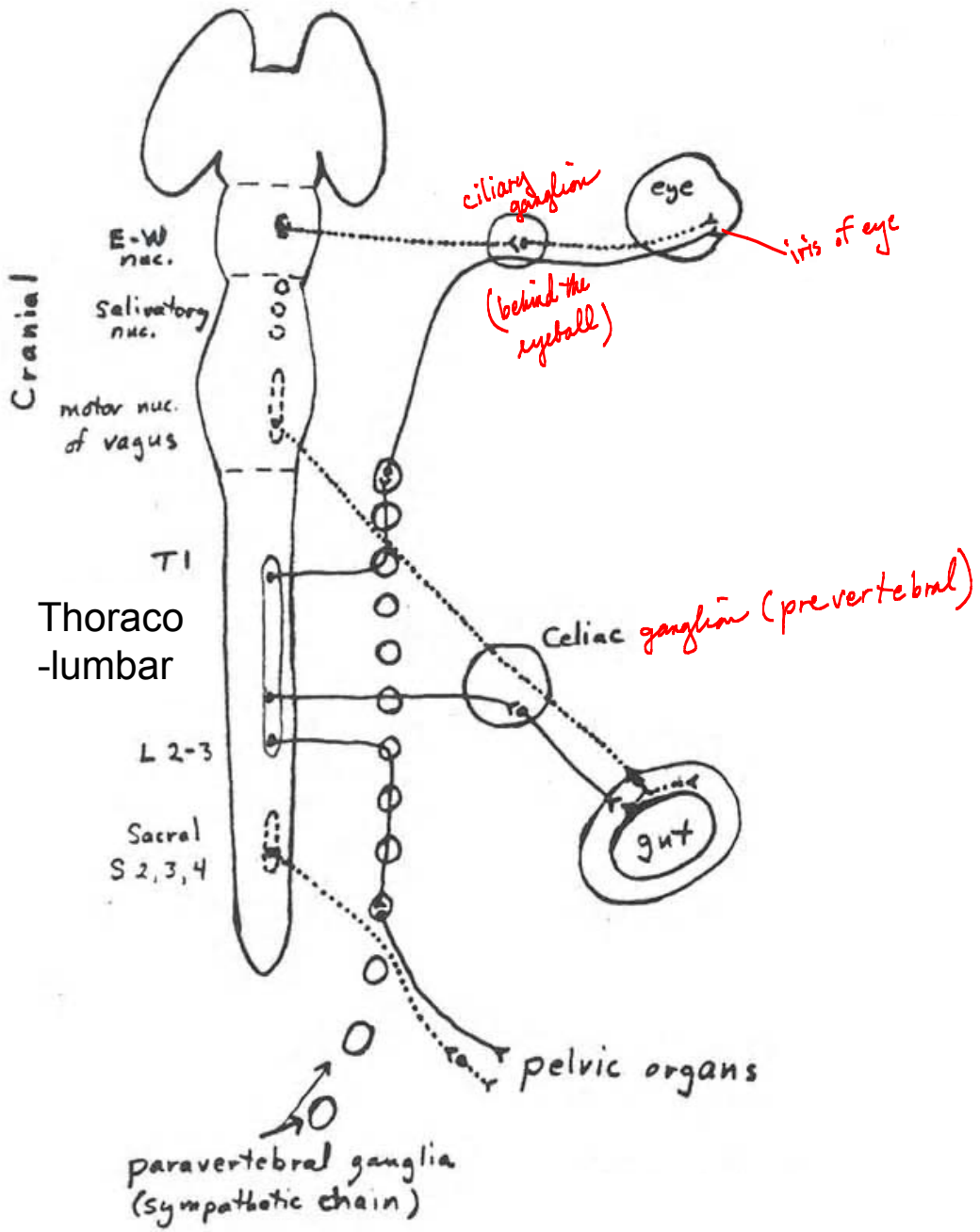
End session 8 / Begin session 9

Autonomic pathways:

a selective schematic view



Autonomic nervous system:

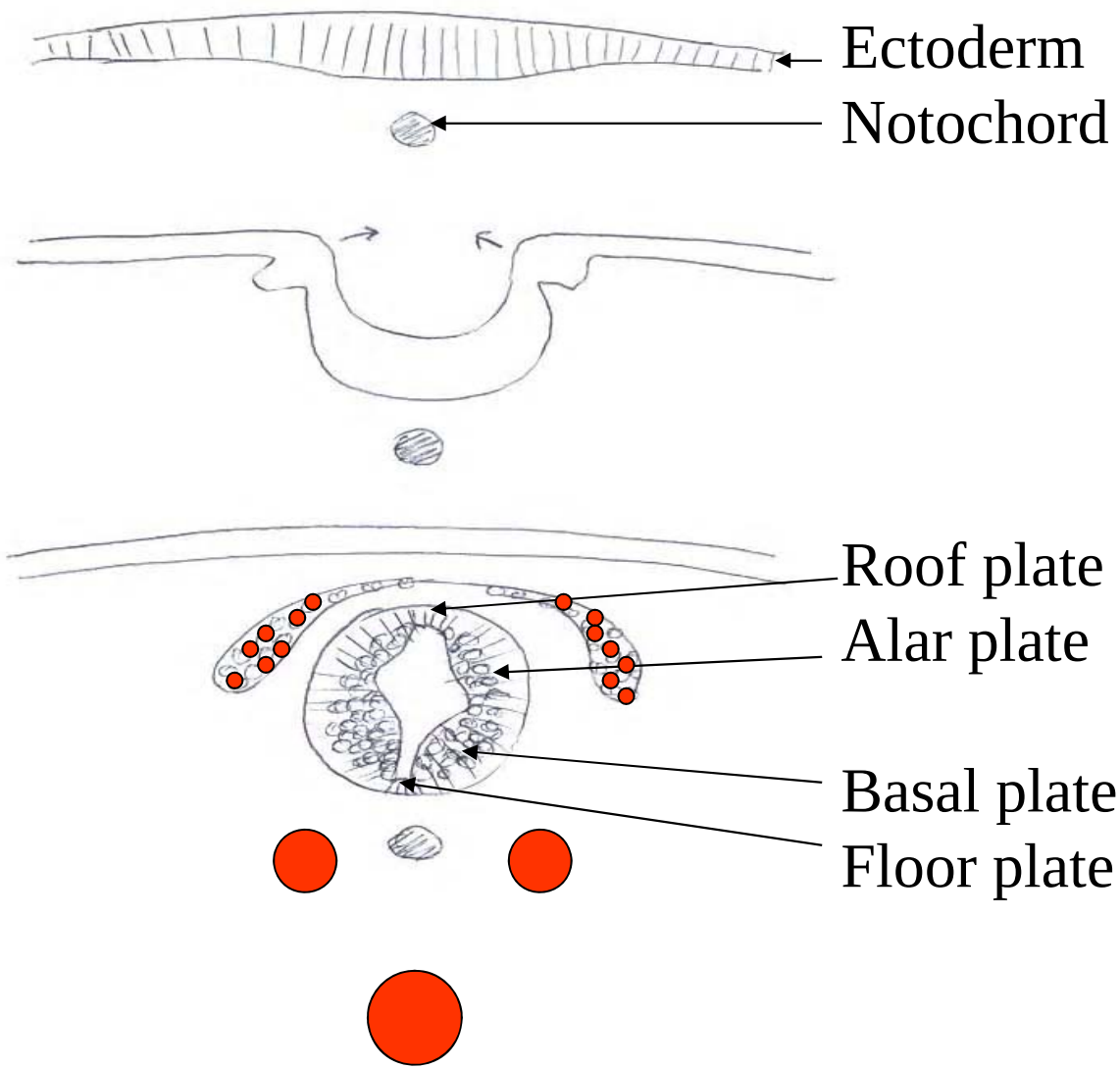
- **Formation of sympathetic ganglia** from the neural crest (REVIEW)

Closure of neural tube; **formation of sympathetic ganglia**

Neural plate

Neural groove

Neural tube and neural crest



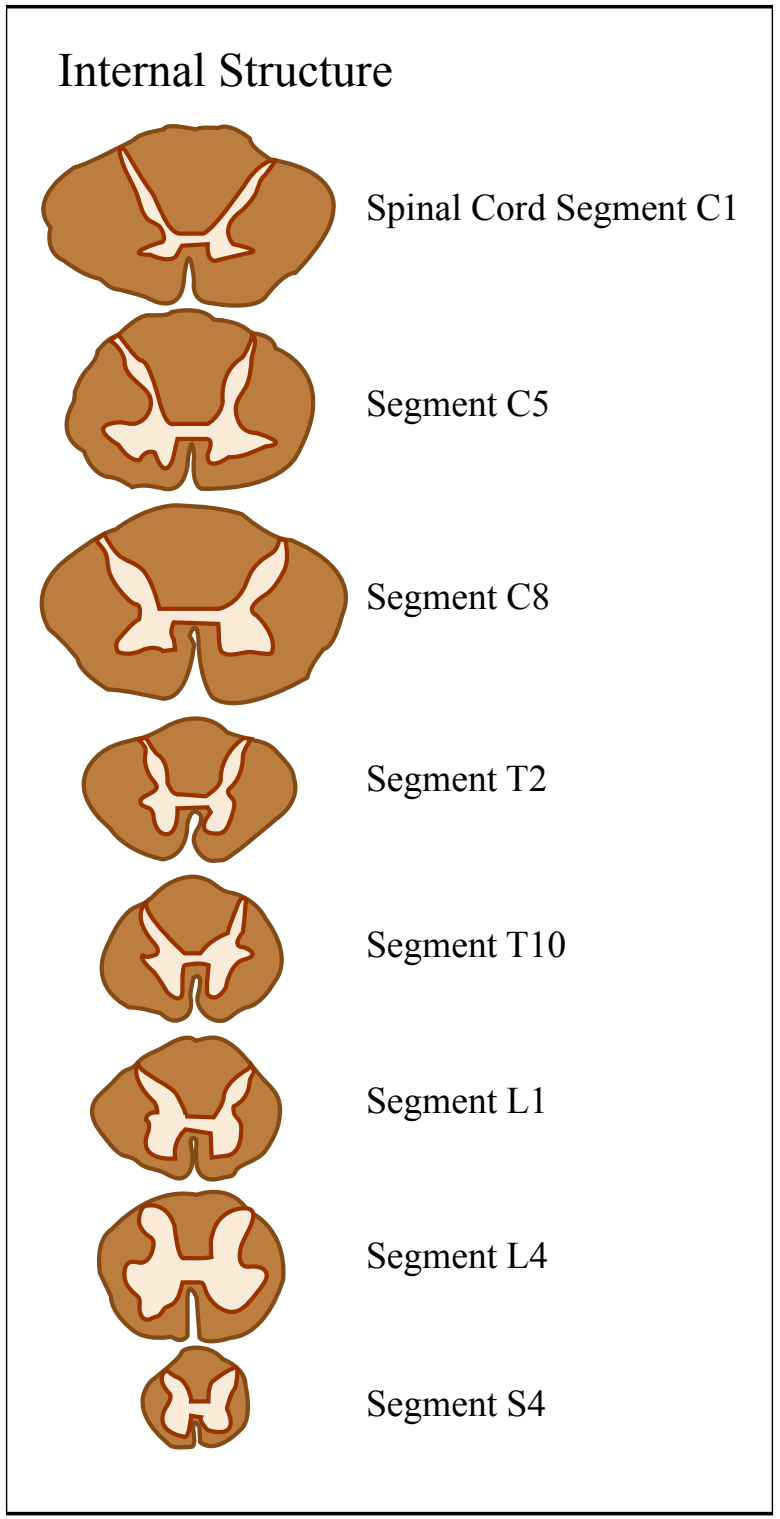
Courtesy of MIT Press. Used with permission.
Schneider, G. E. *Brain structure and its Origins: In the Development and in Evolution of Behavior and the Mind*. MIT Press, 2014. ISBN:9780262026734.

