Hwee Ming Cheng *Editor*

Physiology Question-Based Learning

Neurophysiology, Gastrointestinal and Endocrine Systems

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This “zentangle” drawing brings to mind a myriad of processes and outcomes which intertwine and complement each other, thus depicting the complex nature of homeostasis

Abstract

This Physiology Question-Based Learning (Pq-BL) text focuses on the nervous, hormonal and digestive systems. The previous Pq-BL volume covered cardiovascular, respiratory and renal physiology, and this current Pq-BL completes the selected questions that are asked during the Physiology Quiz International (PQI) competition. The PQI is now in its 14th year and attracts more than 80 medical school teams from over 20 nations.

The illustrations that accompany the questions and explanations in this text include physio-geometric diagrams that summarize essential points in the relevant physiology. The questions are formulated to stimulate students to think and cultivate integrative approaches to understanding physiology. Questions on neuroendocrinology and neural mechanisms in gastrointestinal physiology are included.

The author has taught physiology for 30 years and regularly designs physiology questions to promote conceptual thinking for students of physiology.

Preface

Pleasant words are a honeycomb, sweet to the soul and healing to the bones (Solomon's Proverbs)

This is the second *Physiology Question-Based Learning* (*PqBL*) book and follows on from the first *PqBL* book that contains the physiology of the cardiovascular, respiratory, and renal systems. One theme that was highlighted in the latter was the dynamic aspects of flow, namely, blood flow, airflow, and tubular fluid flow, respectively. This second *PqBL* book covers the other three main physiological systems of neurophysiology, endocrinology, and the gastrointestinal system.

In the former two overlapping areas within neuroendocrinology, we can still think of flow, in this case, of information flow. The human body is "hardwired" by the extensive neural networks that interconnect the central, peripheral, and enteric nervous systems. Neural signals are transmitted as action potentials along myelinated and unmyelinated nerve fibers, and this neural traffic produces motor movements and generates the perception of all sensory modalities.

Information that serves to integrate functions in the multicellular body and maintain homeostasis is also achieved by hormones. We could view these signals as "wireless," circulating in blood as endocrines, in the interstitial fluid as paracrines and autocrines. A large part of these wireless physiologic messages have their controlling server at the hypothalamus in the brain.

Neurophysiology appears to have more eponyms, eg, Monro-Kellie doctrine. To encourage students and teachers to appreciate their physiological heritage, a selected list of eponyms is included as an appendix.

The gastrointestinal (GI) system is a digestive and absorptive biological organ. To perform its diverse functions, from mastication and swallowing to breakdown and absorption of nutrients from carbohydrates, lipids, and fats, both neural and endocrine mechanisms play major roles. The resident GI enteric nervous system (ENS) has been estimated to comprise of just as many neurons within the neural network along the GI tract as there are in the central nervous system (CNS). The CNS and the ENS are functionally linked by the autonomic nervous parasympathetic and sympathetic nerves.

The student might be surprised to be told that the GI could be the largest endocrine organ. The GI endocrine cells are generally not histologically formed as a distinct gland, but are localized in specific segments of the GI tract. Besides major endocrines like gastrin and cholecystokinin that have direct actions related to digestion, paracrines involved in both GI secretory and motility events are also abundant. The GI is also the place where non-adrenergic, non-cholinergic neurons are found.

As in the first book, the last three chapters here contain questions that seek to provide examples of integrative physiology, in neuroendocrinology, and neuro-gastroenterology. Nerves, hormones, and digestion are also interlinked. For example, glucose in the intestinal lumen releases incretin that stimulates a prior insulin response even before any postprandial hyperglycemia. The parasympathetic nerve acts on pancreatic beta cells during the cephalic phase to release some insulin secretion.

The Solomonic proverb above reminds me of the integration between neurophysiology, endocrine, and GI systems. CNS higher centers involved in speech, language, and emotions are tied to the health of our bones; and we are reminded of calcium homeostasis, intestinal calcium absorption, and the role of osteoblastogenic/clastogenic hormones.

The hand-lettering artwork that begins each of the four parts of this book was drawn by Zhiling, a creative biomedical graduate who also leads our "Thank God It's Thursday" (TGIT) Fellowship evenings in my home.

I hope these *PqBL* pages will help students enjoy physiology and the teachers to continue to be innovative in stimulating physiology learning.

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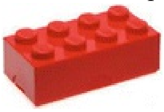
PhysioLego: Concept Building Blocks

Ask students during tutorial with colorful Lego bricks scattered on their shared table:

"What's the next block of information brick you need to stack up and construct the bigger, integrated physiology?"

Using questions, we help to build up, step-by-step, the conceptual knowledge base.

As teachers, we help to construct rationally, with the students, layers of foundational supporting knowledge. Here is an example from cardiovascular physiology (symbolized by red Lego bricks):

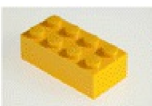
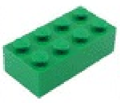
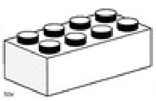


– Teach hemodynamics before respiratory physiology with its unique pulmonary vasculature.

Teach hemodynamics before considering the special features of fetal circulation in utero.

