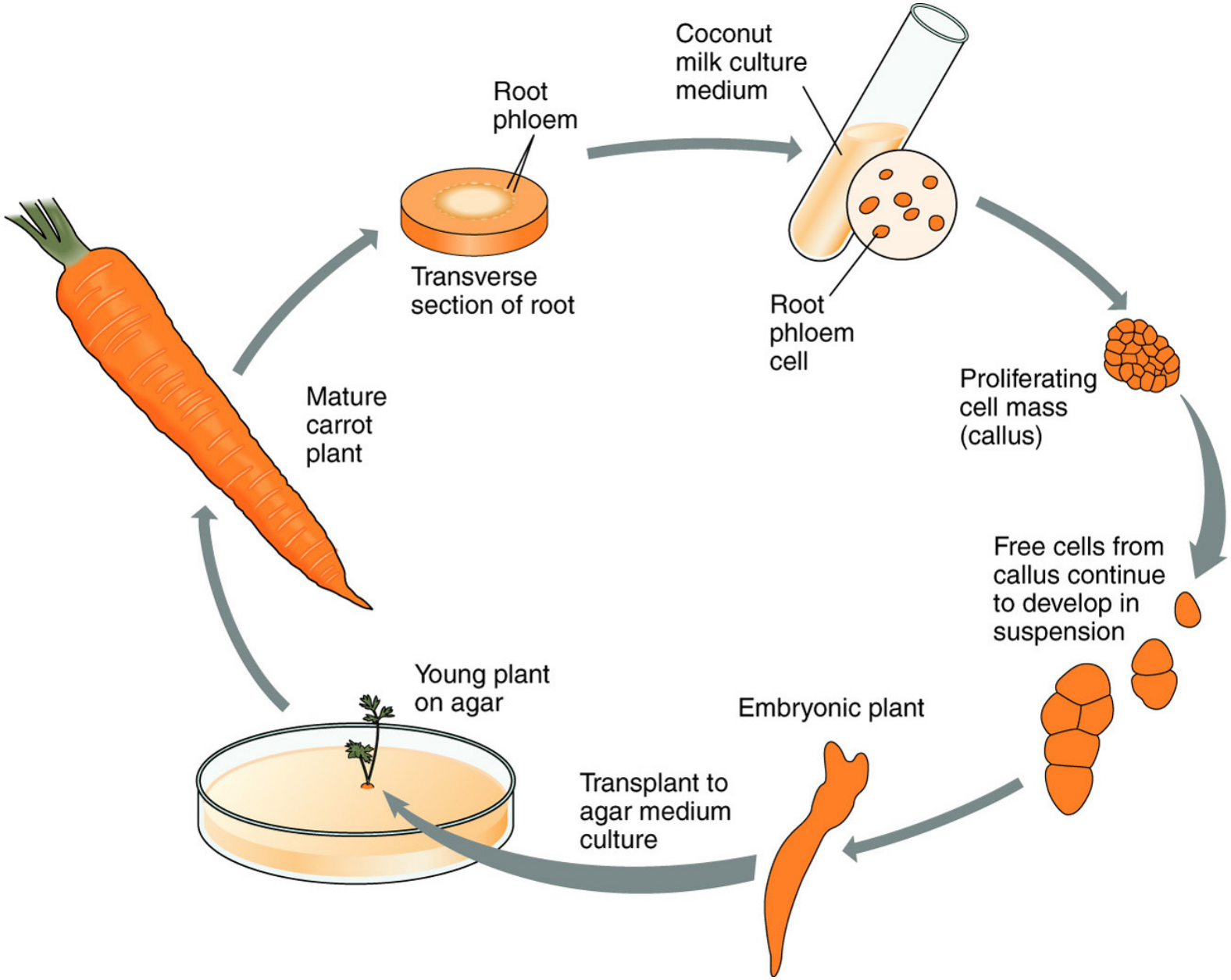

A. Dissociate and culture
Adult Epidermis
B. Obtain nucleus
Pipette
Nucleus
Ruptured
cell body
C. Activate and enucleate egg
Ovulated frog egg
Functionally remove
oocyte nucleus
D. Cleavage
E. Complete tadpole



Limbs regeneration in salamander


Root
phloem
Coconut
milk culture
medium
Transverse
section of root
Root
phloem
cell
Mature
carrot
plant
Proliferating
cell mass
(callus)
Free cells from
callus continue
to develop in
suspension
Young plant
on agar
Embryonic plant
Transplant to
agar medium
culture

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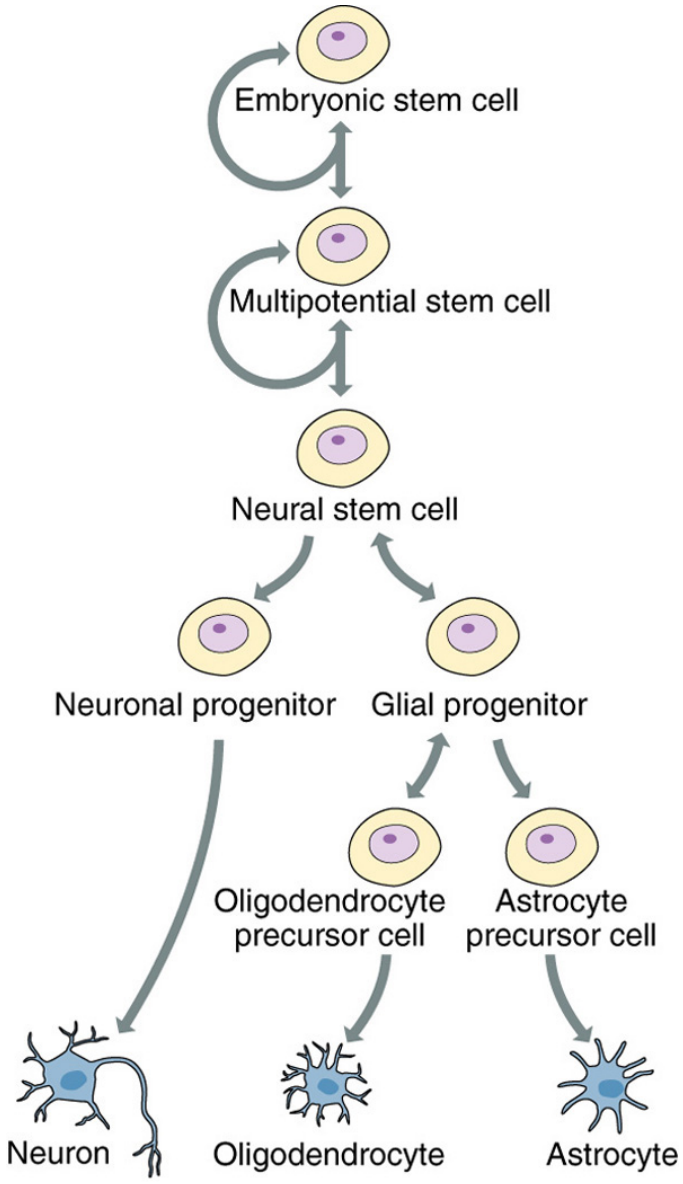
Embryonic stem cell
Multipotential stem cell
Neural stem cell
Neuronal progenitor
Glial progenitor
Oligodendrocyte precursor cell
Astrocyte precursor cell
Neuron
Oligodendrocyte
Astrocyte

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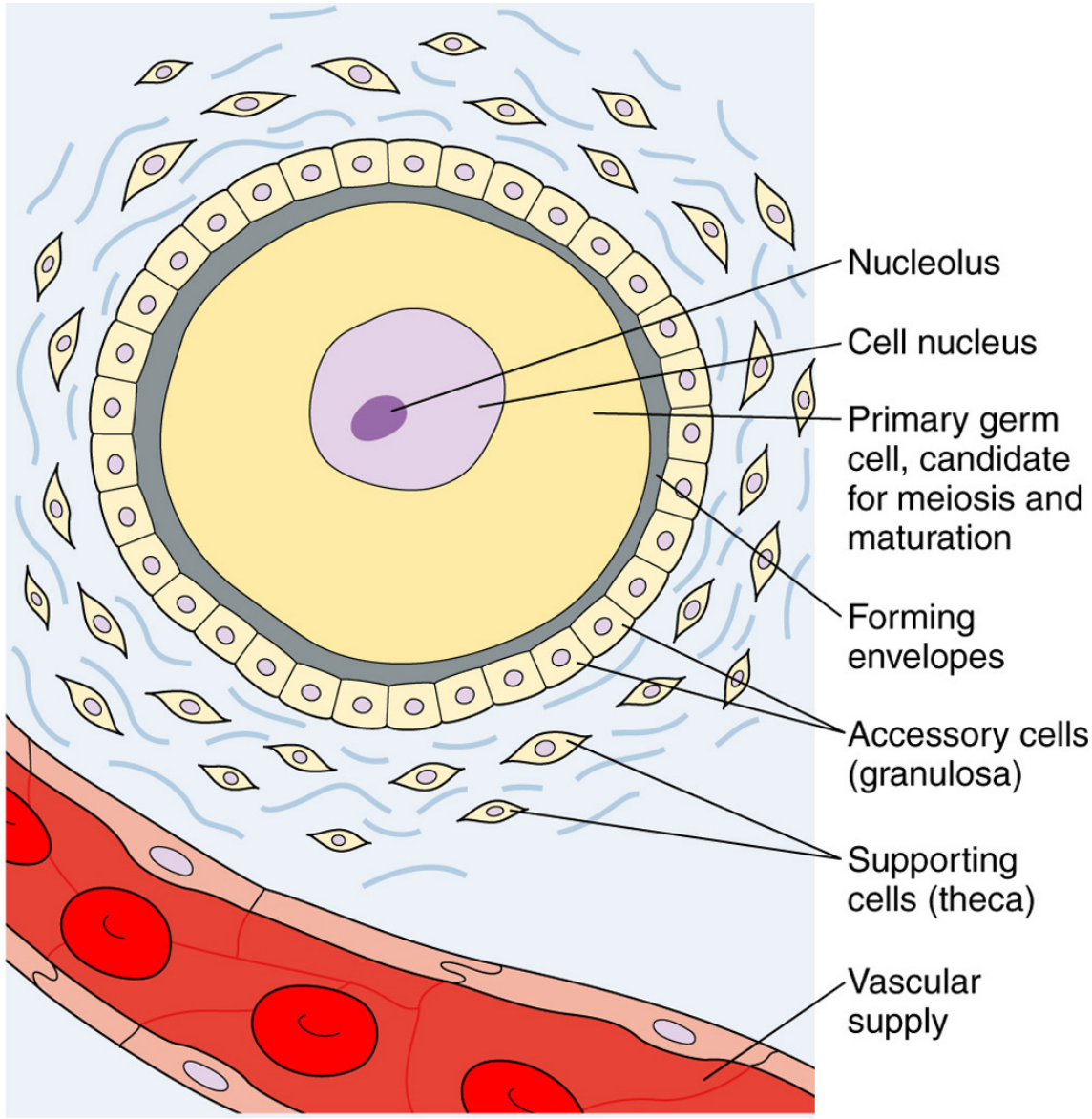
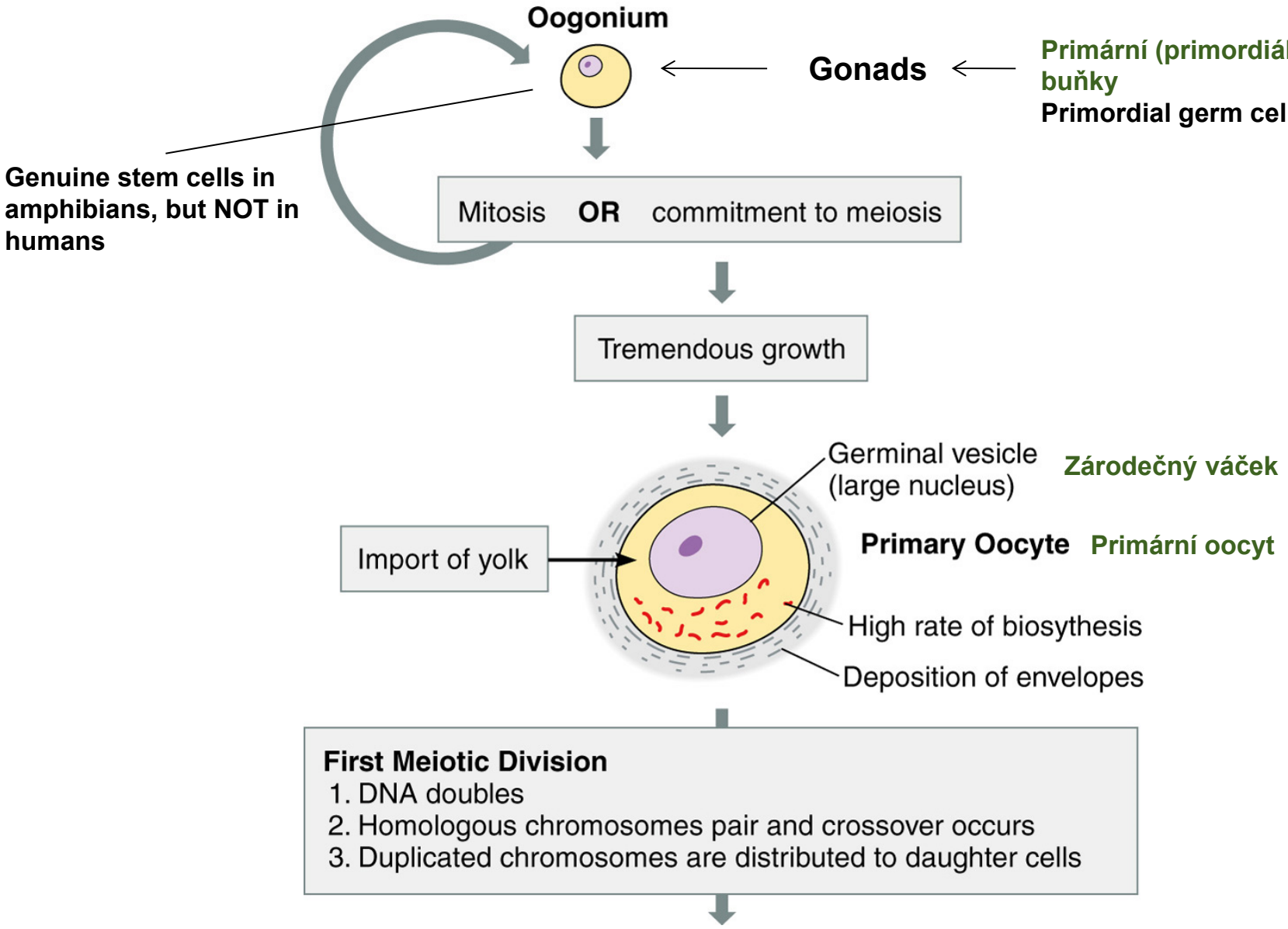