Autonomic nervous system:

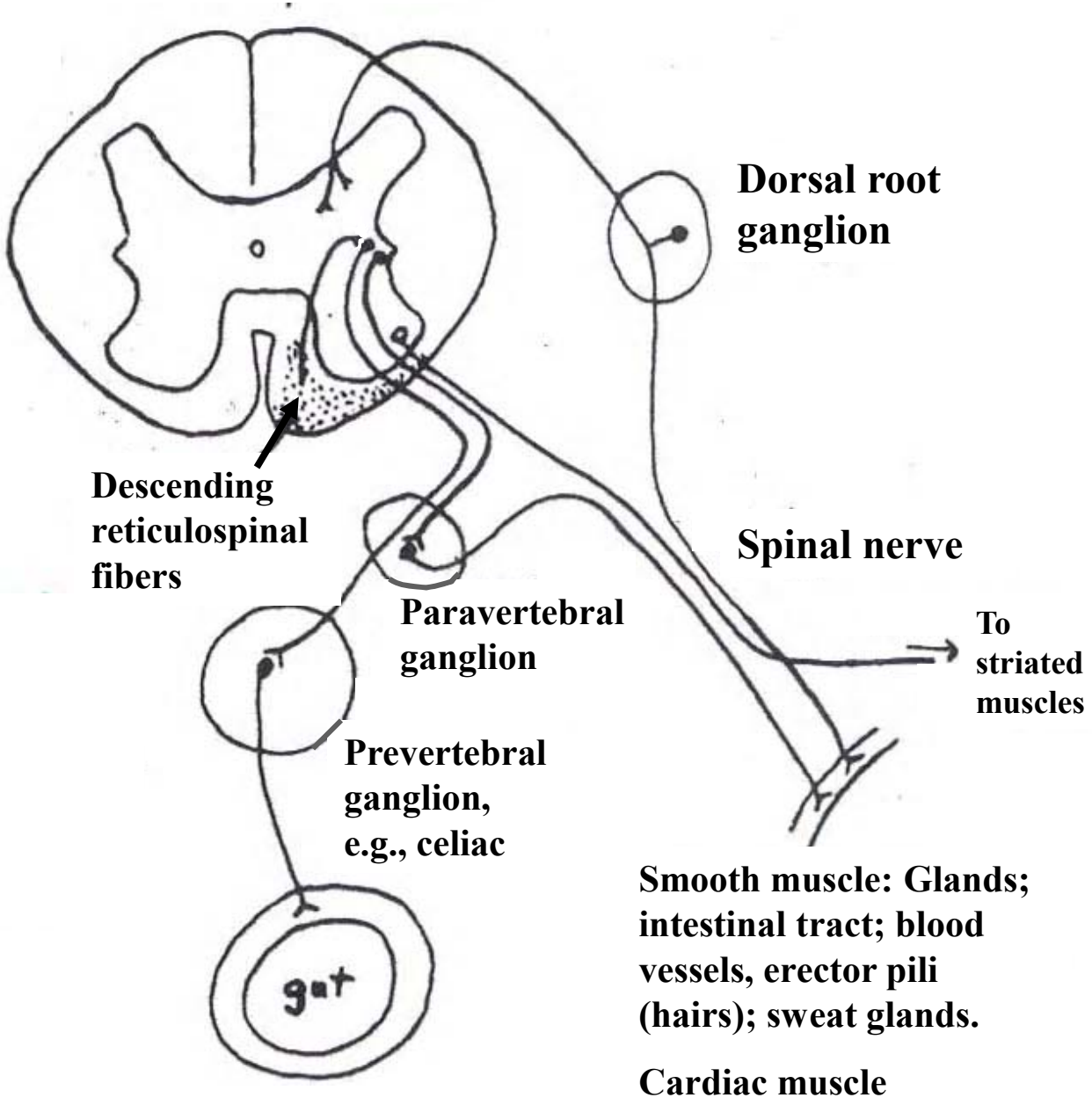
- **Sympathetic innervation pattern** (thoraco-lumbar system)

Internal structure of spinal cord:

Note the lateral horn at levels T2, T10, L1

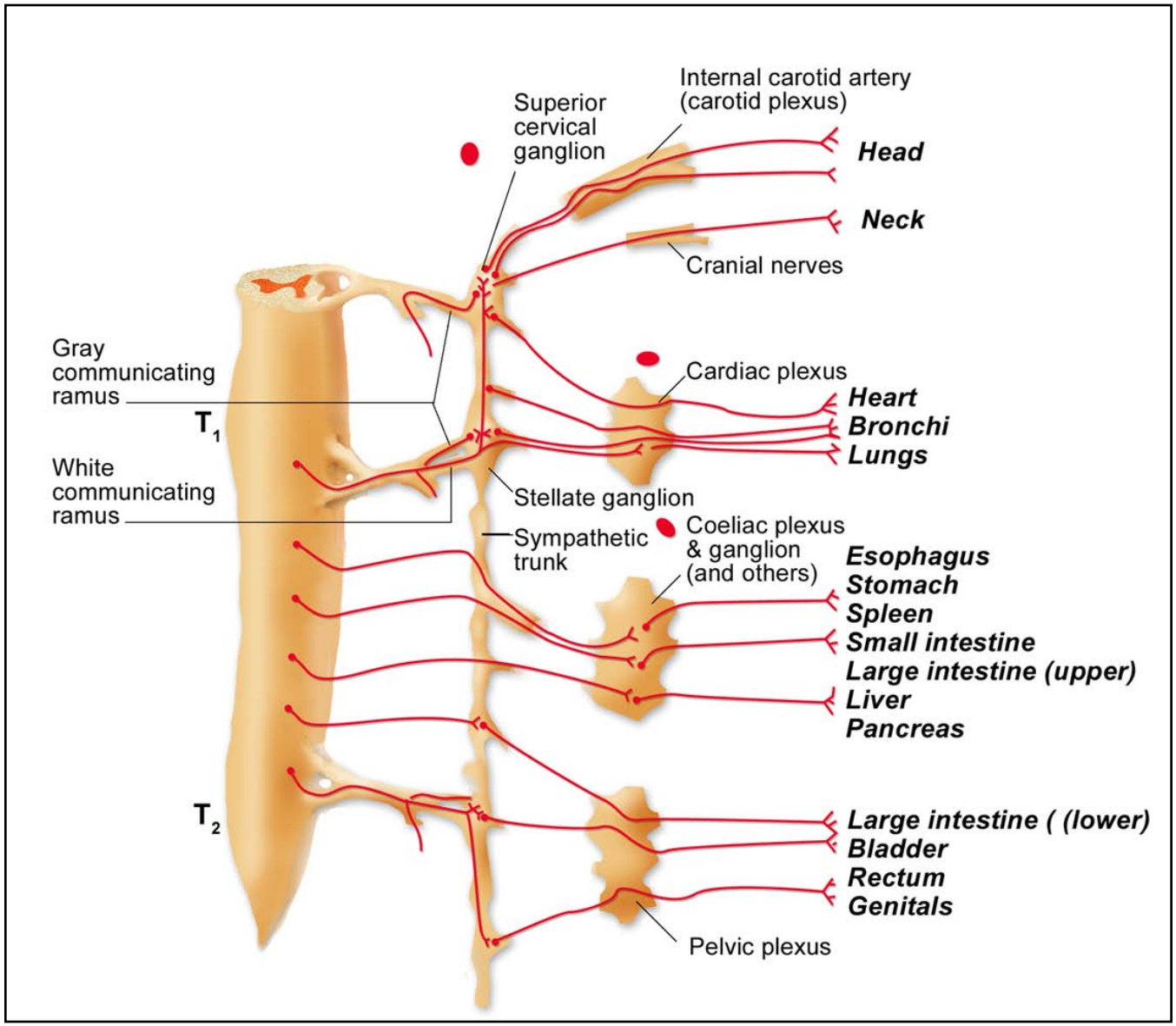


Sympathetic nervous system axons, schematic section of spinal cord, thoracic level



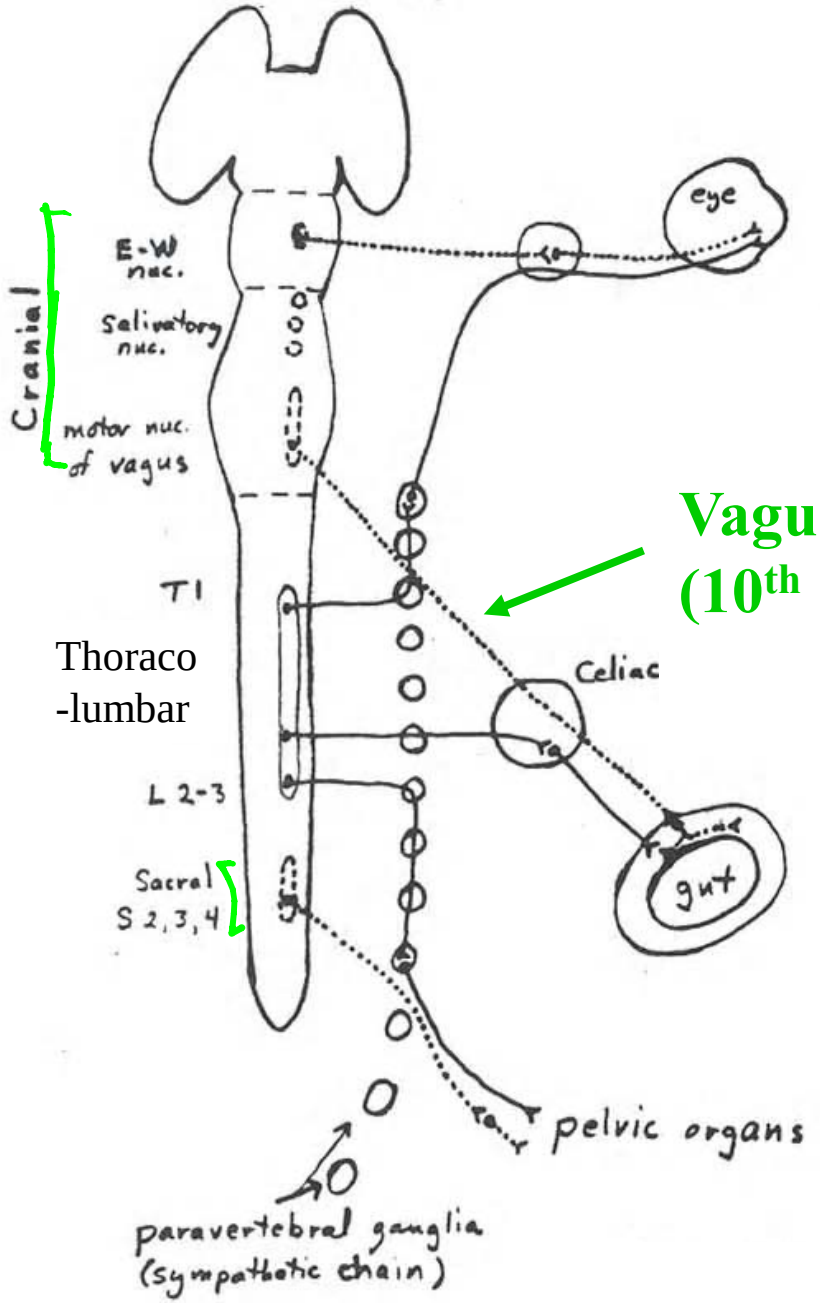
Schneider, G. E. *Brain structure and its Origins: In the Development and in Evolution of Behavior and the Mind*. MIT Press, 2014. ISBN:9780262026734.

