Autonomic pathways: a selective schematic view

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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

Ectoderm
Notochord
Roof plate
Alar plate
Basal plate
Floor plate

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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

- Dorsal root ganglion
- Spinal nerve
- Prevertebral ganglion, e.g., celiac
- Paravertebral ganglion
- Descending reticulospinal fibers
- Smooth muscle: Glands; intestinal tract; blood vessels, erector pili (hairs); sweat glands.
- Cardiac muscle

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Sympathetic Innervation

Image by MIT OpenCourseWare.
Autonomic nervous system:

- **Parasympathetic innervation**
  (cranio-sacral system)
Vagus nerve
(10th cranial nerve)

Thoraco-lumbar

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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
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.
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.
Autonomic pathways: schematic of structural arrangements

Note the CNS locations of the preganglionic motor neurons of the two divisions of the ANS.
Another schematic view of ANS
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?

3) Where is the Aqueduct of Sylvius?

* largest in the endbrain
- lateral ventricles

choroid plexus

see next slide: openings at c6 level

ventricle, midbrain
**Ventricular system:**
The foramena of Luschka (lateral apertures), and the foramena of Magendie (median aperture)

**Choroid plexus:**
specialized ependymal cells which make cerebrospinal fluid

Image by MIT OpenCourseWare.
Ventricular system:

Note the foramina 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): 
Astrocytes, pial cells, subarachnoid space 
(Peters, Palay & Webster, 1976)

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

Figure removed due to copyright restrictions.
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. Spinal cord
b. Hindbrain (rhombencephalon)
c. Midbrain (mesencephalon)
d. 'Tweenbrain (diencephalon)
e. Endbrain (telencephalon)

Forebrain (proencephalon)

Reminder: Students should understand and know this figure!
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
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.
Embryonic spinal cord & hindbrain compared

**Embryonic spinal cord**
*(in cross section)*

- Ventricular zone
- Intermediate zone
- Marginal zone

**Embryonic hindbrain**

- Secondary sensory cell groups in intermediate zone of alar plate
- Motor neuron cell groups in intermediate zone of basal plate

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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
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

- Axons with very wide distributions
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

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.

Figure removed due to copyright restrictions. Please see course textbook or:

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

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).

(Function 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.
The mesoderm below the head region becomes segmented:

Somites,
2-day chick embryo

(Photo from Wolpert, 2002, p. 22)
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
Homeobox genes in Drosophila, and 13 paralogous groups in 4 chromosomes of mouse.
Hox gene expression in the mouse embryo after neurulation

Figure removed due to copyright restrictions.
Please see course textbook or figure 4.11 of:

E 9.5 mouse embryos, immunostained using antibodies specific for the protein products of the indicated Hox genes.
(Wolpert, 2002, fig. 4.11)
Hox gene expression along the antero-posterior axis of the mouse mesoderm

Vertebral regions

Caudal | Sacral | Lumbar | Thoracic | Cervical

Anterior margins of expression

Image by MIT OpenCourseWare.