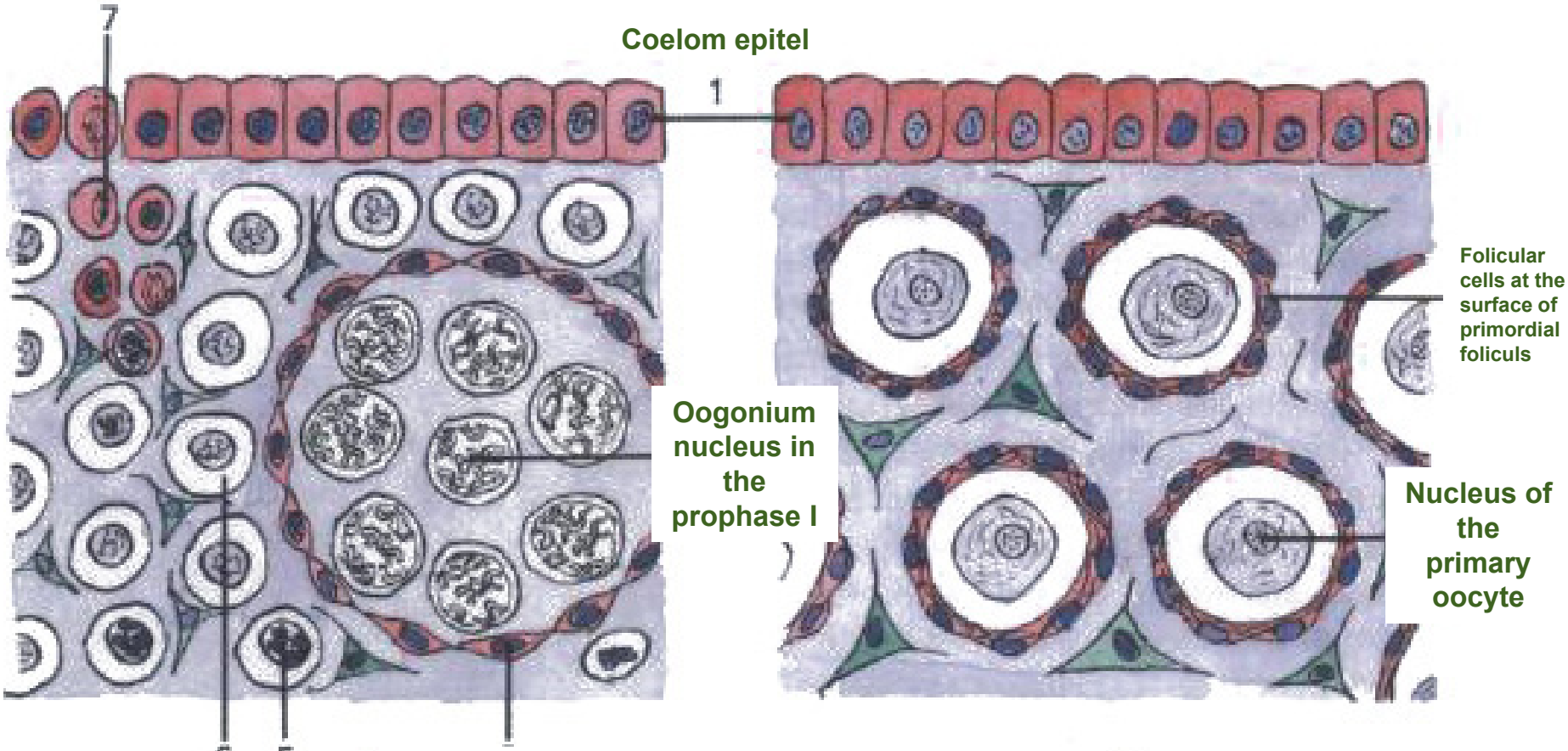
Primární zárodečná buňka

Folikulární buňky na povrchu vyvíjejících se primordiálních folikulů

Podpůrné buňky

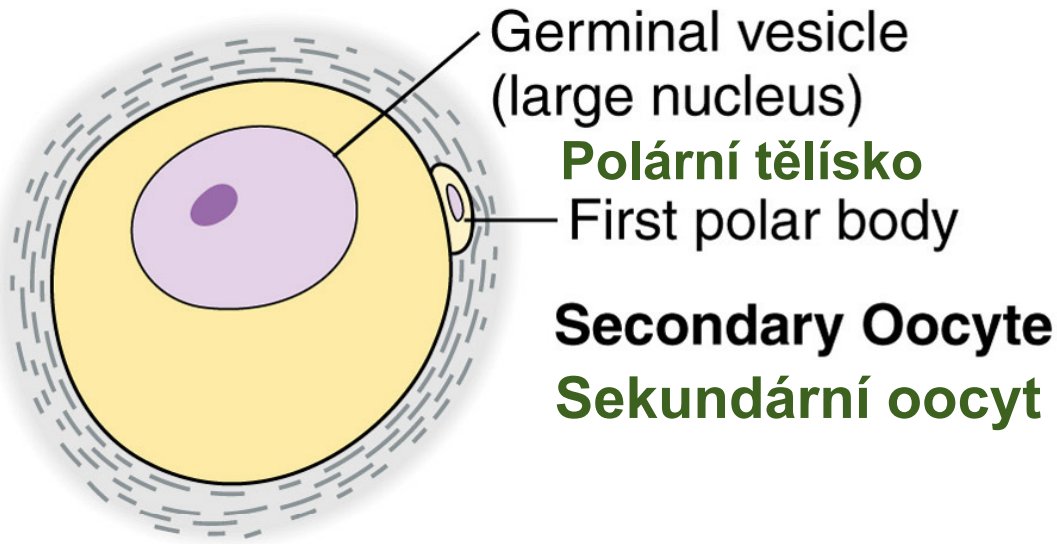

Oogonium
Gonads
Primární (primordiální) zárodečné buňky
Primordial germ cells
Genuine stem cells in amphibians, but NOT in humans
Mitosis OR commitment to meiosis
Tremendous growth
Germinal vesicle (large nucleus)
Zárodečný váček
Import of yolk
Primary Oocyte
Primární oocyt
High rate of biosythesis
Deposition of envelopes
First Meiotic Division
1. DNA doubles
2. Homologous chromosomes pair and crossover occurs
3. Duplicated chromosomes are distributed to daughter cells

Section through the ovary of 2-months- (A) and 7-months-old (B) human foetus



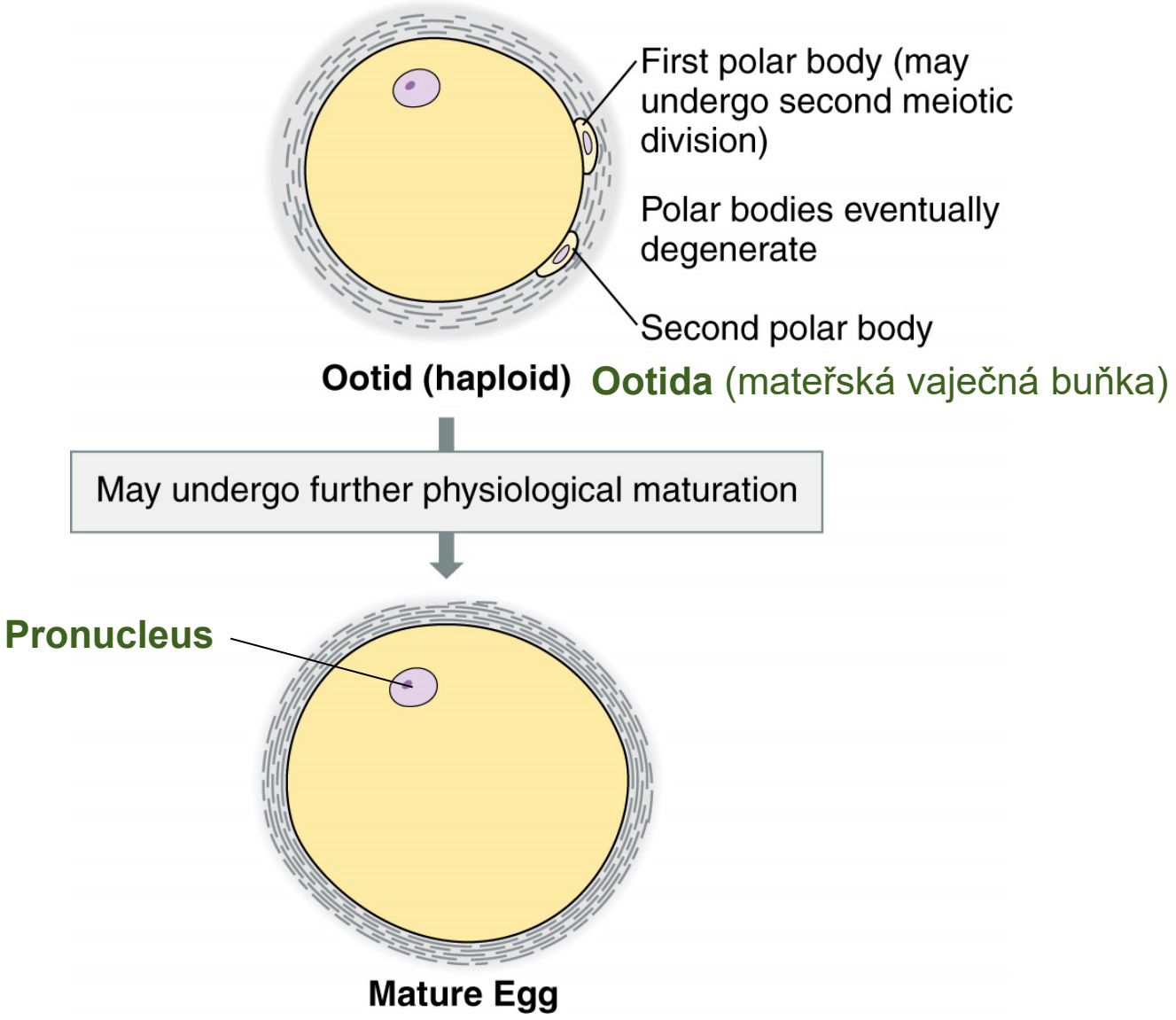
Vacek, *Embryologie* (2006)