Sympathetic Innervation



Autonomic nervous system:

- **Parasympathetic innervation** (cranio-sacral system)



Schneider, G. E. *Brain structure and its Origins: In the Development and in Evolution of Behavior and the Mind*. MIT Press, 2014. ISBN:9780262026734.

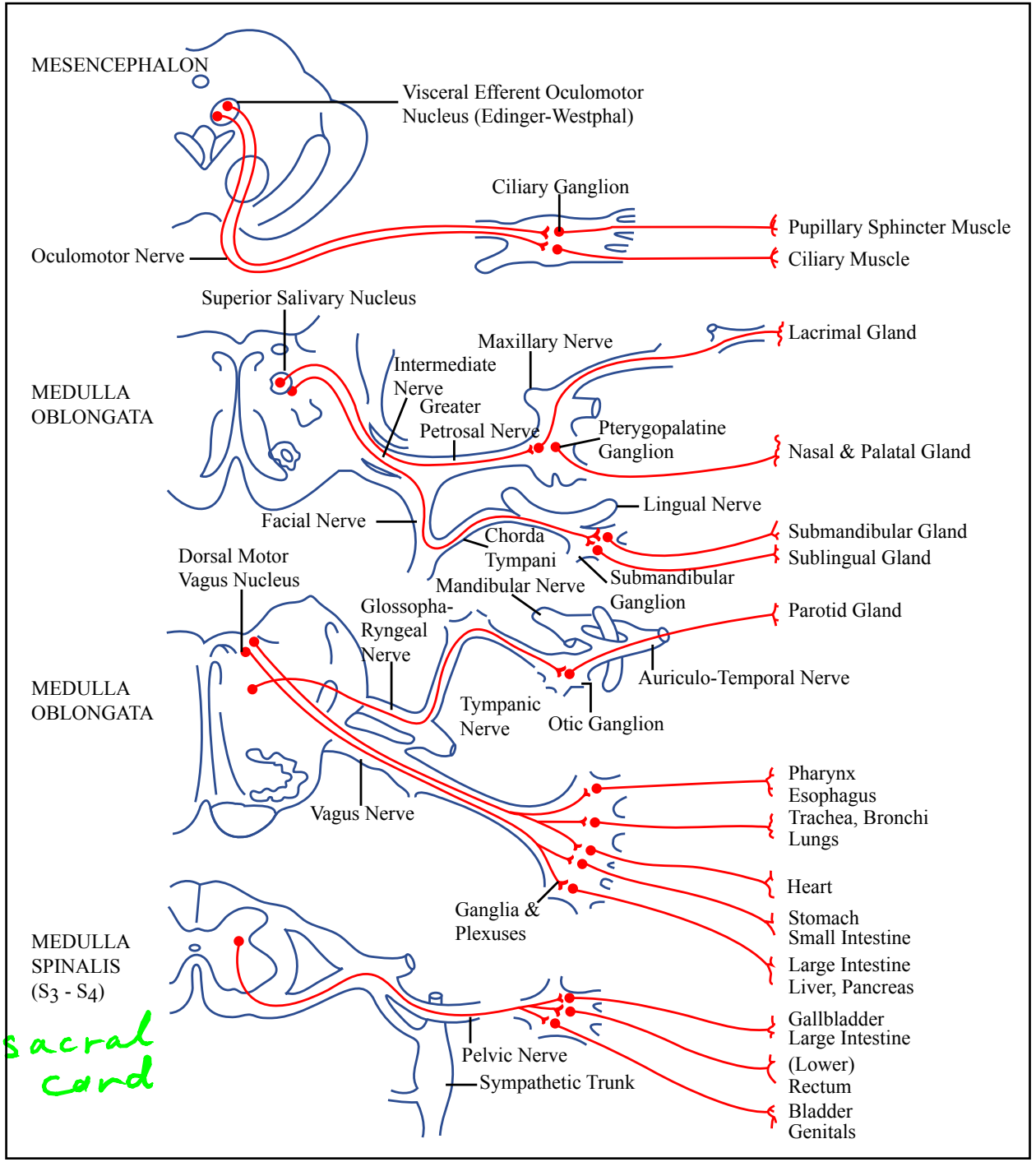


Image by MIT OpenCourseWare.

Parasympathetic Innervation

Questions, chapter 9

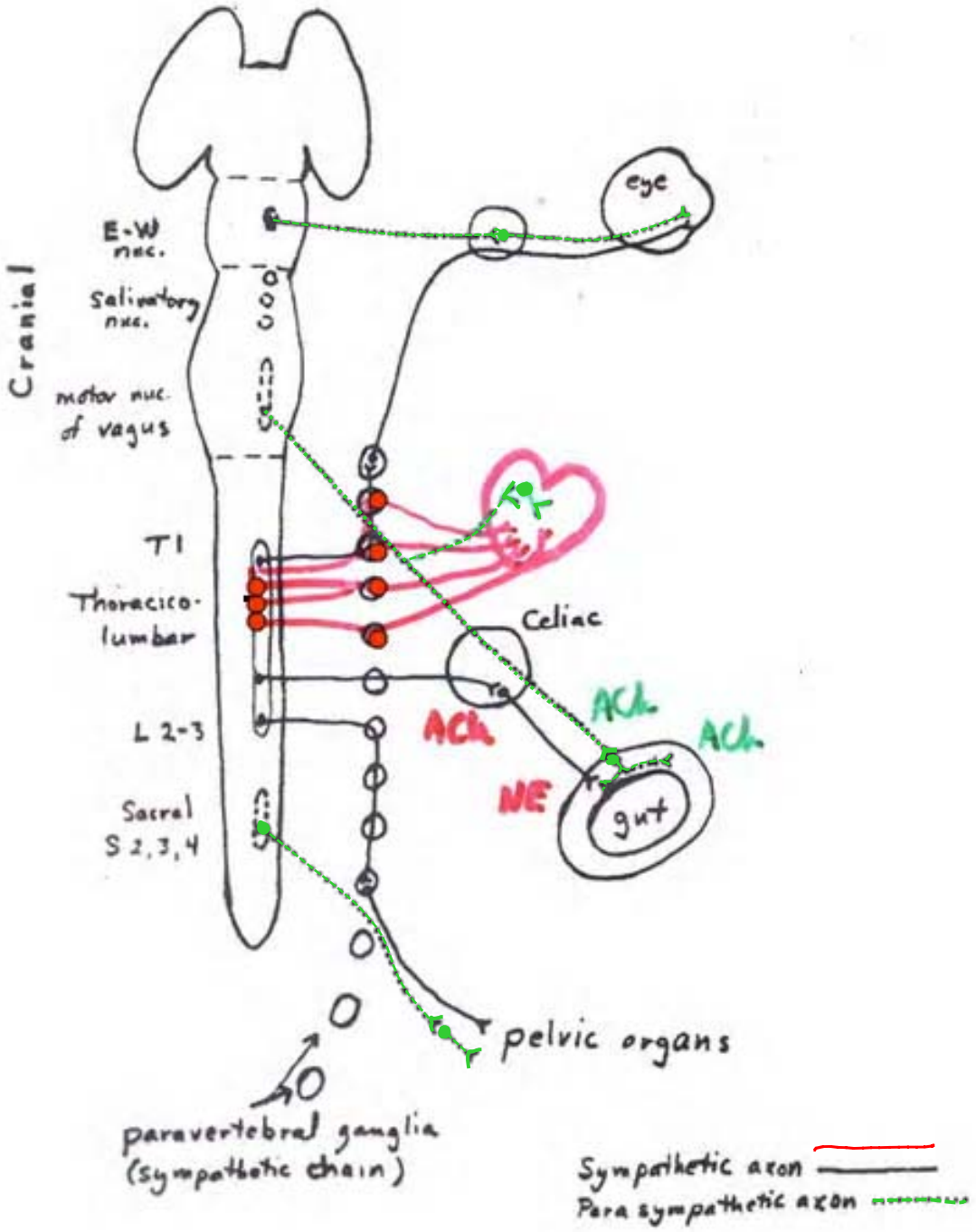
16) Compare and contrast the neurotransmitters used by the two divisions of the visceral nervous system.

Autonomic nervous system:

- **Chemical mediation at synapses**: discovered by Otto Loewi in 1921 (REVIEW)

Autonomic pathways with neurotransmitters

showing accelerator & decelerator nerves of the heart



Schneider, G. E. *Brain Structure and its Origins: In the Development and in Evolution of Behavior and the Mind*. MIT Press, 2014. ISBN:9780262026734.

Questions, chapter 9

17) What is meant by the enteric nervous system?
Why is it considered to be a separate system?

An advance in PNS anatomy in the late part of the 20th century:

The enteric nervous system

The "little brain" in the gut: A semi-autonomous network that may contain as many neurons as the entire spinal cord.

, including many interneurons,

In the wall of the intestine, this network contains multiple plexi:

- Myenteric plexus (the outer plexus)
- Submucous plexus (the middle plexus)
- Villous plexus (inner plexus)
- Periglandular plexus (inner plexus)

Innervation by vagus nerve

Cf. Cardiac Ganglion: Does the heart have a brain?

Various neurotransmitters are used in this system.

Questions, chapter 9

18) Briefly describe the hierarchy of central control of body temperature.

Intro:

Levels of autonomic control

- The enteric nervous system shows autonomy at the lowest level, in control of the alimentary tract.
- Within the CNS, there are lower levels of control of the internal environment capable of some autonomy.
- Temperature regulation is a good example.
  - For this function, each higher level adds more refinement.

Levels of control in the ANS: the temperature regulation systems

- **Temperature is regulated by mechanisms operating at all levels:**
  - **spinal,**
  - **hindbrain,**
  - **midbrain,**
  - **hypothalamus of the 'tweenbrain.**
- **Each higher level adds refinements: for endothermic animals, this means speed and a narrower range of target temperatures.**
- *See reviews by Evelyn Satinoff.*

- For other functions, there is probably a similar hierarchy.

Supplementary figures

- Autonomic innervation of the intestine in several vertebrate classes: There are large differences.
- Textbook views of autonomic nervous system innervation

Autonomic innervation of the intestine in several vertebrate classes.