– Build concepts of osmotic pressure before capillary dynamics.
– Build concepts of body fluid spaces (just before) renal physiology.
– Build concepts of blood volume/blood pressure (just before) renal control of blood pressure.
– Build concepts of interrelated sodium balance and volume control (just before) renal regulation of ECF volume.
– Build concepts of second active transport (just before) giving examples of intestinal and renal (re)absorption followed by water osmotic flow.
– Concept of concentration and freely filtered (remaining unfiltered plasma concentration unaltered).
– Concept of parallel blood flow in systemic circulation and ability for local, regional regulation.
– Concept of central brain stem control of arterial blood pressure and local tissue perfusion control (selective, central vasoconstriction with concurrent local vasodilatation).
– Concept of gravitational effects on blood pressure and objective of maintaining arterial blood pressure to adequately perfuse cerebral circulation.
– Concept of arterial elastic recoil and diastolic blood pressure.
– Concept of "upstream" and "downstream" effects of increased/decreased vasoconstriction.
– Concept of venous compliance/capacitance and effects of venoconstriction.
– Concept of central venous pressure/right arterial pressure and perfusion pressure gradient that drives venous return.

We can use the various colors of the Lego bricks to denote the different physiological systems. When asking students to think integratively, building a more wholistic, whole body understanding, we can take a Lego brick (either blue, yellow, green, white, or black, representing respiratory, renal, gastrointestinal, endocrine, and neurophysiology, respectively) and probe accordingly, eg, with a green and a black brick, ask "how is the neural pathway involved in gastric function?" or with a white and black brick, ask "how are the neuroendocrine reflex mechanisms activated in the compensation to restore arterial blood pressure?"

For more Lego concept bricks, "the secretion of the endocrine hormone renin from the kidneys by renal sympathetic nerve during blood pressure control" would include a green renal, a white endocrine, a black neural, and a red cardio Lego brick.

Contents

Part I
Neurophysiology

Synaptic plasticity and Religio-physio phenomenon? "…be transformed (*metamorphousthe*) by the renewing of your mind…" Message to the Romans

Introduction: Neural Impulses and Homeostatic Balance

The adjective in the name 'Nervous System' (NS) is certainly not a description of controlled function of neurophysiology in homeostasis. The brain and the spinal cord is termed Central NS (CNS). Projecting from the CNS is the peripheral NS (PNS) which is divided functionally into the somatic and autonomic NS.

All intentional motor movements are initiated in the brain and meaningful execution of specific skeletal muscle groups is by activation of the corresponding alpha motor neuron pool. The autonomic NS (ANS) effects contraction or relaxation of smooth muscles, which are not themselves entirely dependent on extrinsic innervations. Some visceral smooth muscles have intrinsic electrical property that can produce action potentials and contribute to their inherent smooth muscle tone. Unlike the somatic motor action via the alpha motor neurons, which only produces excitation of skeletal muscles, ANS motor smooth muscle events can be inhibitory or stimulatory.

The autonomic sympathetic and parasympathetic nerves also modify the cardiac muscle function. The efferent motor signals that are transmitted along both somatic and autonomic motor fibers are action potentials. The actual ionic events during an action potential and its propagation are predominantly passive sodium and potassium ionic fluxes. The high trans-membrane sodium and potassium concentration gradients of excitable cells are prepared and established by the membrane Na/K ATPase, on alert to stimulus that will depolarize the neuron or muscle cell sufficiently to fire an action potential.

The human body is a sensate, multicellular community. Perception of diverse sensations by mechanoreceptors, chemoreceptors, nociceptors, thermoreceptors and photoreceptors are all conveyed by the same neural signal, an action potential ascending the afferent fibers to the CNS. We see, hear and keep our posture and balance through sensory AP from retinal photoreceptors, hair cell mechanoreceptors in the ear respectively.

The analogy of the neural network to the electrical wiring of a home does not match completely. Neurotransmission of action potentials (AP) are in most cases chemically mediated at the synapses. Both inhibitory and excitatory synapses exist, containing their respective inhibitory and excitatory neurotransmitters. Inhibitory synapses decrease and excitatory synapses increase the likelihood (or excitability) of the post-synaptic neuron to fire AP that will continue the neuronal AP traffic to the target cells. Control of order (and prevention of accidents) is the essential function of road traffic lights. The inhibitory (red) and excitatory (green) signals in the CNS, PNS serve to ensure homeostasis and health.

There is a well described brain-gut axis. This refers to the embedded neural network in the gastrointestinal system, called the enteric NS (ENS). The ENS is largely the final common pathway for the actions of the autonomic parasympathetic and sympathetic nerves on the pattern of motility and secretory activities of the gut.

Specialized neurons also secrete hormones. These neurohormones include the hypothalamic vasopressin and oxytocin and also the spectrum of hypothalamic releasing and inhibiting factors that act on the anterior pituitary.

The discerning student will realize that some aspects of human behavior cannot be easily reduced to neurophysiological and hormonal mechanisms. Human faculties and expressions like emotions (shyness, fear, hate, love), likes/dislikes (Facebook!) memory, learning, understanding, language, music appreciation remains a mystery to be understood in part in future.