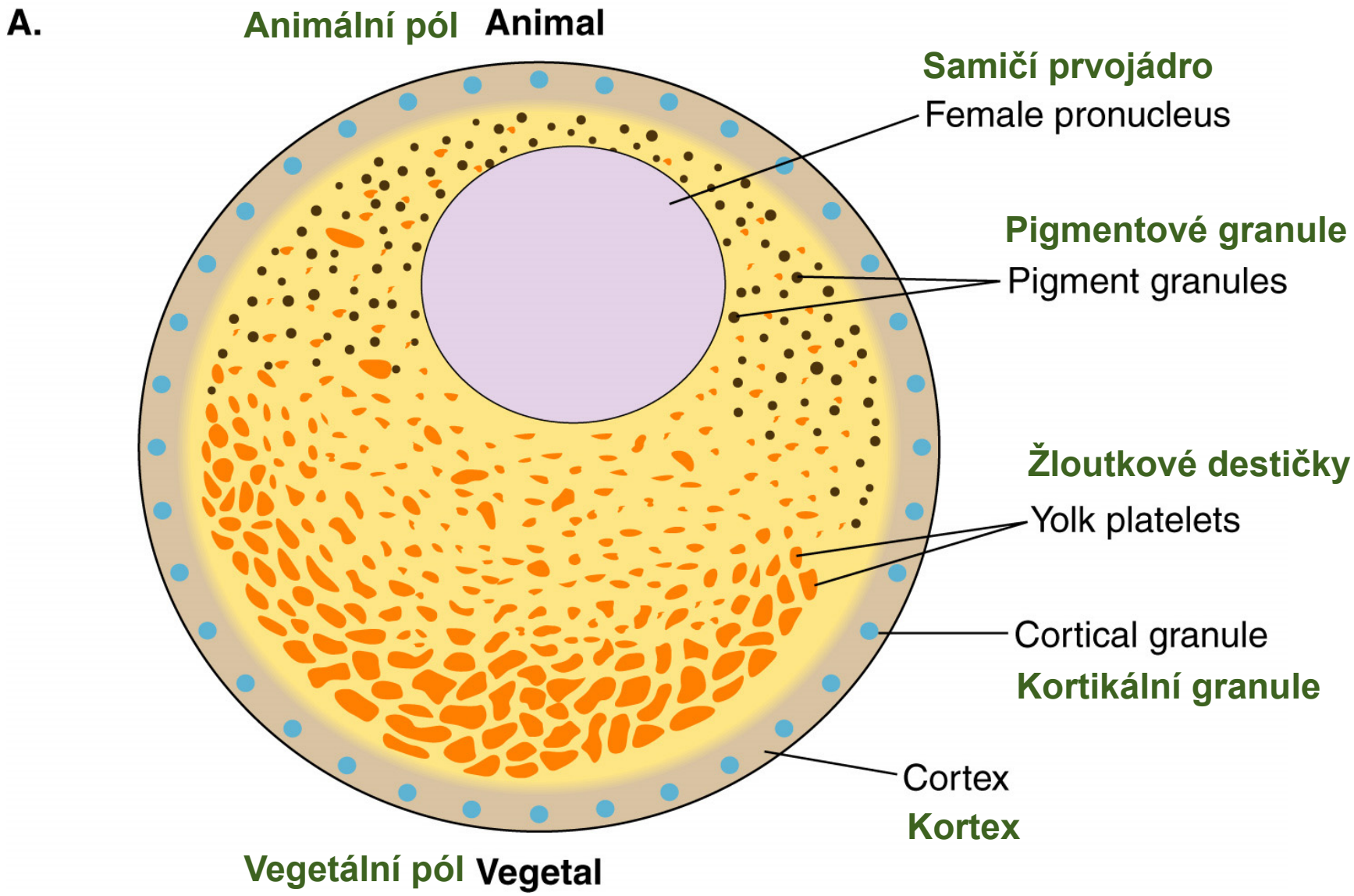
A Folicular cells at the surface of primordial foliculs → Oocyte Maturation Inhibitor (OMI) → **B** Stopping the cell cycle in the leptotene of prophase 1 until the pubescence



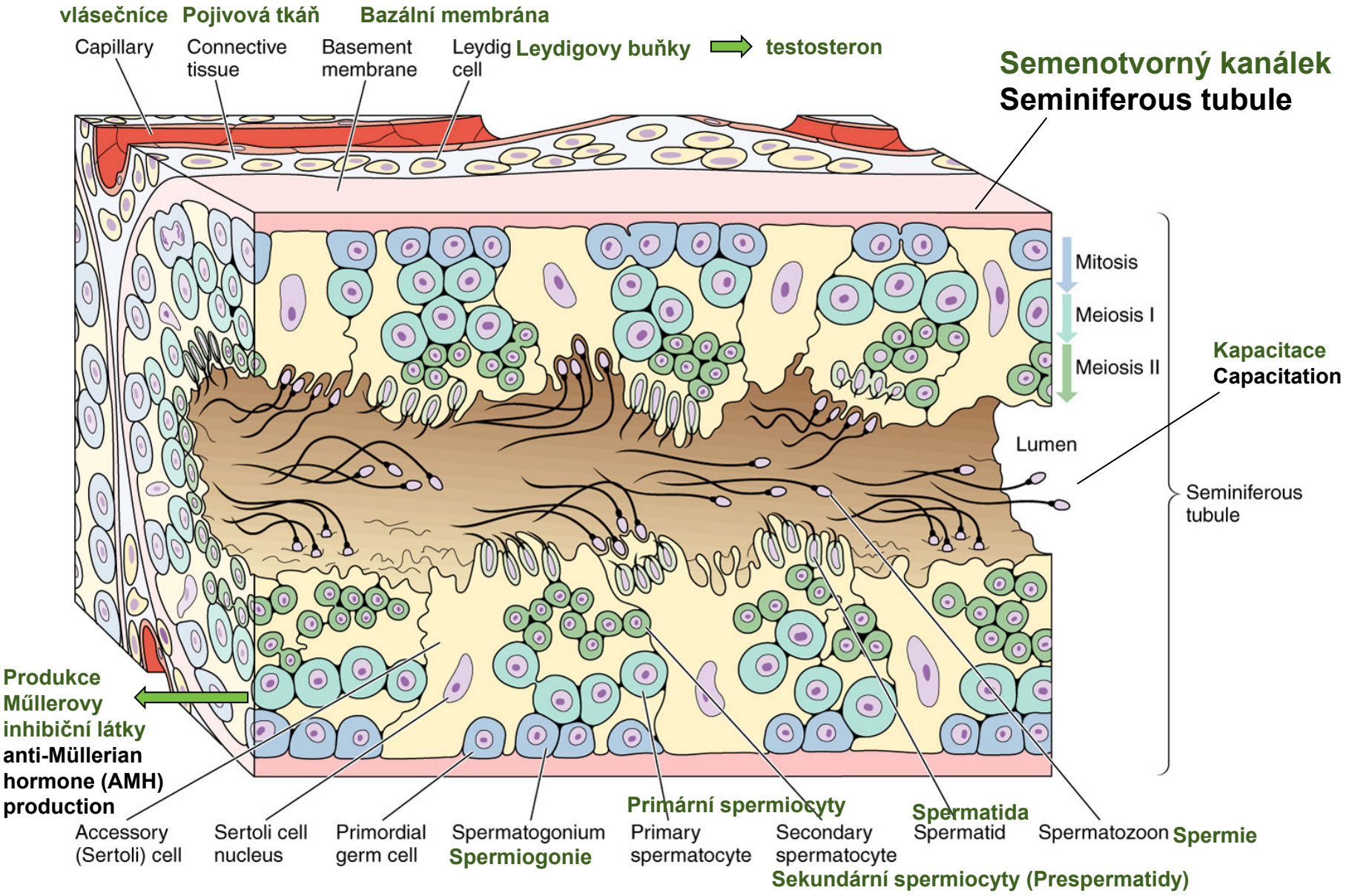
Second Meiotic Division

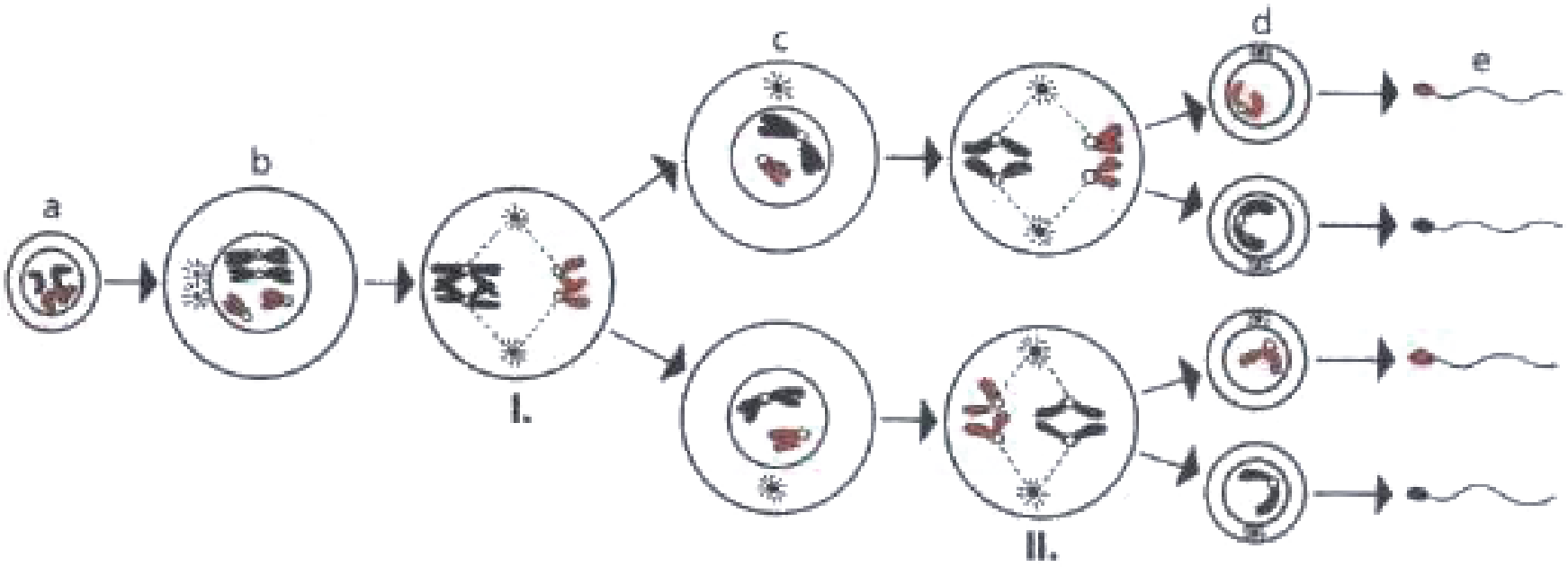
1. No DNA synthesis
2. Duplicated chromatids separate and are distributed to daughter cells (which are haploid)


First polar body (may undergo second meiotic division)
Polar bodies eventually degenerate
Second polar body
Ootid (haploid)
Ootida (mateřská vaječná buňka)
May undergo further physiological maturation
Pronucleus
Mature Egg


A.
Animální pól Animal
Samičí prvojádro
Female pronucleus
Pigmentové granule
Pigment granules
Žloutkové destičky
Yolk platelets
Cortical granule
Kortikální granule
Cortex
Kortex
Vegetální pól Vegetal

Ostrich’s egg…the largest cell in the world ☺.