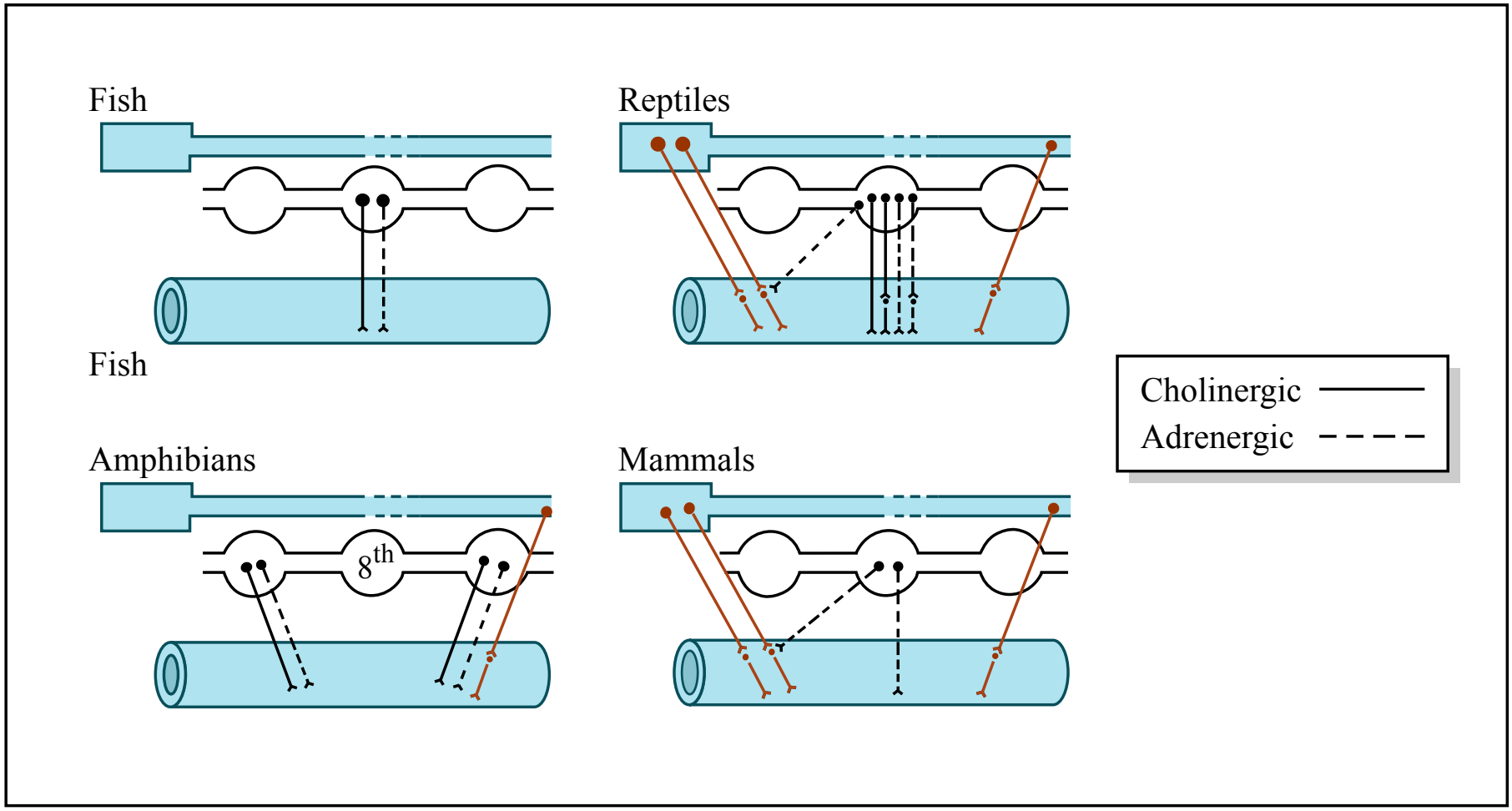


Image by MIT OpenCourseWare.

Autonomic pathways: schematic of structural arrangements

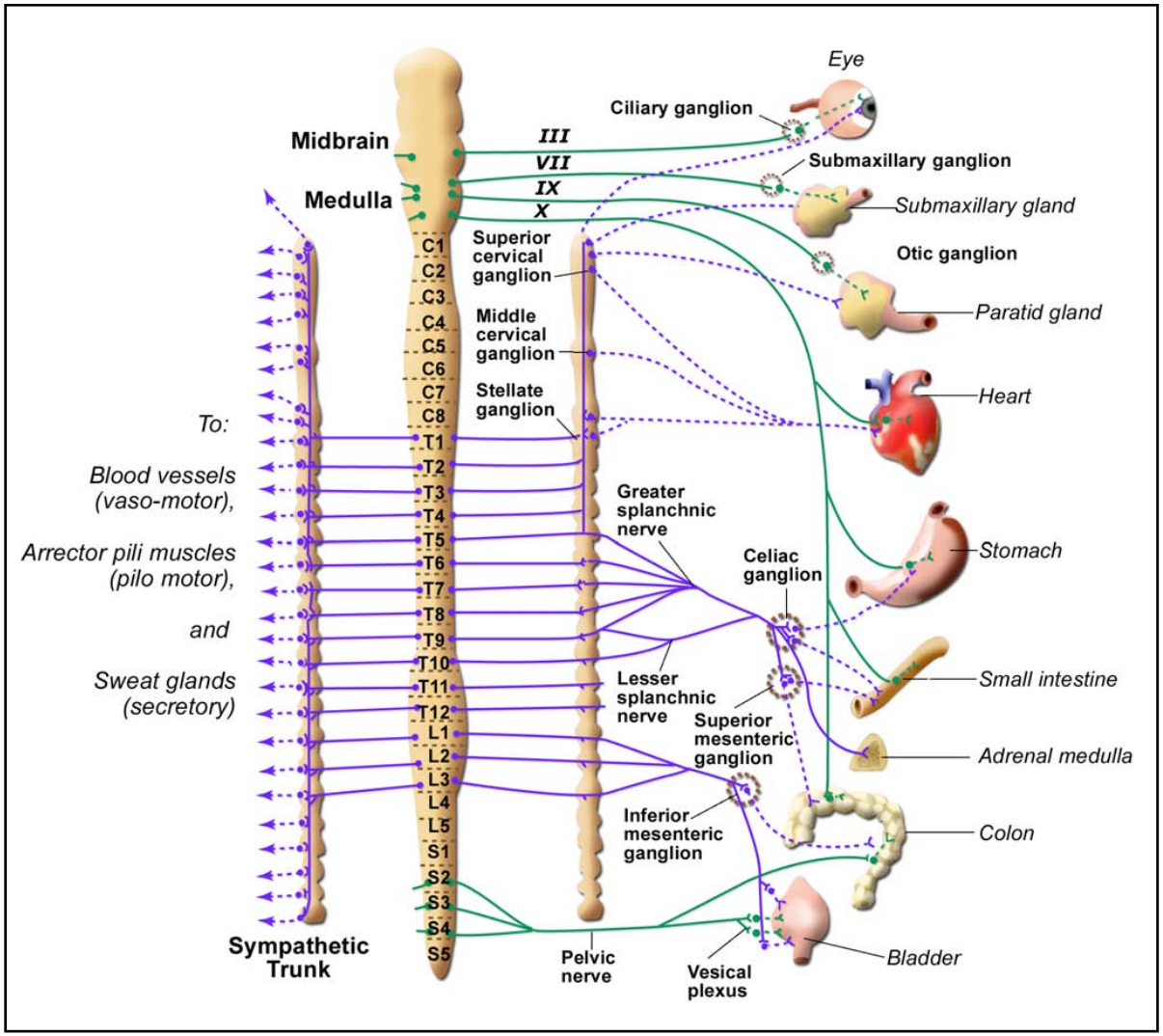


Image by MIT OpenCourseWare.

Note the CNS locations of the preganglionic motor neurons of the two divisions of the ANS.

Another schematic view of ANS

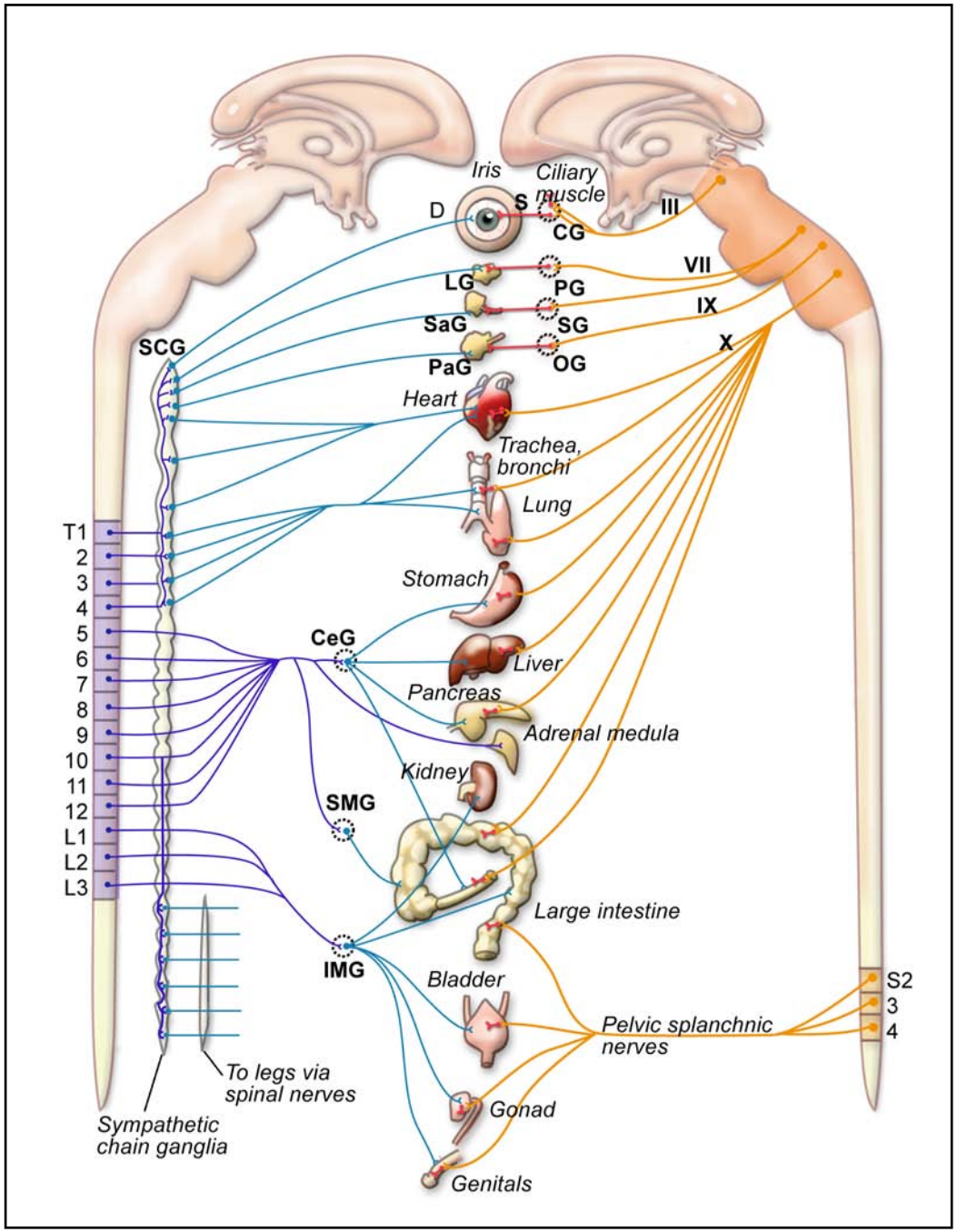


Image by MIT OpenCourseWare.

A sketch of the central nervous system and its origins

G. E. Schneider 2014

Part 4: Development and differentiation, spinal level

MIT 9.14 Class 9a

Intermission:

Meninges and glial cells

Intermission:

The ventricular system; the meninges and glia

- Remember: the origins of the ventricle in the formation of the neural tube
- The importance of the cerebrospinal fluid in the mature CNS:
  - Nutrients
  - Fluid balance regulation *via* specific cell regions
  - Also a communication medium (because of chemical secretions into it and diffusion from it)
- Where the fluid is made and how it flows: next

Questions, Intermission on meninges and glia

2) What cells make the cerebrospinal fluid (CSF)? How does the CSF get from the ventricles of the brain into the subarachnoid space surrounding the brain?