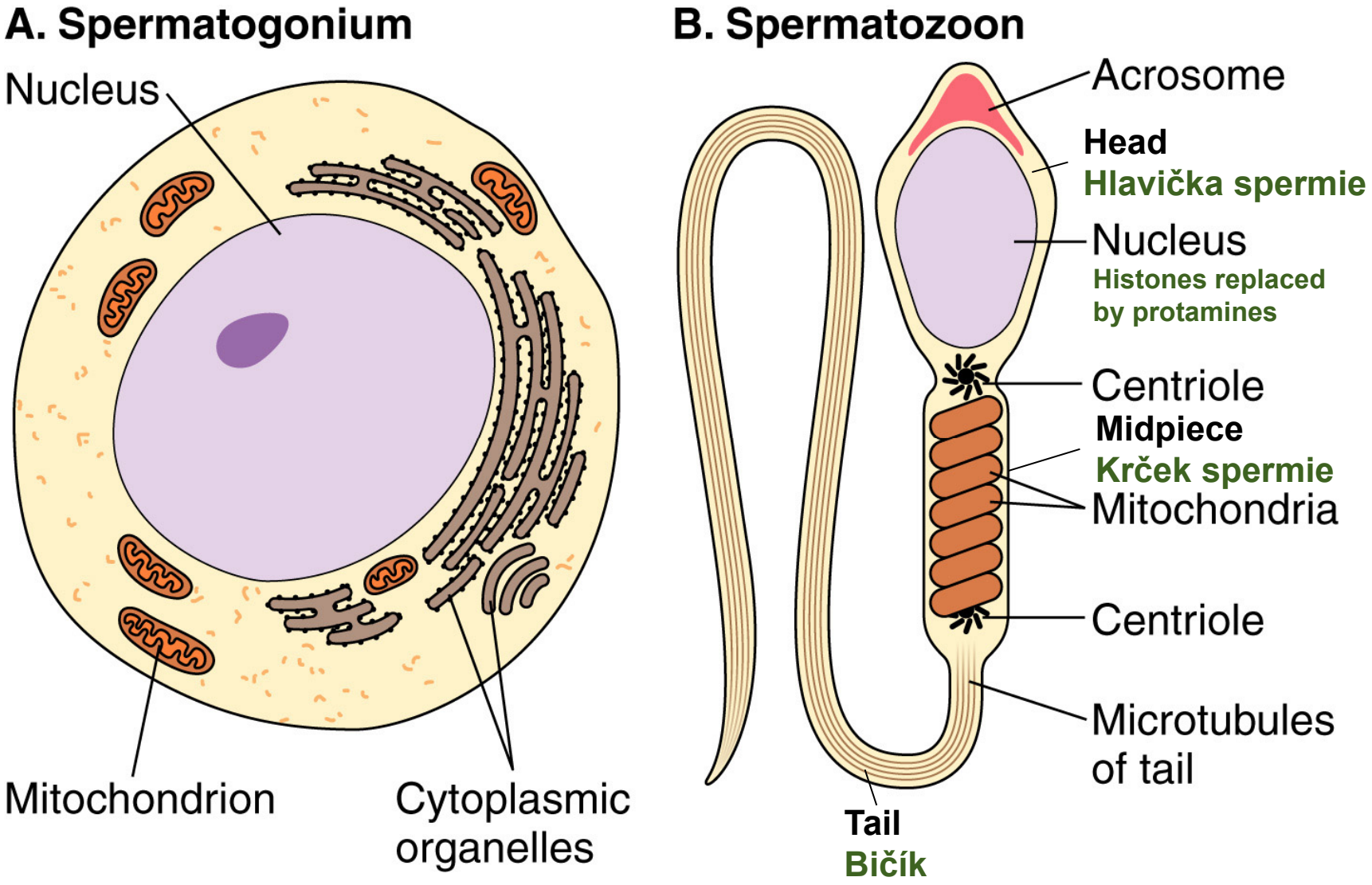

vlásečnice
Pojivová tkáň
Bazální membrána
Capillary
Connective tissue
Basement membrane
Leydig cell
Leydigovy buňky
testosteron
Semenotvorný kanálek
Seminiferous tubule
Mitosis
Meiosis I
Meiosis II
Kapacitace
Capacitation
Lumen
Seminiferous tubule
Produkce Müllerovy inhibiční látky
anti-Müllerian hormone (AMH) production
Accessory (Sertoli) cell
Sertoli cell nucleus
Primordial germ cell
Spermatogonium
Spermiogonie
Primární spermiocyty
Primary spermatocyte
Secondary spermatocyte
Sekundární spermiocyty (Prespermatidy)
Spermatida
Spermatid
Spermatozoon
Spermie

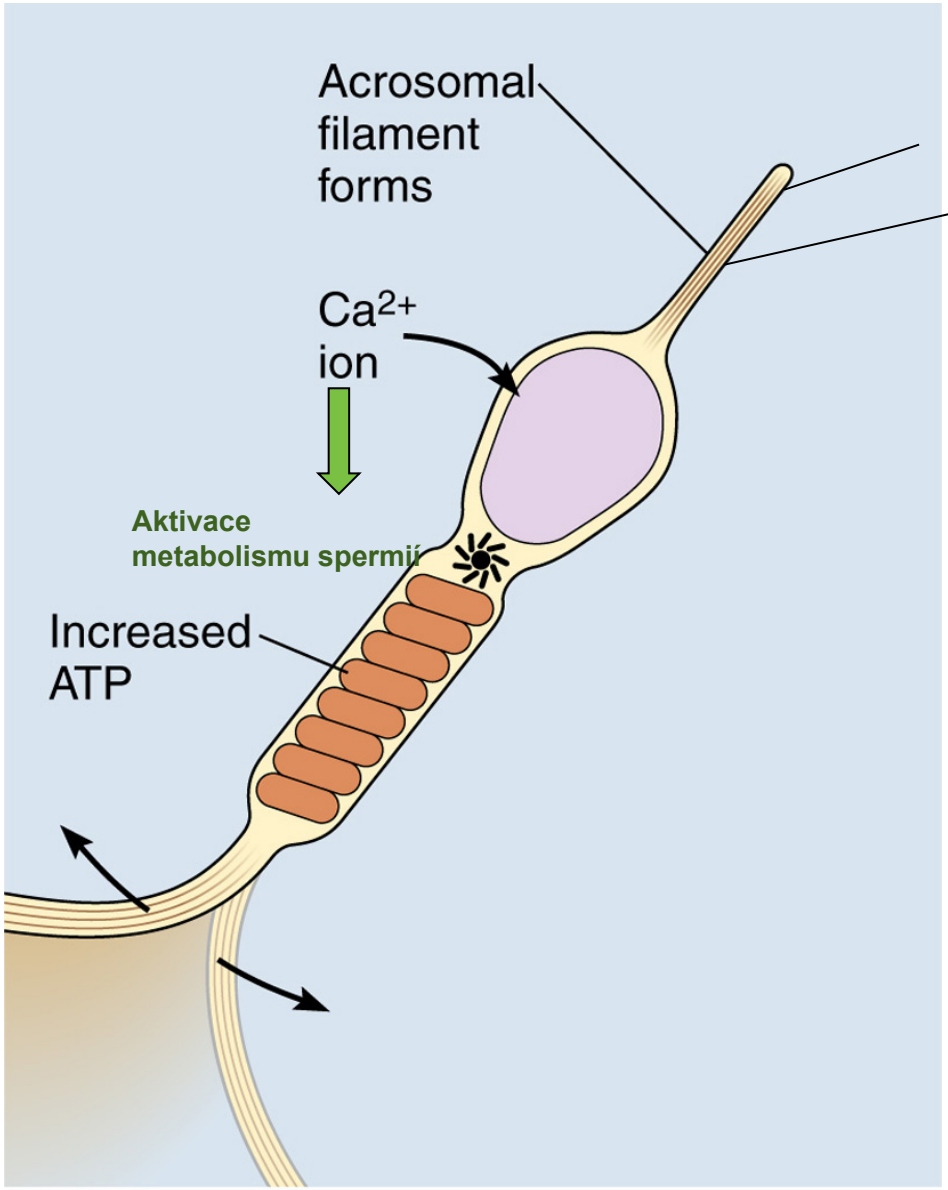


Spermatogonium **Primary spermatocyte** **Secondary spermatocyte** **Spermatid** **Spermatozoon**

Spermiogonie **Primární spermiocyty** **Sekundární spermiocyty (Prespermatidy)** **Spermatidy** **Spermie**

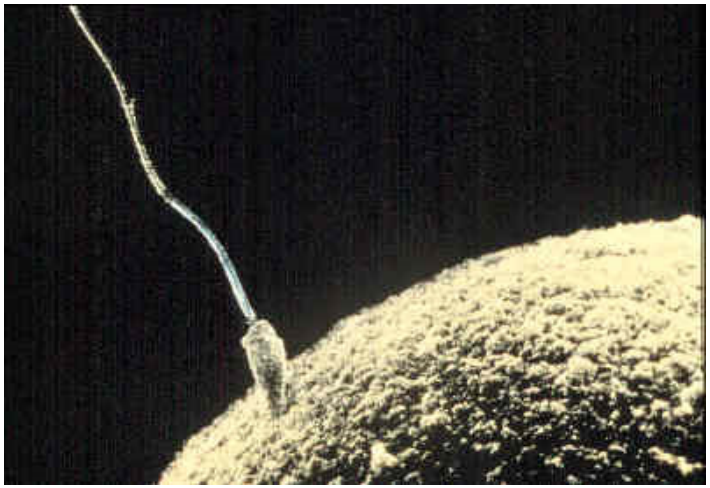
Vacek, *Embryologie* (2006)


A. Spermatogonium
Nucleus
Mitochondrion
Cytoplasmic organelles
B. Spermatozoon
Acrosome
Head
Hlavička spermie
Nucleus
Histones replaced by protamines
Centriole
Midpiece
Krček spermie
Mitochondria
Centriole
Microtubules of tail
Tail
Bičík



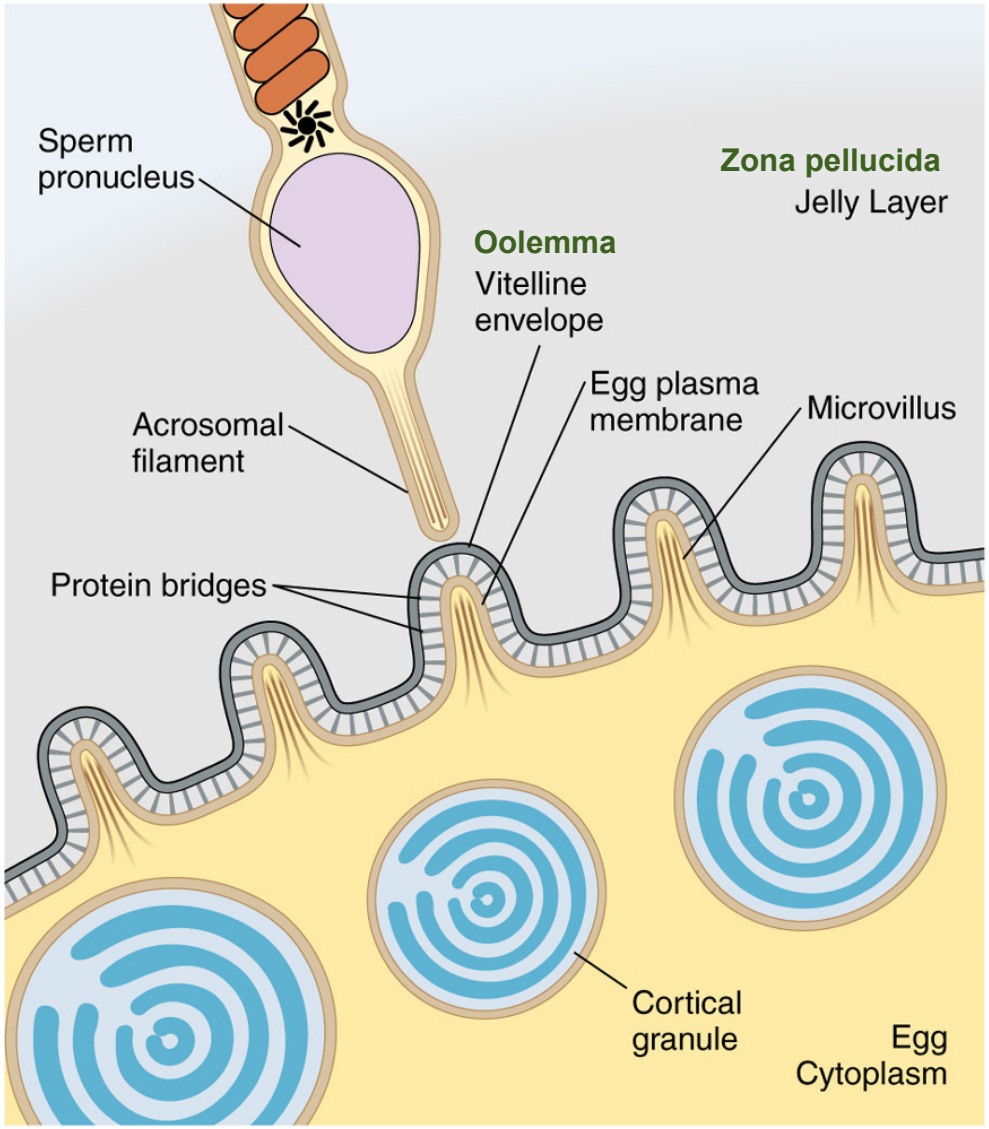
Bindin

Fertilizační filament

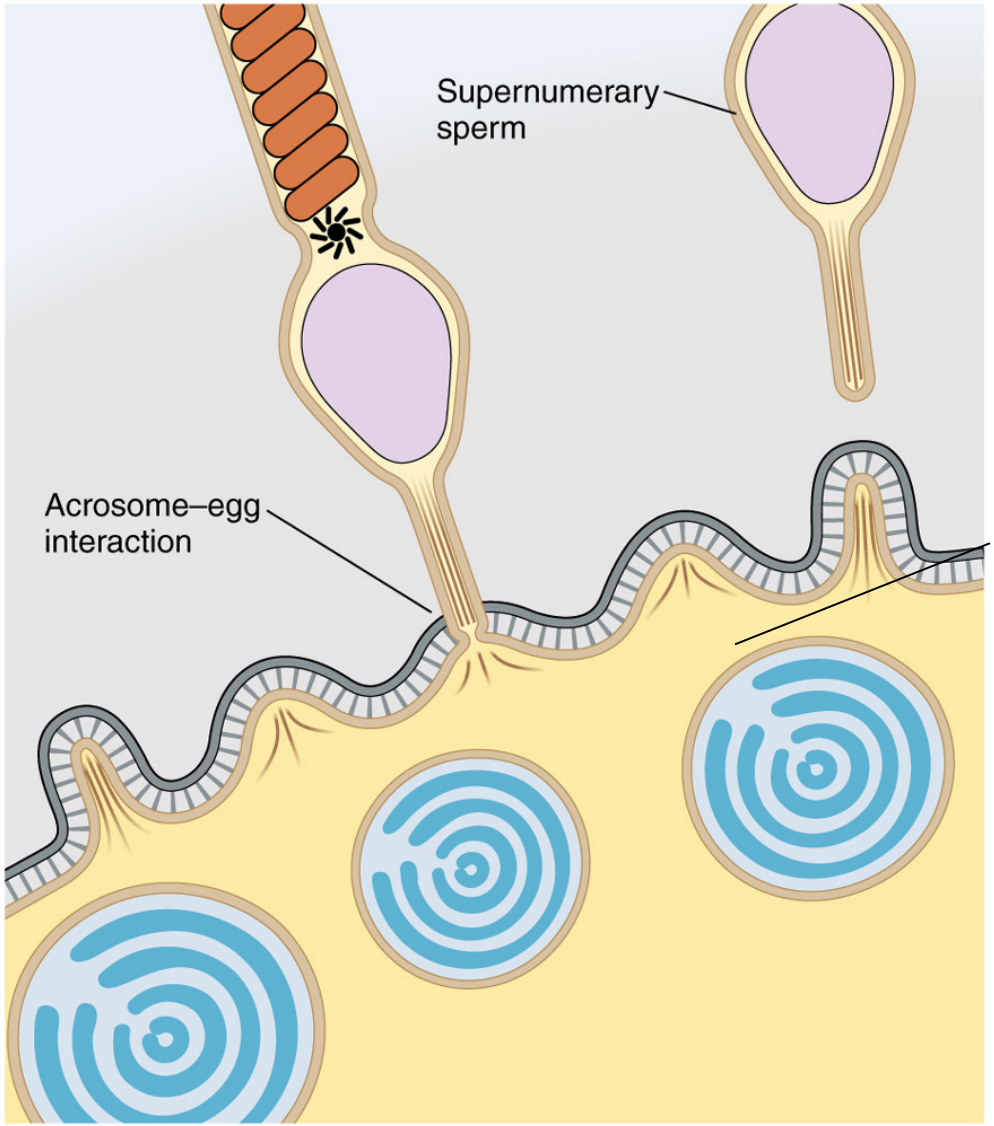


Wikipedia

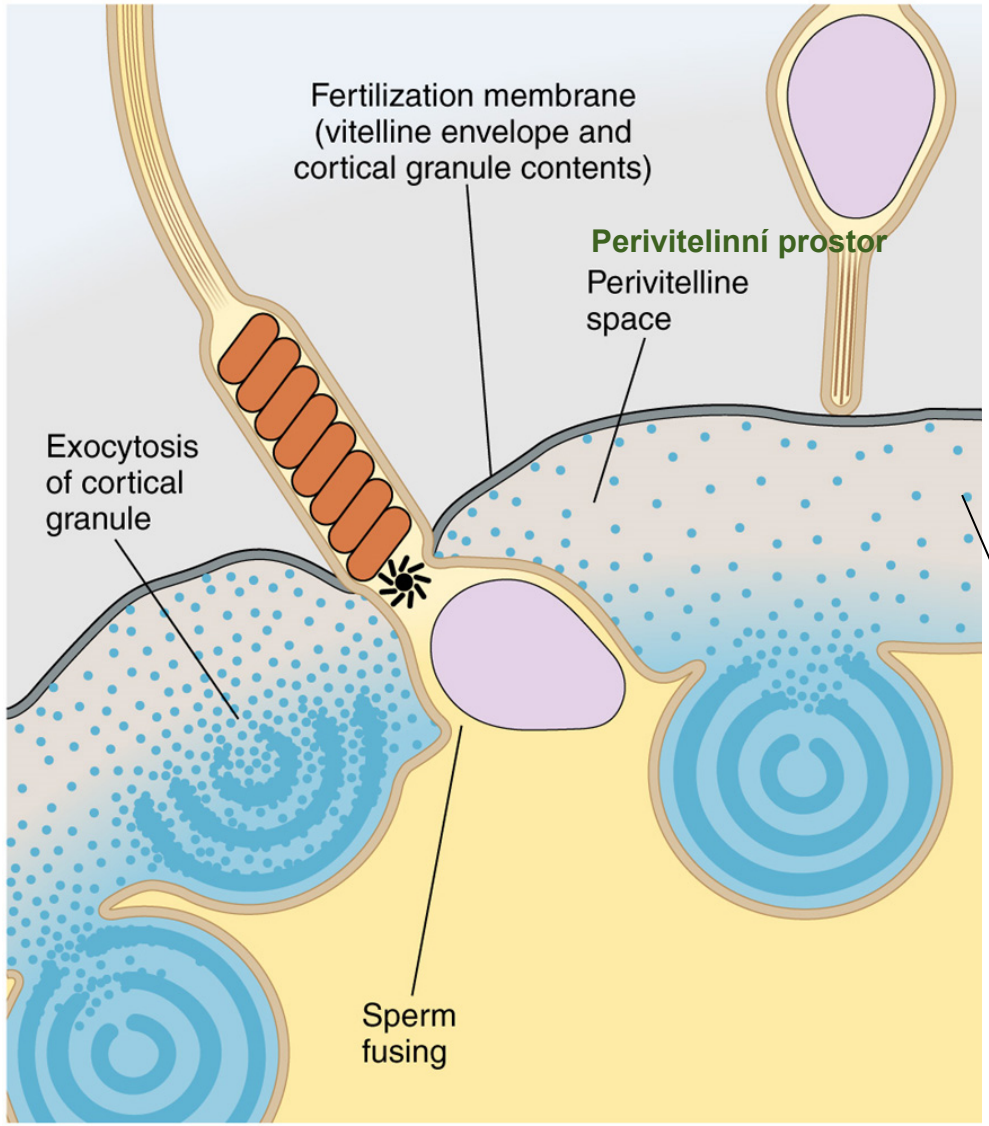
A.


Sperm pronucleus
Zona pellucida
Jelly Layer
Oolemma
Vitelline envelope
Egg plasma membrane
Microvillus
Acrosomal filament
Protein bridges
Cortical granule
Egg Cytoplasm

B.



Change of the osmotic pressure due to release of the cortical granules content (macromolecules) and lifting of the vitelline envelope.