Choroid plexus*

See next slide: openings at Cb level

3) Where is the Aqueduct of Svlvius?

ventricle, midbrain

* largest in the endbrain - lateral ventricles

Ventricular system:

The foramena of Luschka (lateral apertures), and the foramen of Magendie (median aperture)

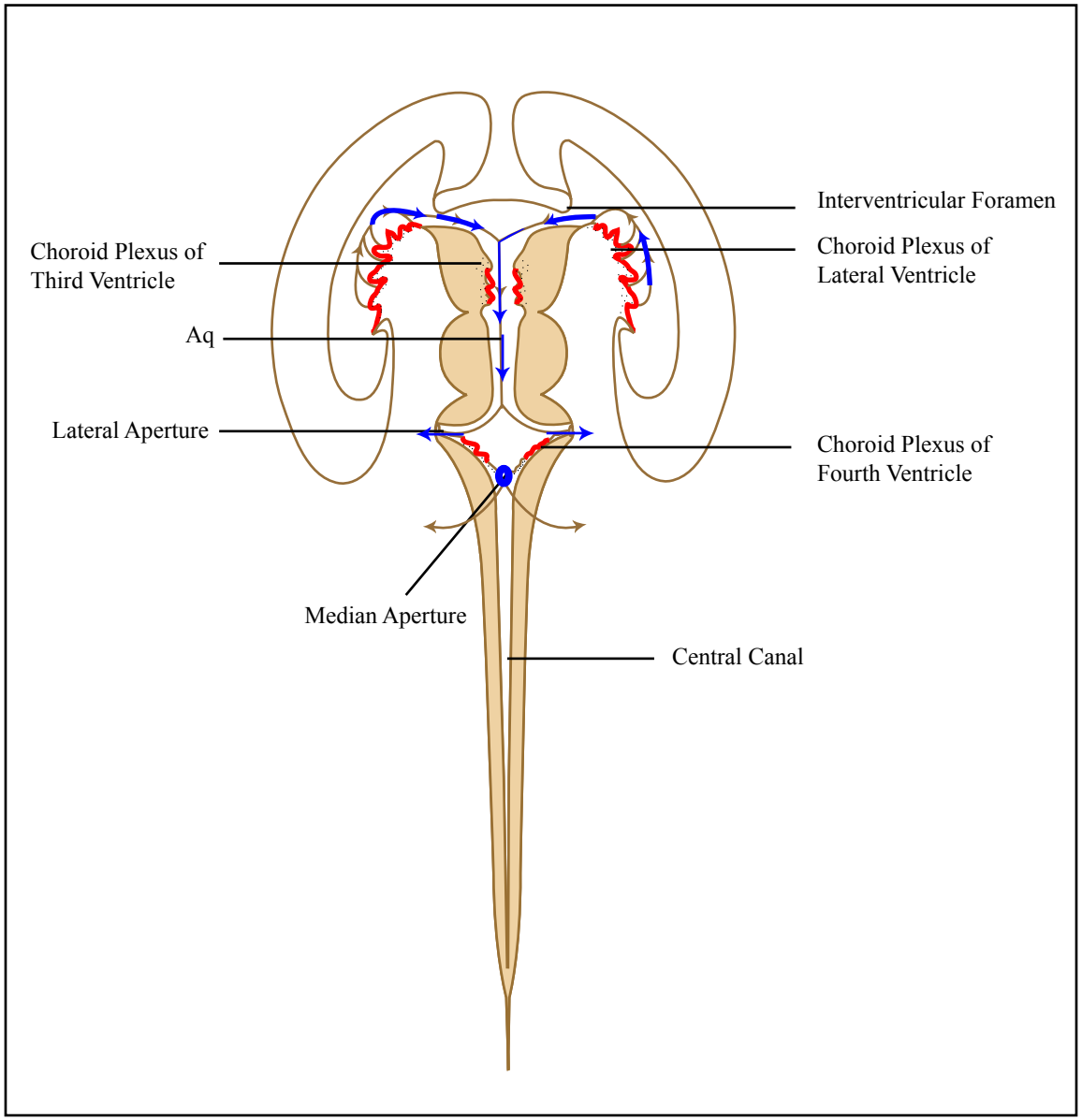


Image by MIT OpenCourseWare.

Choroid plexus: specialized ependymal cells which make cerebrospinal fluid

Ventricular system:

Note the foramena of Luschka (lateral apertures), and the foramen of Magendie (median aperture)

Also note:
the choroid plexus: specialized ependymal cells which make cerebrospinal fluid

Questions, Intermission on meninges and glia

1) What are the names of the three layers of the meninges that surround the brain and spinal cord?

4) What is the pial-glial membrane? What cell types participate in its formation?

The Meninges

1. Define "**dura mater**" and "**pia mater**": meaning of the Latin terms, and basic anatomy.
2. Define "**arachnoid membrane**" and "**subarachnoid space**".

See Nauta & Feirtag, ch. 10; also P. Brodal, ch. 1, and other texts

Meninges & Glia

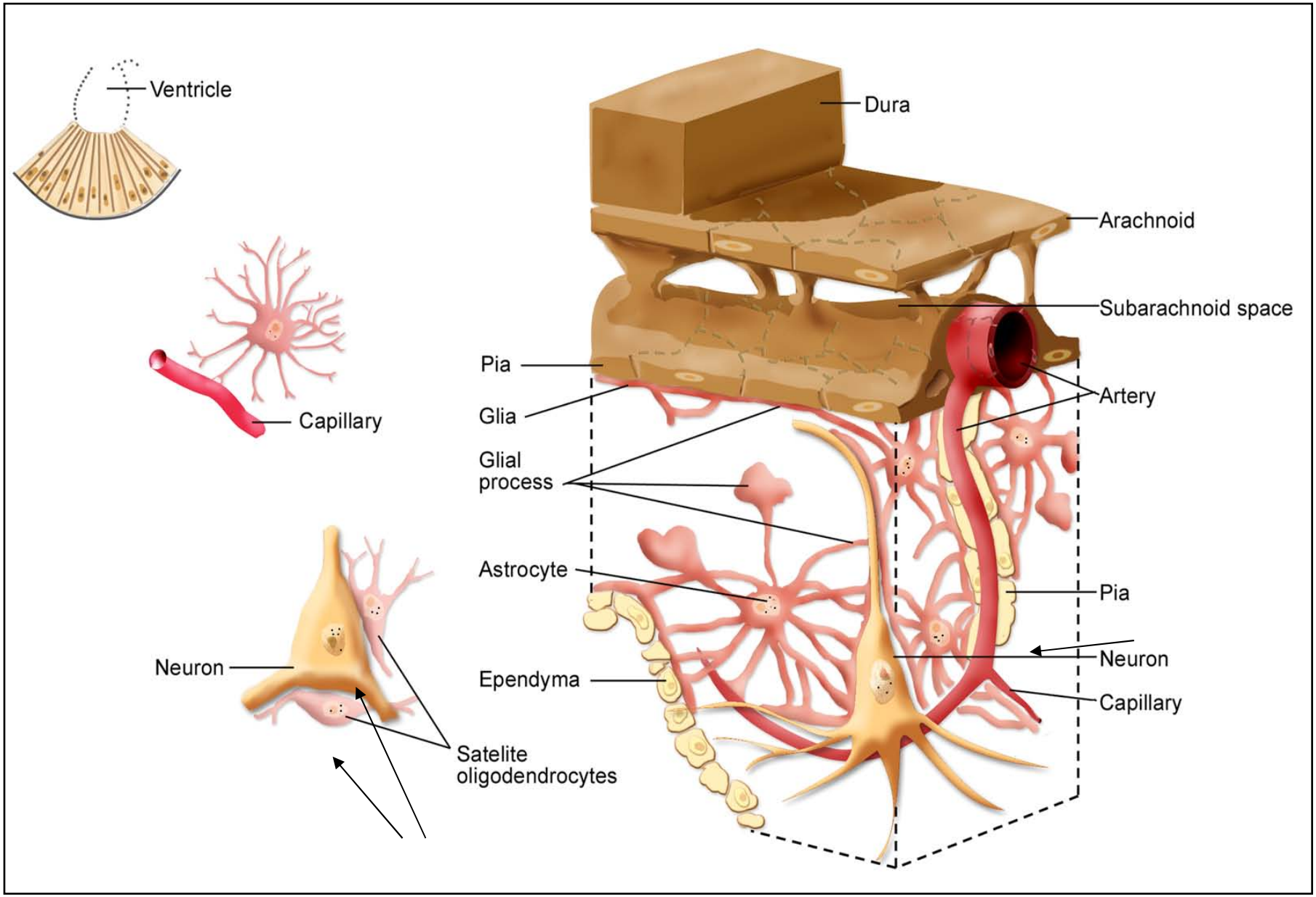


Image by MIT OpenCourseWare.

Picture taken with transmission electron microscope (EM):
Astroctyes, pial cells, subarachnoid space
(Peters, Palay & Webster, 1976)

Figure removed due to copyright restrictions.

SS = subarachnoid space
PM = pial membrane
Col = collagen fibers
SM = smooth muscle
GL = glia limitans (astrocyte processes)
B = basal lamina
As = astrocyte
arrows, lower fig: attachment points

End of Intermission on the ventricular system and glial cells

Next: Hindbrain introduction

A sketch of the central nervous system and its origins

G. E. Schneider 2014

Part 5: Differentiation of the brain vesicles

MIT 9.14 Class 9b

Introduction to hindbrain and segmentation

with questions on chapter 10

First, some terms and a little embryology:

The ***encephalon**** (brain)

- **Hindbrain (*rhombencephalon*)**
- **Midbrain (*mesencephalon*)**
- **Forebrain (*prosencephalon*)**
  - **‘Tweenbrain (*diencephalon*)**
  - **Endbrain (*telencephalon*)**

* “In the head”

The embryonic neural tube above the spinal cord

- What are the "flexures" in the neural tube?
  (*See, e.g., Nauta & Feirtag, pp 162-163*)

The **flexures** of the developing human neural tube's rostral end, viewed from the right side