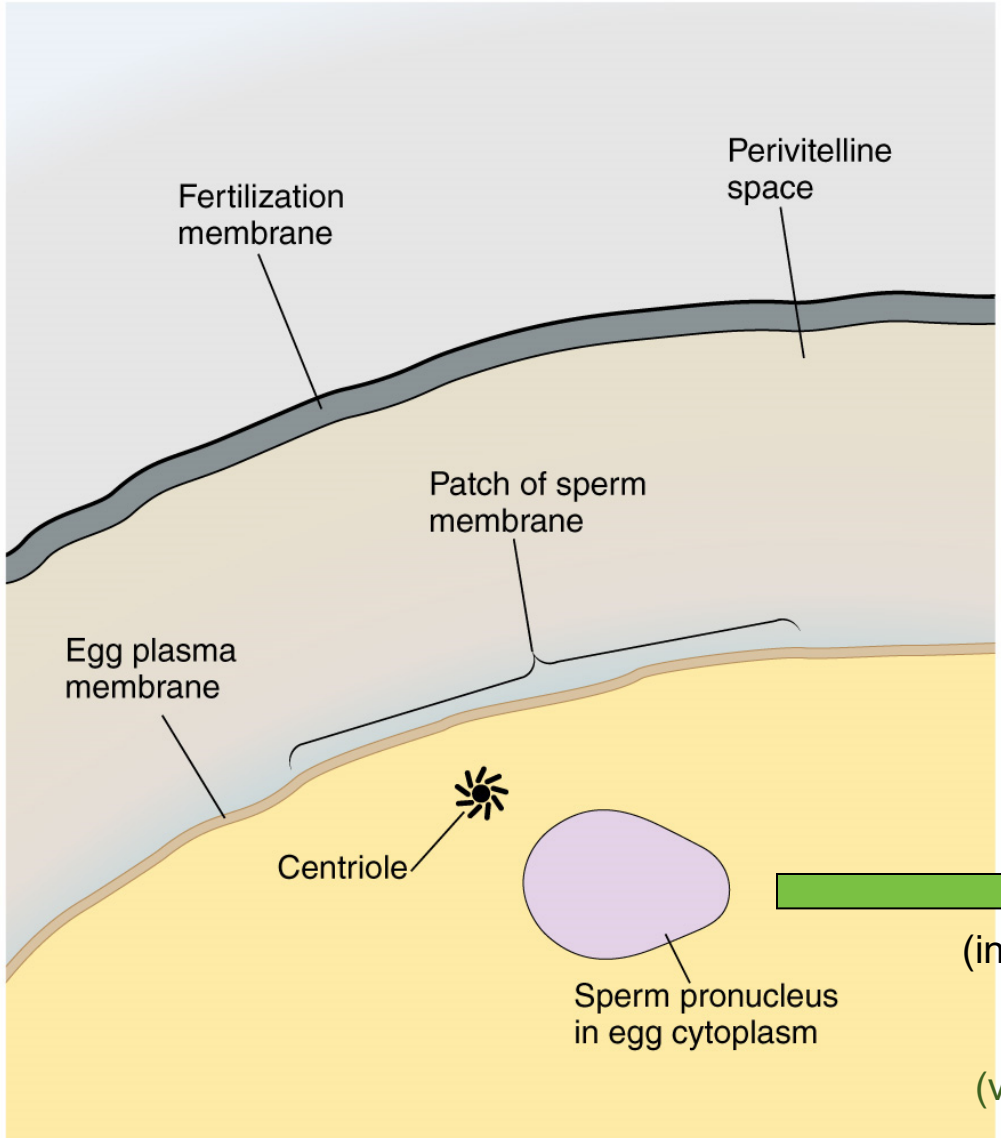


Cortical reaction

- proteolytic enzymes remove the sperm receptors
- Changes in the vitelline envelope mechanical propeties
- Changes in the membrane potential

Avoiding of polyspermy

D.

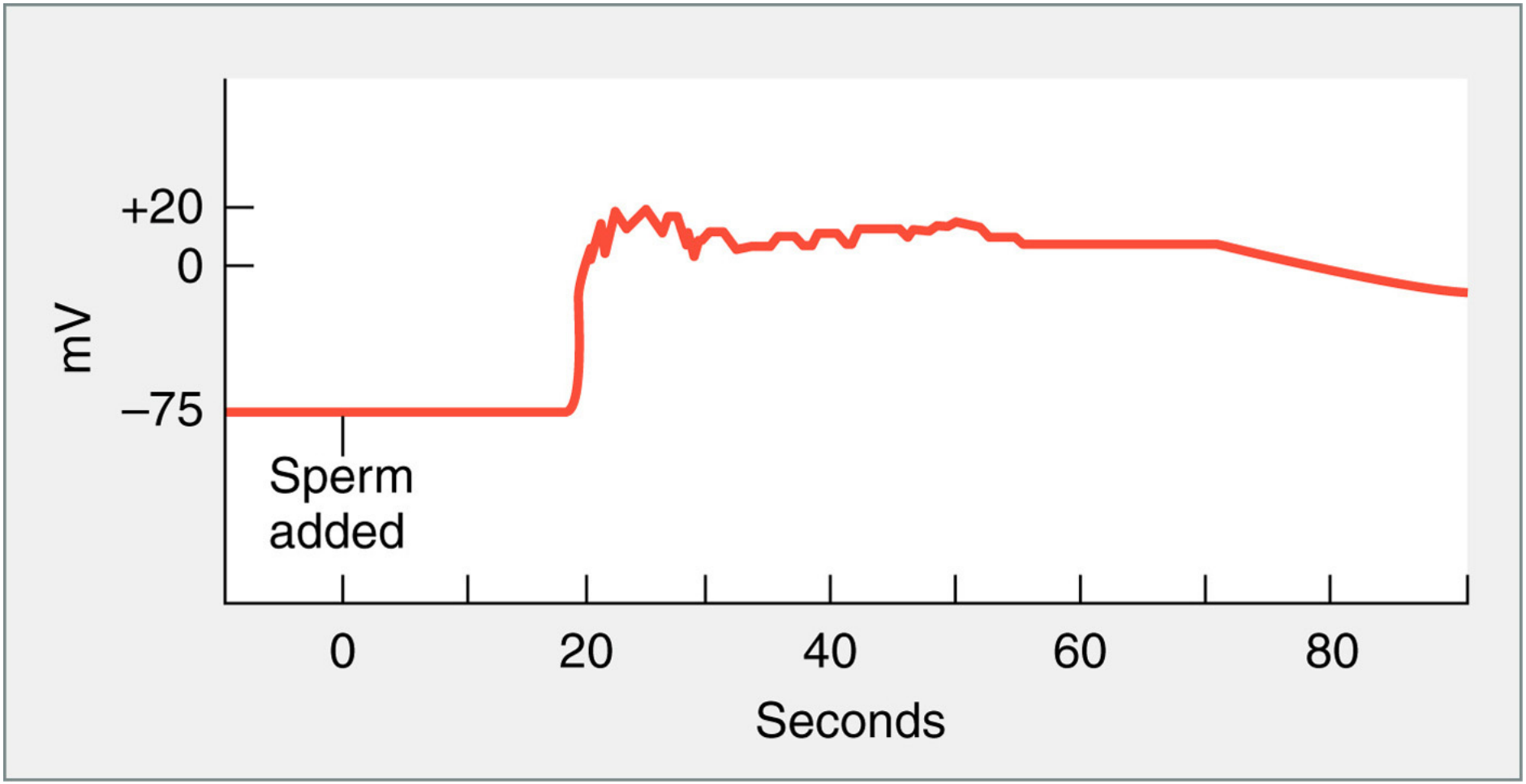


karyogamy

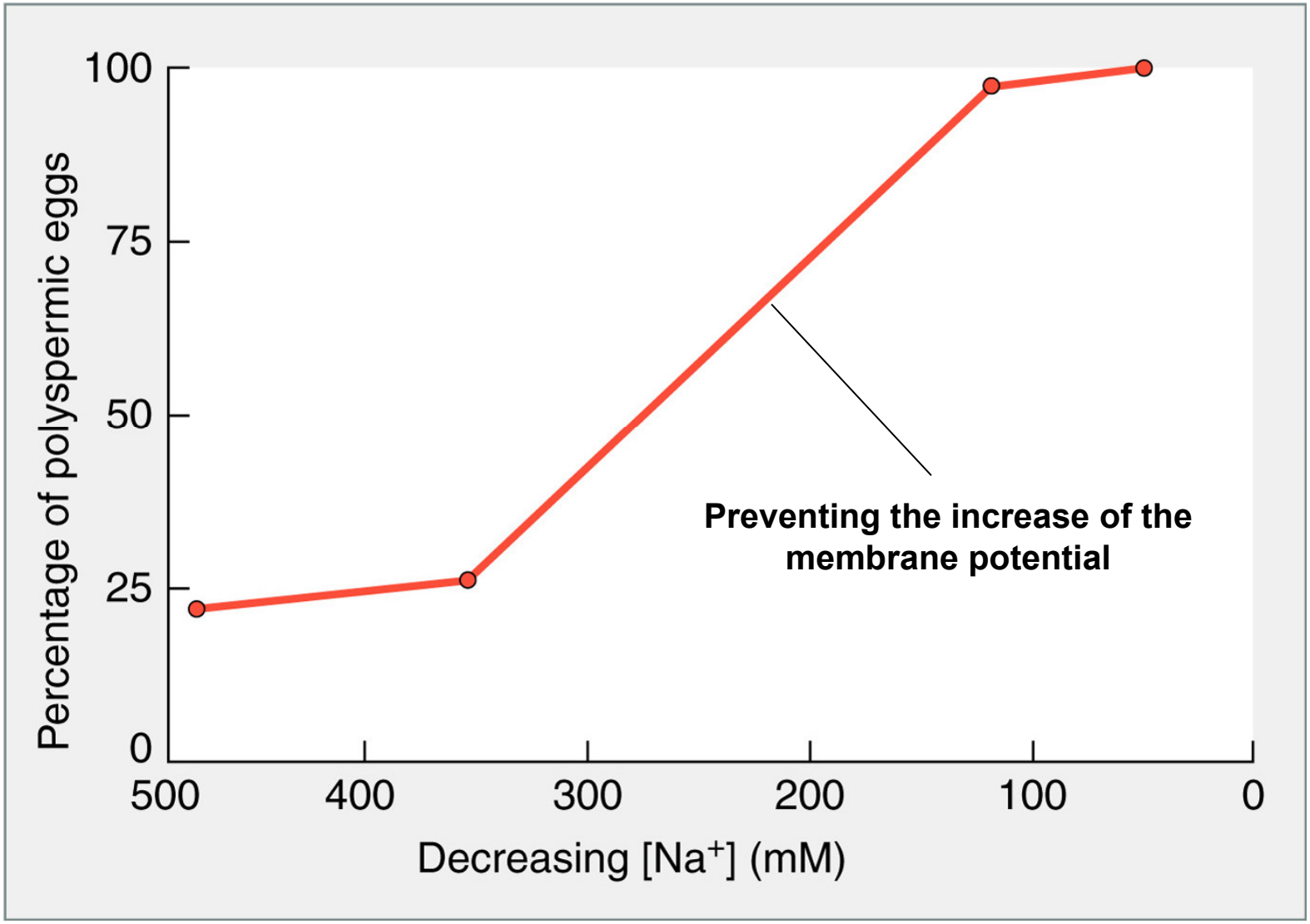
(in the S stage of mitosis 1)