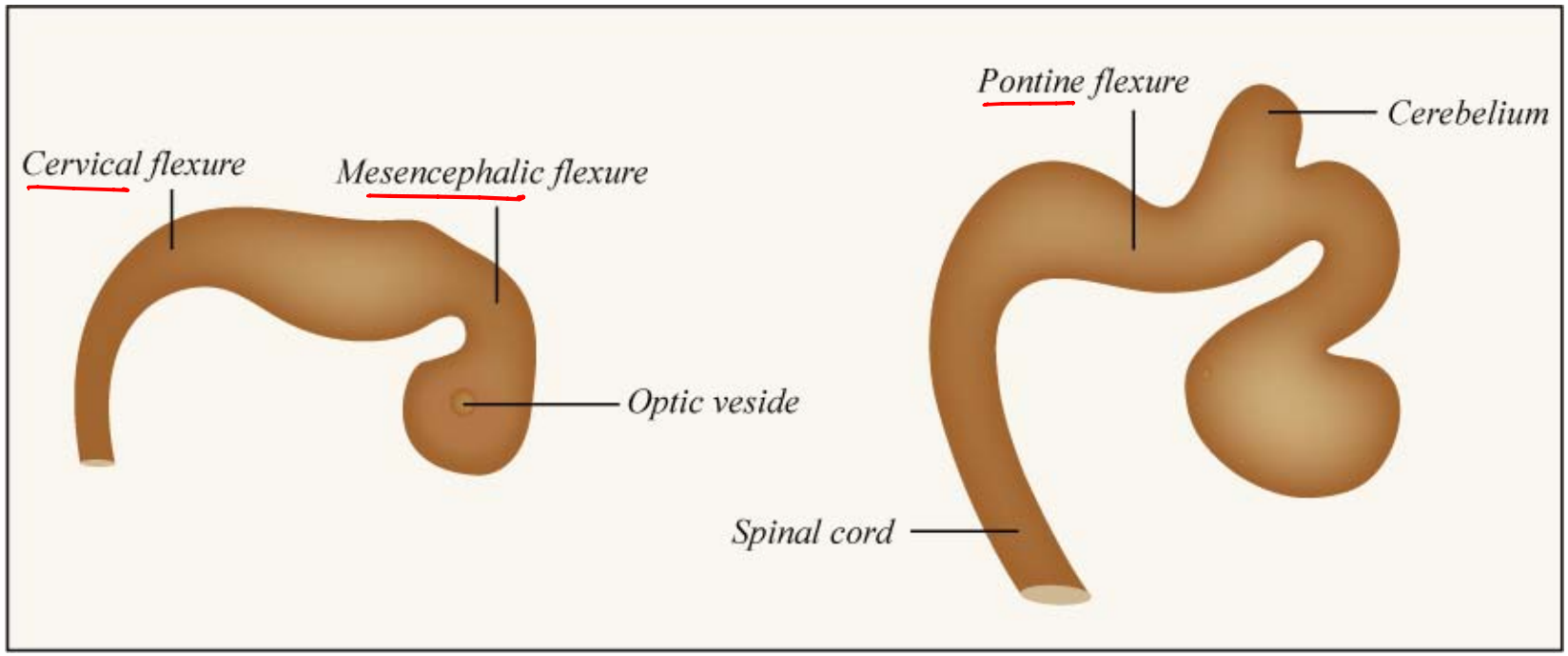
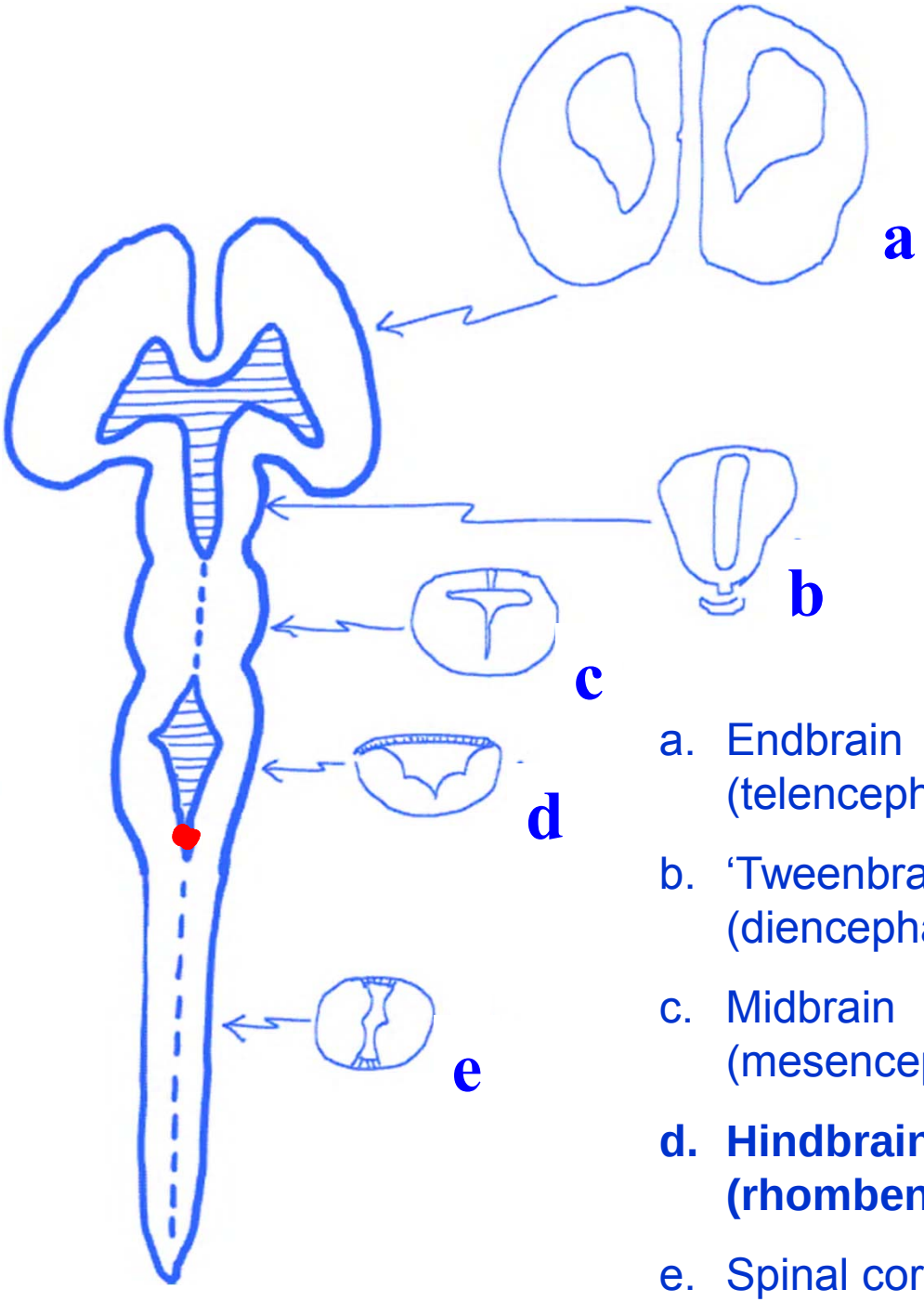


Image by MIT OpenCourseWare.

Origin of the term “rhombencephalon”

- What happens to the roof plate where the pontine flexure (bend) forms? *(See, e.g., Nauta & Feirtag, p. 162)*



Basic subdivisions, embryonic neural tube:

Where is the rhombus? What is it?

a. Endbrain (telencephalon)
b. 'Tweenbrain (diencephalon)

} Forebrain (prosencephalon)

c. Midbrain (mesencephalon)

d. Hindbrain (rhombencephalon

e. Spinal cord

Reminder: Students should understand and know this figure!

Schneider, G. E. *Brain Structure and its Origins: In the Development and in Evolution of Behavior and the Mind*. MIT Press, 2014. ISBN:9780262026734.

Questions, chapter 10

2) The obex is a landmark in the hindbrain viewed from the dorsal side. What is the obex?
   - Find it in the previous picture.

The hindbrain (*rhombencephalon*)
topics

- Basic structural organization compared with spinal cord
- Basic functions
- Cell groupings; origins
- Sensory channels and the trigeminal nerve
- The "distortions" in the basic organization

next class

Questions, chapter 10

1) How is the hindbrain embryologically very similar to the spinal cord?

8) Compare and contrast the columns of secondary sensory and motor neurons of the hindbrain and spinal cord.

Basic organization:
"a glamorized spinal cord"

- Alar and basal plates; widened roof plate (with widened ventricle – the 4th ventricle)
- No more law of roots; some cranial nerves are "mixed nerves" containing both sensory and motor components.

Cell groupings

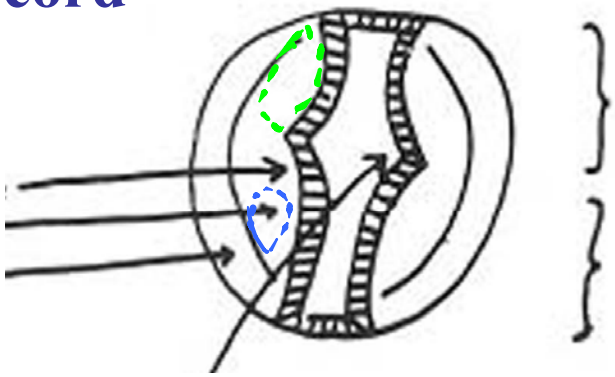
- Secondary sensory nuclei (cell groups) in the alar plate
- Motor nuclei (groups of motor neurons) in the basal plate

- The arrangement can be understood as a simple modification of spinal cord organization.

Embyonic spinal cord & hindbrain compared

Embryonic spinal cord (in cross section)

Ventricular zone
Intermediate zone
Marginal zone



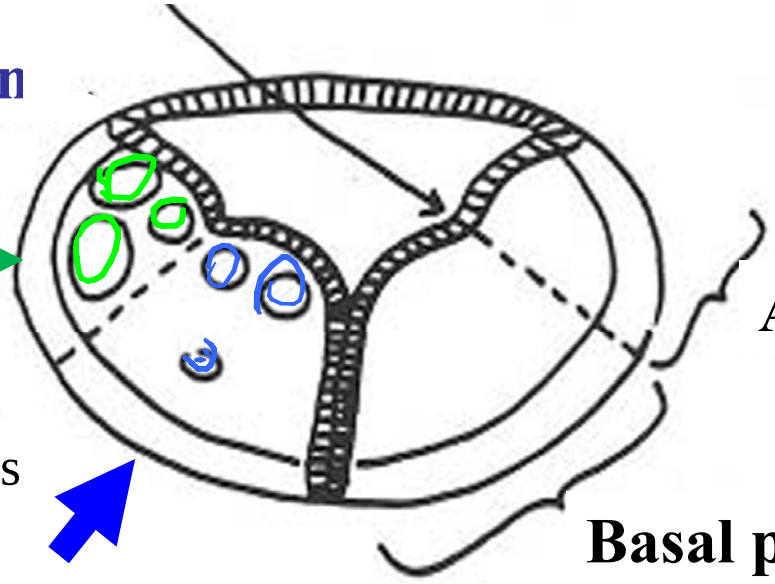
Alar plate

Basal plate

Sulcus limitans

Embryonic hindbrain

Secondary sensory cell groups in intermediate zone of alar plate



Alar plate

Motor neuron cell groups in intermediate zone of basal plate

Basal plate

Questions, chapter 10

3) The hindbrain is known to be an essential controller of “vital functions.” What vital functions are involved?

4) In what other “routine maintenance functions” is the hindbrain important or even essential?

5) How is the hindbrain involved in human speech?

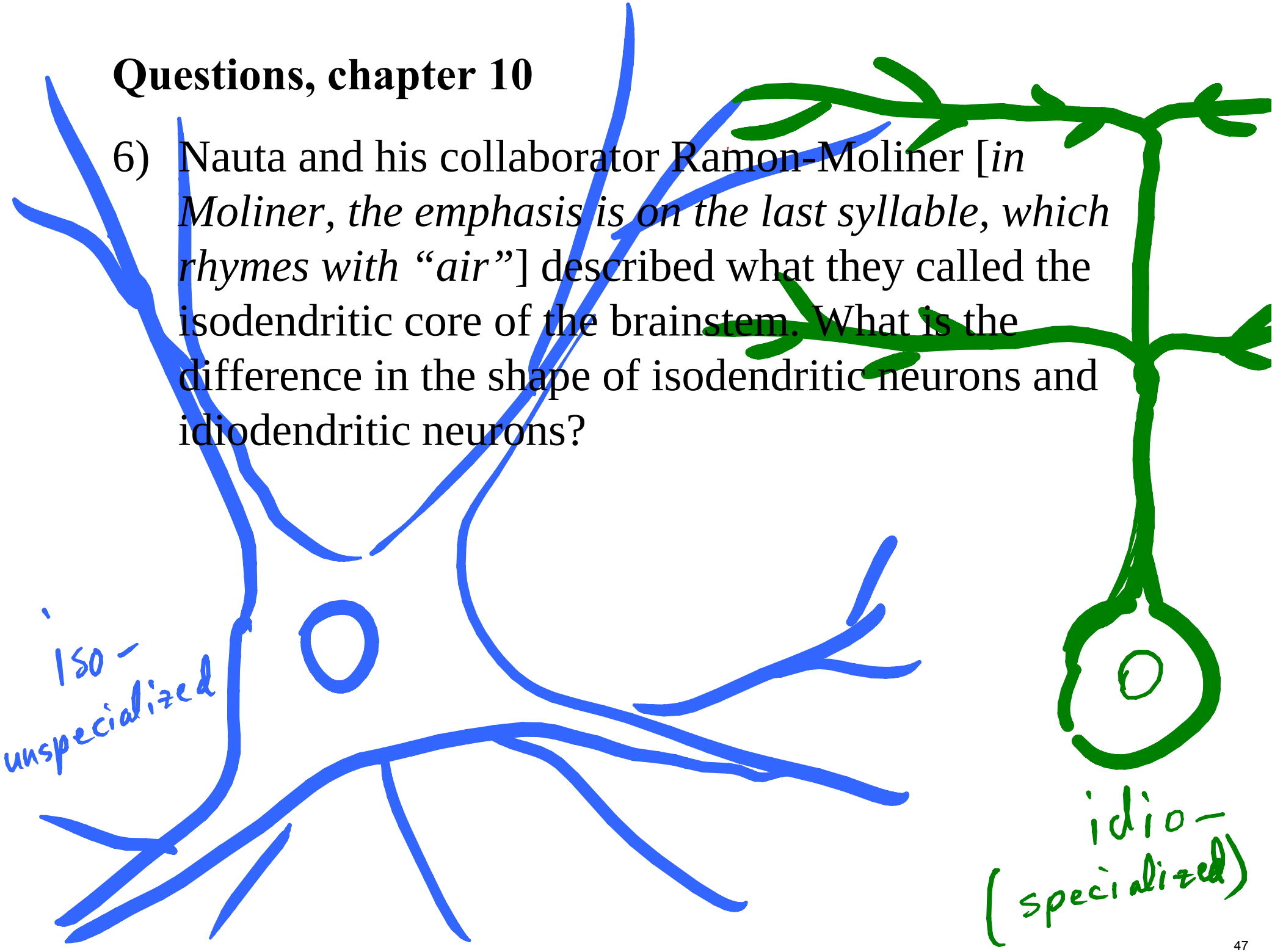
19) Try to describe the critical roles of the hindbrain in feeding behavior.

Hindbrain functions

- **Routine maintenance**: the support services area of the CNS, for centralized control of spinal functions
  - Vital functions (control of breathing, blood pressure & heart rate, & other visceral regulation)
  - Motor coordination (cerebellum, vestibular system)
  - Fixed Action Patterns, the motor component: swallowing, vomiting, eyeblink, grooming, etc.
  - Widespread modulation of brain activity: sleep & waking; arousal effects [See following illustrations]
- **Role in mammalian higher functions**: movement control for functions of more rostral brain systems
  - for speech (tongue, lip, breath control)
  - for emotional displays, especially in facial expressions
  - for eye movements

Questions, chapter 10

6) Nauta and his collaborator Ramon-Moliner [*in Moliner, the emphasis is on the last syllable, which rhymes with "air"*] described what they called the isodendritic core of the brainstem. What is the difference in the shape of isodendritic neurons and idiodendritic neurons?



Neurons of the reticular formation

- "Isodendritic" core of the brainstem *(Ramon-Moliner & Nauta)*
  - *Contrast:* ***isodendritic*** *&* ***idiodendritic***
- Neuropil segments next
- Axons with very wide distributions next

Dendritic orientation of reticular formation neurons in hindbrain, forming a series of neuropil segments:

Collaterals of pyramidal tract axons have similar distributions.
For contrast, cells of the hypoglossal nucleus are also shown

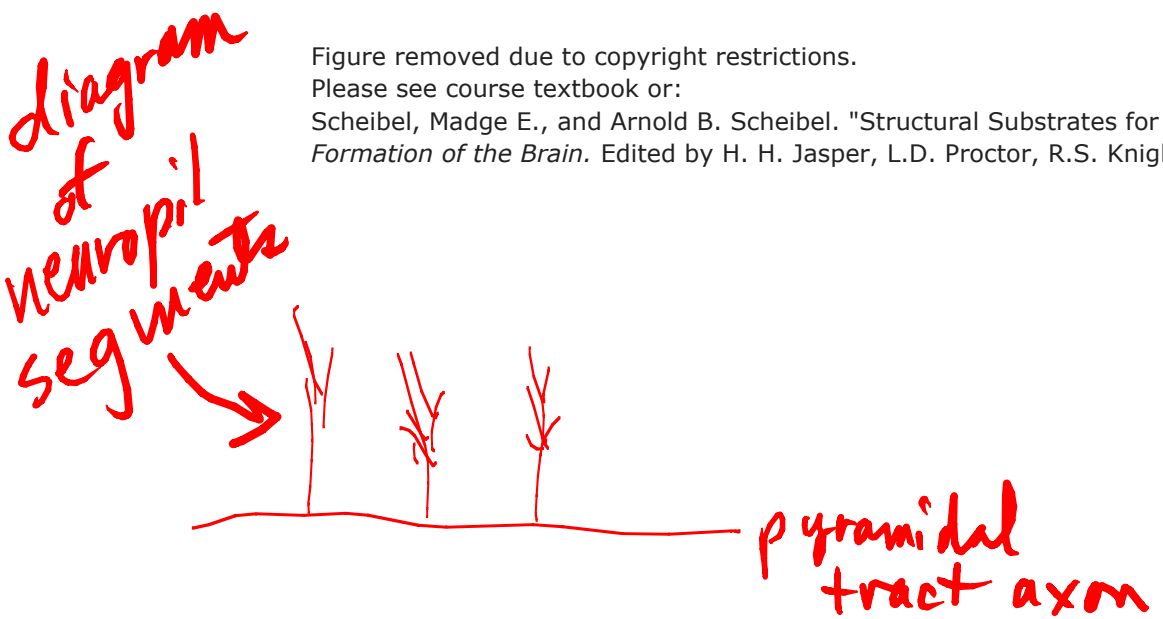


Figure removed due to copyright restrictions.
Please see course textbook or:
Scheibel, Madge E., and Arnold B. Scheibel. "Structural Substrates for Integrative Patterns in the Brain Stem Reticular Core." In *Reticular Formation of the Brain.* Edited by H. H. Jasper, L.D. Proctor, R.S. Knighton, W.C. Noshay, and R.T. Costello. Little, Brown, 1958.

Golgi stain, parasagittal section of hindbrain, young rat. From Scheibel & Scheibel, 1958

Neuron of hindbrain reticular formation: Axon has ascending and descending branches, each with widespread distribution of terminations

single

Figure removed due to copyright restrictions.
Please see course textbook or:
Scheibel, Madge E., and Arnold B. Scheibel. "Structural Substrates for Integrative Patterns in the Brain Stem Reticular Core." In *Reticular Formation of the Brain.* Edited by H. H. Jasper, L.D. Proctor, R.S. Knighton, W.C. Noshay, and R.T. Costello. Little, Brown, 1958.

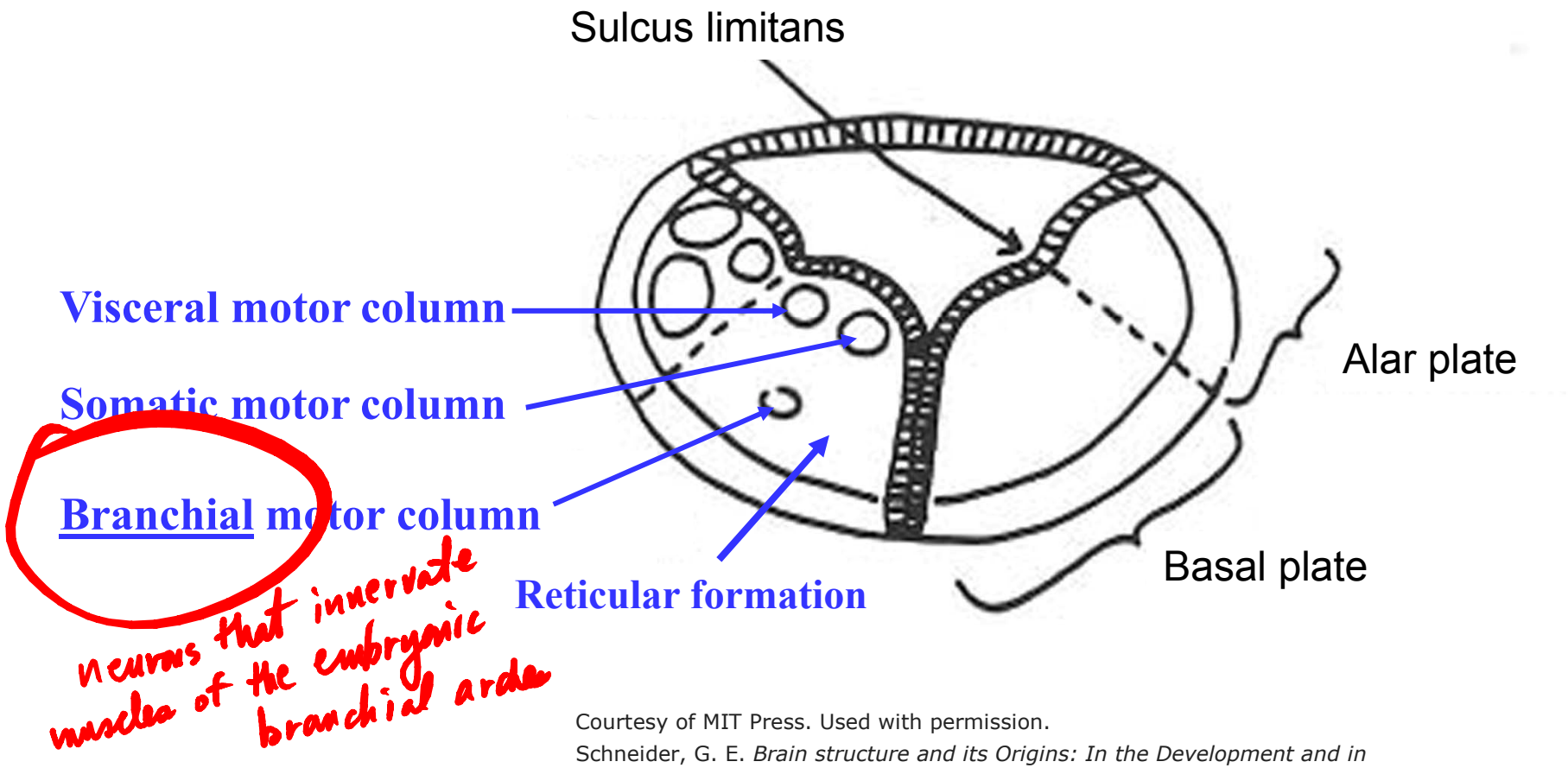
2-day old rat, Rapid Golgi stain, from Scheibel & Scheibel, 1958

Questions, chapter 10

7) Describe segmentation of the hindbrain and the evidence for it. Compare the expression of hindbrain segmentation with segmentation of the spinal cord.