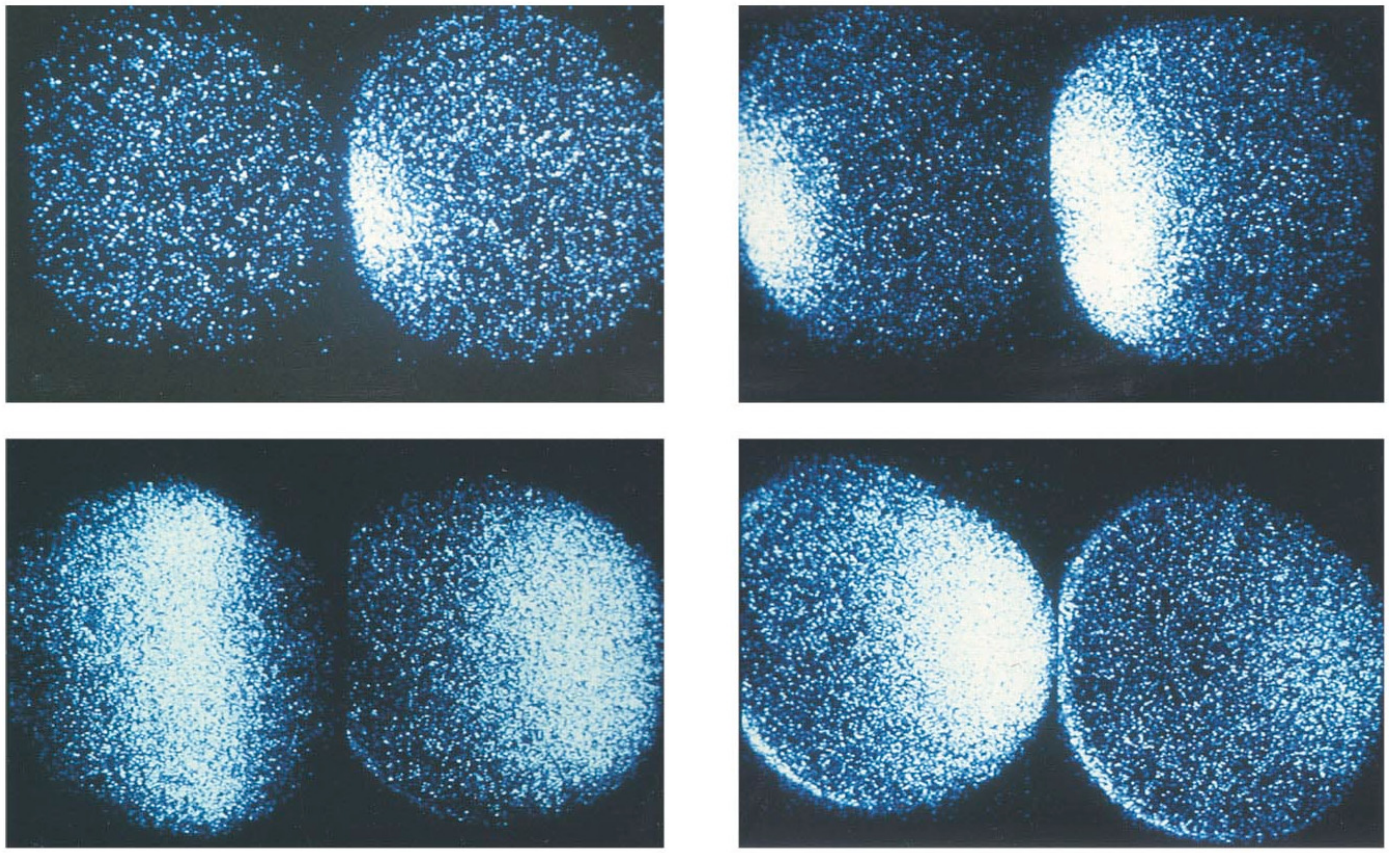
karyogamie

(ve stádiu S fáze 1. mitózy)


+20
0
mV
–75
Sperm
added
0
20
40
60
80
Seconds

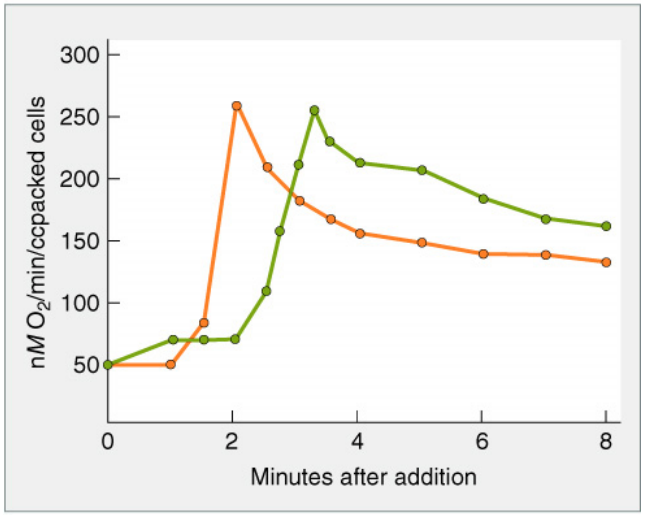
C.


100
75
50
25
0
Percentage of polyspermic eggs
500
400
300
200
100
0
Decreasing [Na+] (mM)
Preventing the increase of the membrane potential

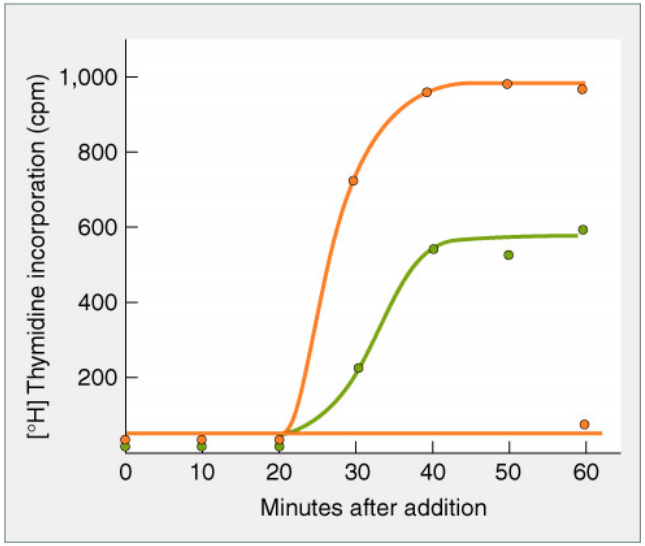


Lectures of Michael Lehmann, Ph.D., University of Arkansas, USA

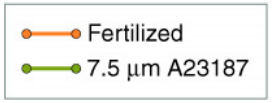
A.



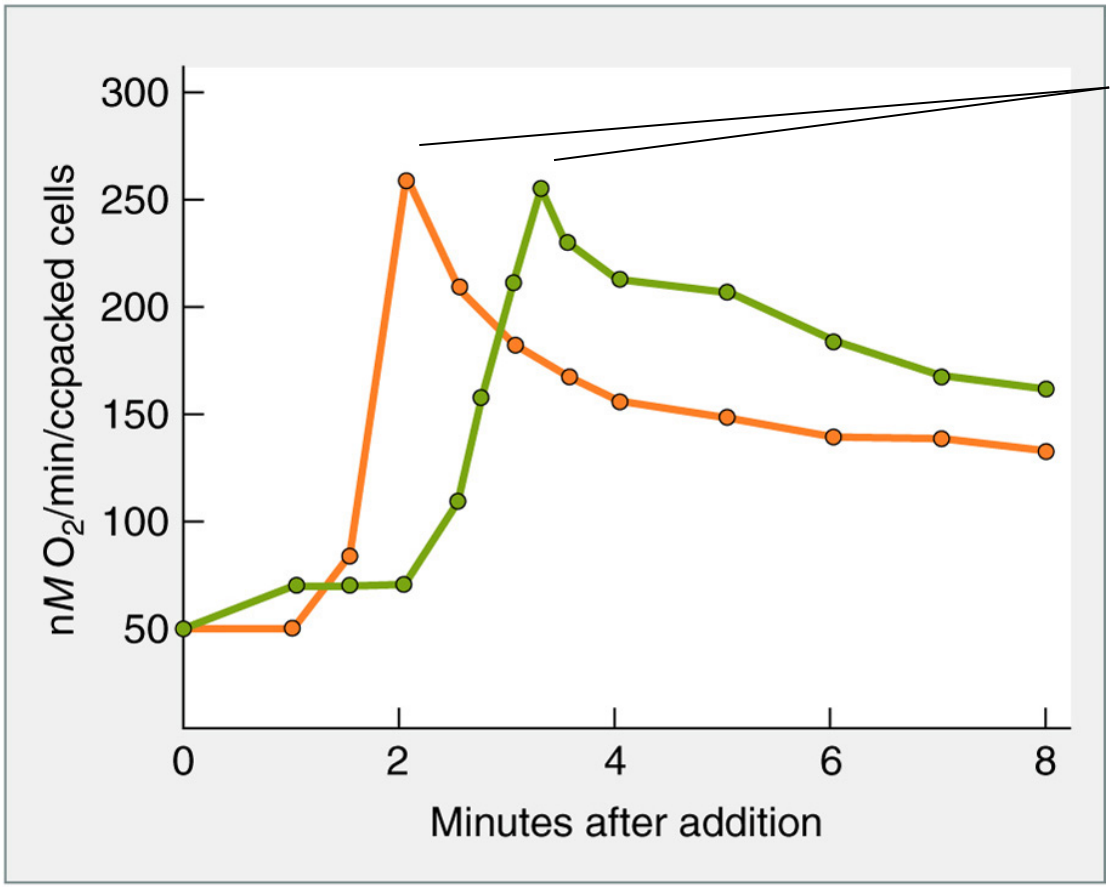
B.



KEY



A.



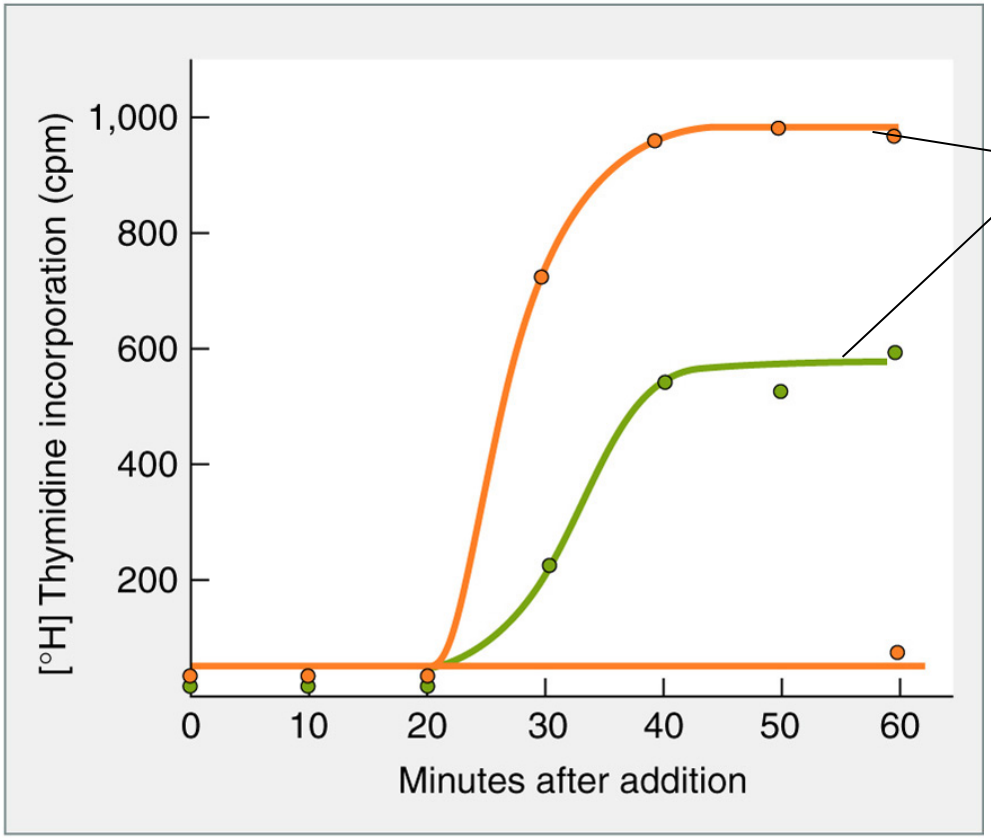
Activation of respiration

KEY

Fertilized

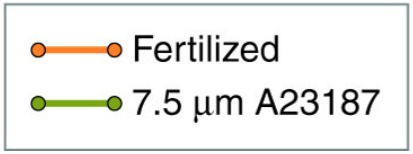
7.5 µm A23187

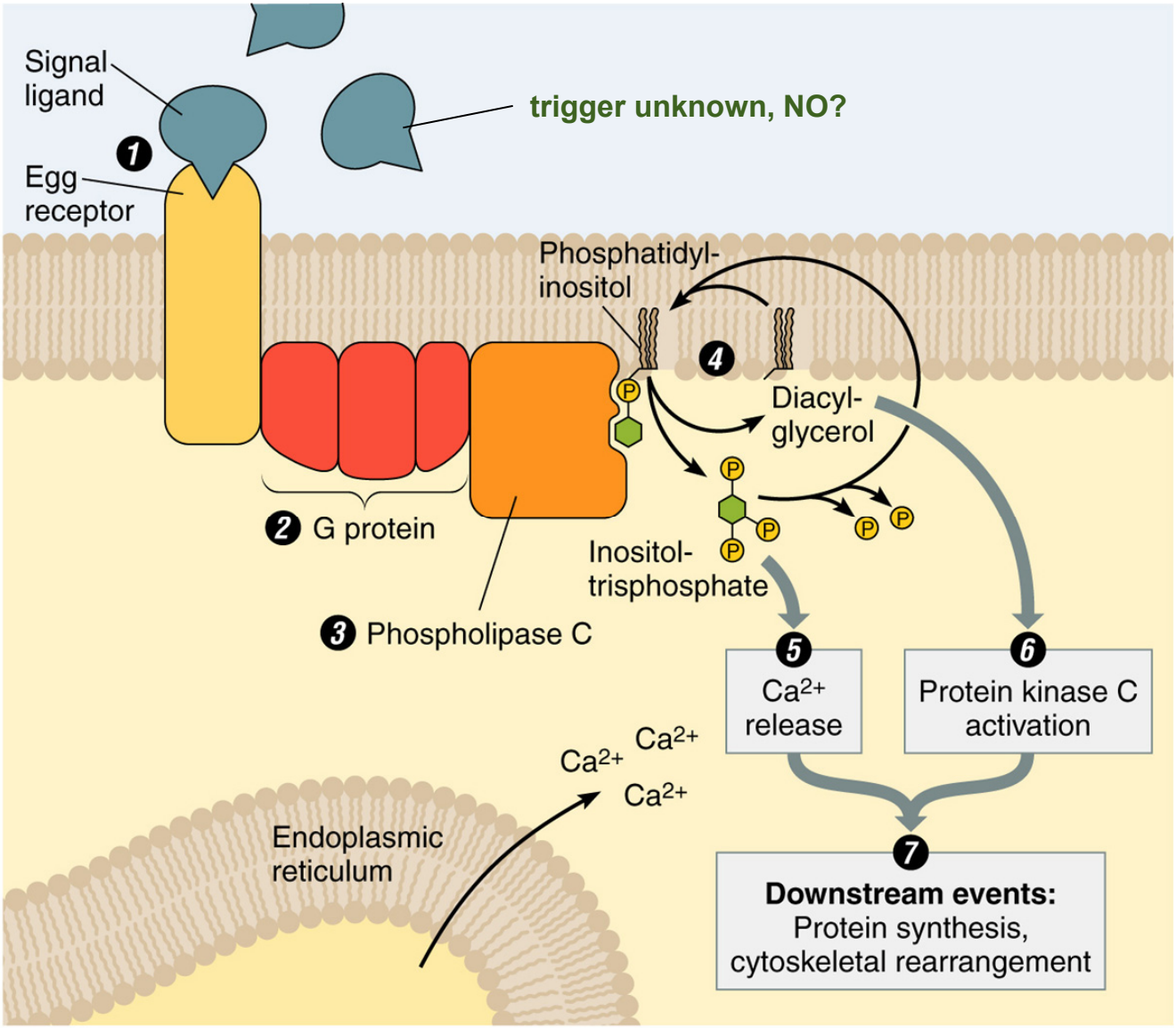
B.



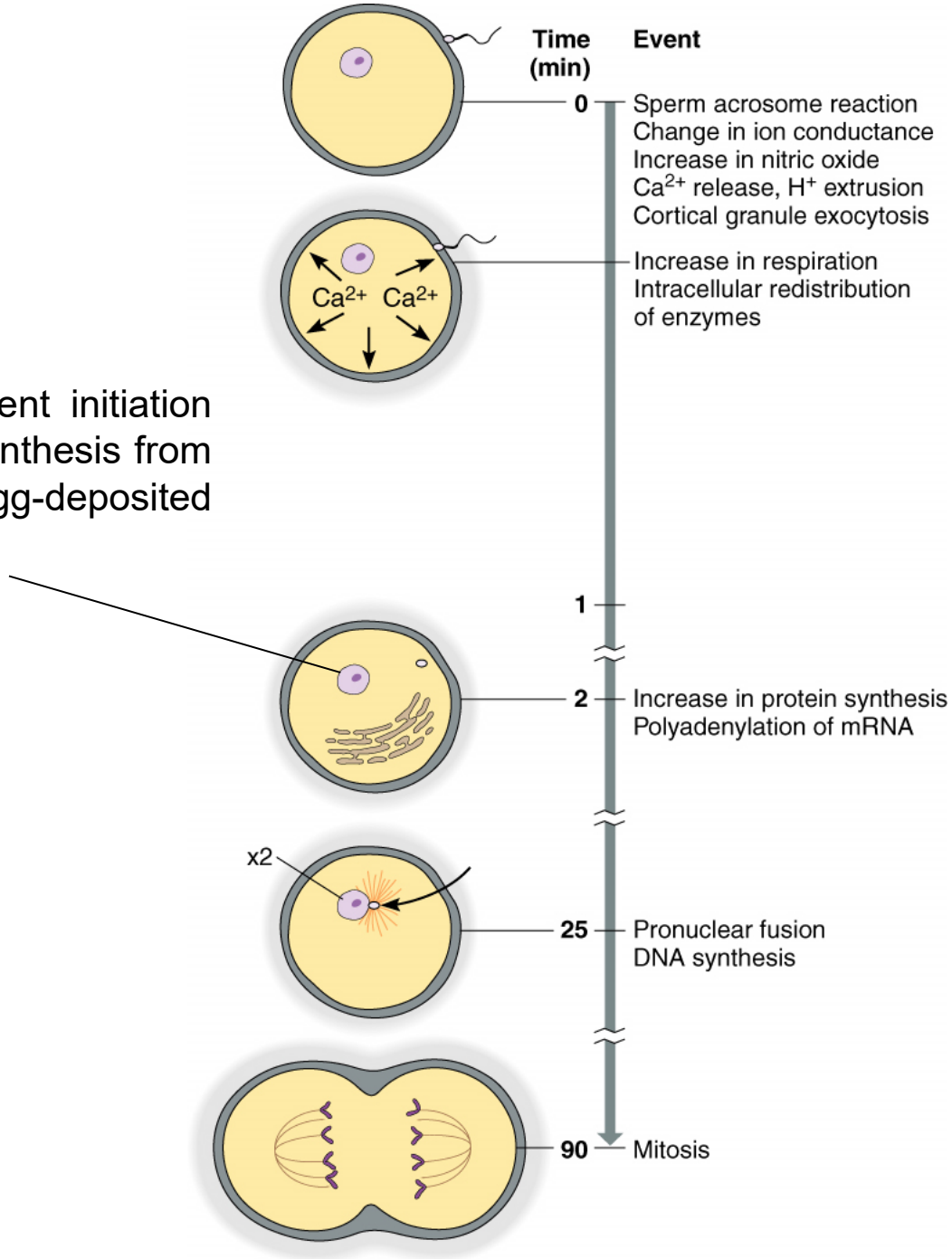
Activation of DNA synthesis

KEY

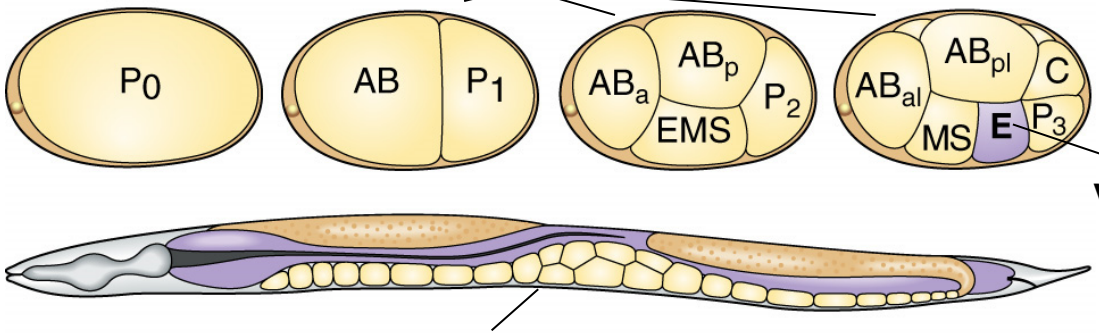



Signal ligand
trigger unknown, NO?
1
Egg receptor
Phosphatidyl-inositol
4
Diacyl-glycerol
P
2 G protein
Inositol-trisphosphate
3 Phospholipase C
5
Ca2+ release
6
Protein kinase C activation
Ca2+
Ca2+
Ca2+
Endoplasmic reticulum
7
Downstream events:
Protein synthesis, cytoskeletal rearrangement

pH-dependent initiation of proteosynthesis from the egg-deposited mRNA

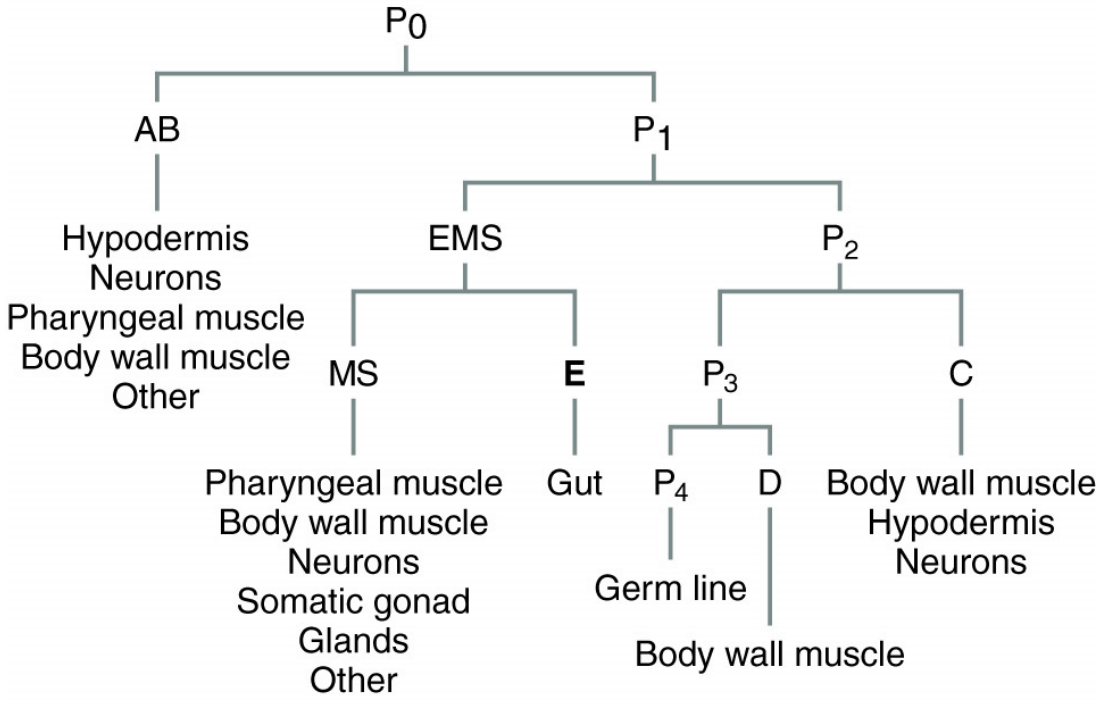


A. **Fertilization-initiated cleavage/rýhování vajíčka**



Regular and stereotypical cell pattern in *C. elegans*

B. (558 embryonic and 9590 somatic cells)



Key Concepts

- ***Asymmetric cell division*** and underlying molecular mechanisms are the ***core problem*** of the developmental biology
- ***Genetic integrity is maintained*** during cell (de-)differentiation
- ***Gametes*** arise from a population of stem cells via ***differentiation and reduction of the genome*** to the haploid level
- ***Formation of the oocyte*** places a huge demands on the organism and ***stocked material*** allows the early development
- ***Fertilization restores the chromosome number*** and activates the egg. The activated gametes ***reenter the cell cycle*** and trigger the further development
- During animal development, ***cell lineages*** with ***predetermined developmental fate*** are ***established in the early development***, which is not the case in the development of plants.

Discussion