Notes on hindbrain origins: *definitions*

- Segmentation above the segments of the spinal cord: The somitomeres & **branchial arches in the mesoderm,** and the **rhombomeres of the CNS**
- *See Nauta & Feirtag, ch.11, p. 170, on the "**branchial motor column**" -- in addition to the **somatic and visceral motor columns**.*



Segmented systems, 3-day chick embryo:

Somites, spinal segments. Branchial arches, rhombomeres

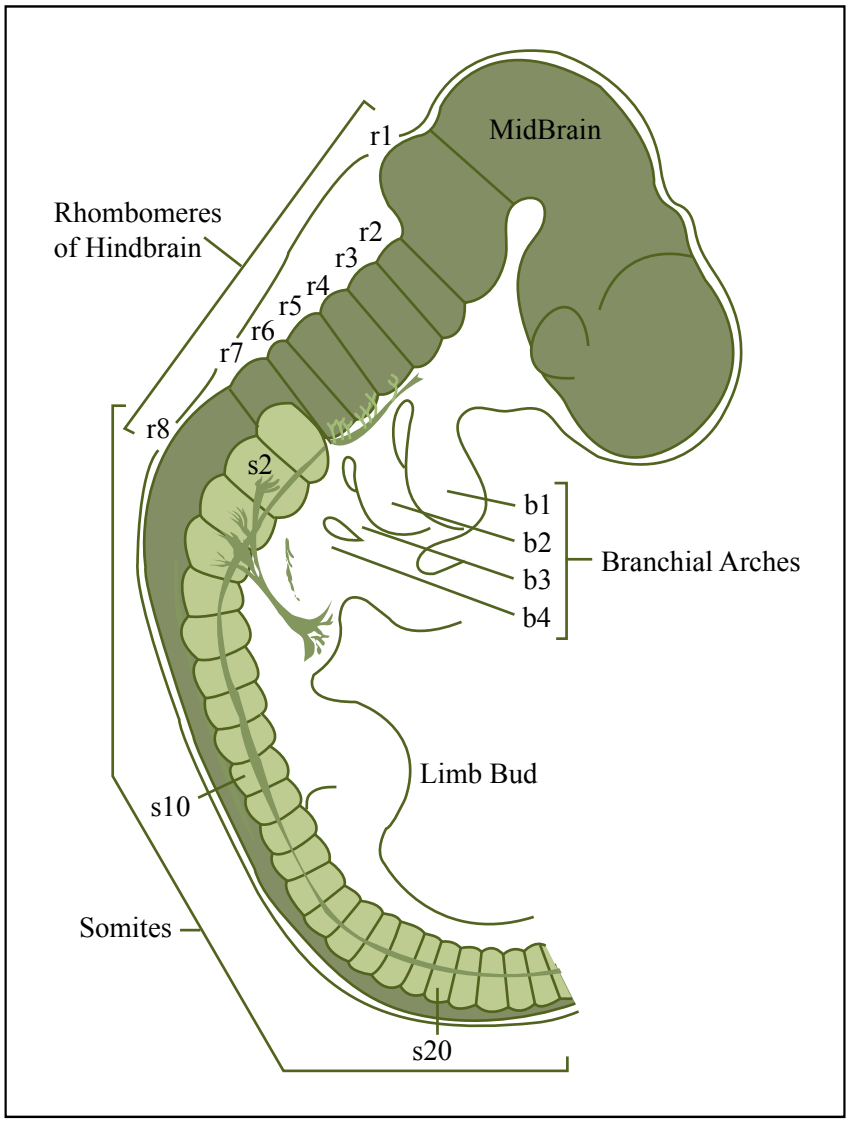


Image by MIT OpenCourseWare.

Branchial arches of the mesoderm, innervated by the trigeminal motor nucleus (*via* cranial n 5), the facial nucleus (*via* n 7), and by nucleus ambiguus (*via* n 9, n 10).

(Functions of Nuc. Ambiguus: swallowing and vocalization)

The branchial arches in humans form jaws, the auditory ossicles, the hyoid, and the pharyngeal skeleton including thyroid cartilage.

X

The mesoderm below the head region becomes segmented:

Somites.

2-day chick embryo

(Photo from Wolpert, 2002, p. 22)

Figure removed due to copyright restrictions.
Please see:
Wolpert, Lewis, et al. *Principles of Development*. 2nd ed. Oxford University Press, 2002, pp. 22. ISBN: 0198792913.

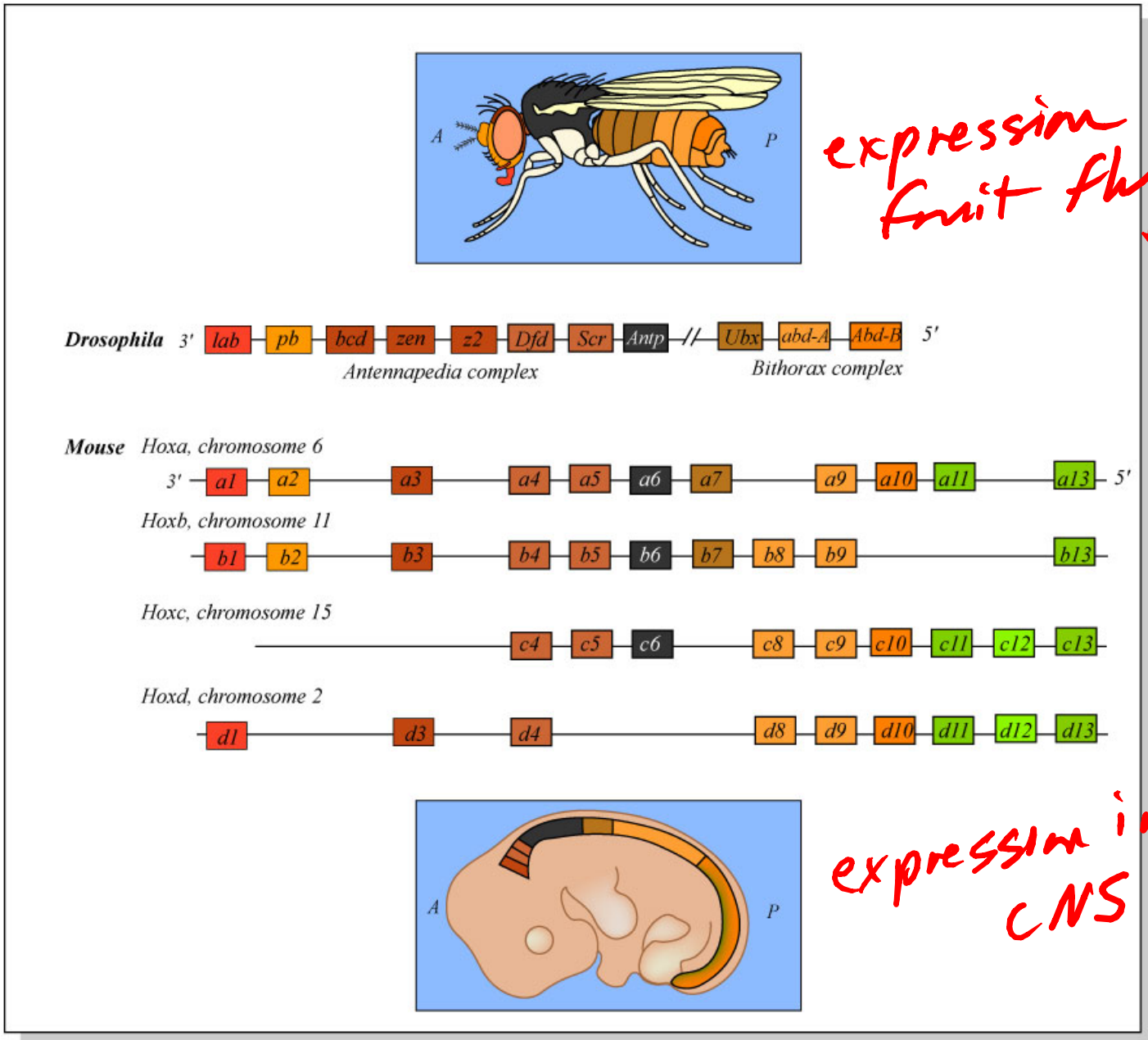
Genes underlying segmentation
topics

- Ancient origins of segmentation along the A-P axis, with corresponding nervous system differentiation
- The homeobox genes: What are they?
- Examples of gene expression patterns

next

a family of genes for transcription factors

Homeobox genes in Drosophila, and 13 paralogous groups in 4 chromosomes of mouse



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Hox gene expression in the mouse embryo after neurulation

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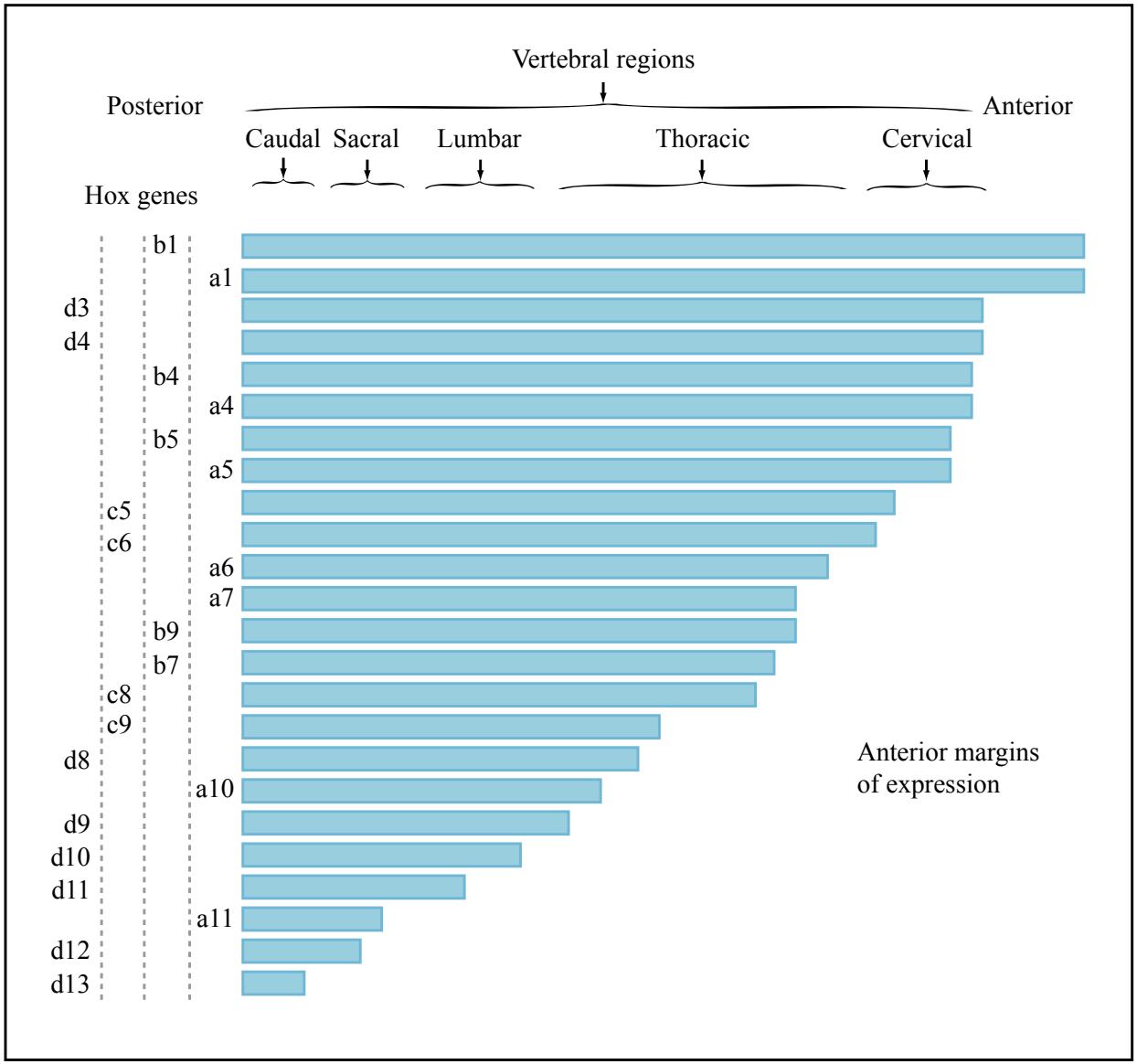
Please see course textbook or figure 4.11 of:
Wolpert, L., J. Smith, et al. *Principles of Development*. 3rd ed. Oxford University Press, 2006.

E 9.5 mouse embryos, immunostained using antibodies specific For the protein products of the indicated Hox genes.
(Wolpert, 2002, fig. 4.11)

End session 9

Hox gene expression along the antero-posterior axis of the mouse mesoderm



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9.14 Brain Structure and Its Origins

Spring 2014