Chapter 14 The Autonomic Nervous System and Homeostasis

The Case of John Doe (JD): The Unidentified Bicyclist

Introduction

A bicycle rider has been found in the tall grass on the shoulder of a local country highway, popular with local cyclists. Another bicycle rider happened to see a rather expensive bike in pieces on the shoulder before she noticed the unconscious rider lying a few feet away. She checked that the man had a pulse and was breathing before she called 911. She was told not to move the man until help arrived. She waited with the unconscious cyclist until the authorities and the ambulance arrived.

A sheriff's deputy arrived on the scene first. He took a statement from the woman who had found the injured man. Unfortunately, she had not seen anything, and had no idea who the male cyclist was or how long he might have been lying in the grass. The deputy waited for the ambulance crew to arrive before he began to look around the area for anything that might identify the rider. He did not have a wallet, ID, or cell phone in his pockets or in the nearby vicinity. His bike did have a local bike shop logo with a phone number attached near the pedals.

This case follows the clinical course of this unidentified middle-aged male bicyclist, known as John Doe (JD), after he arrived in the trauma unit at the university medical center.

You have been volunteering at the university medical center, as you anticipate applying to the college of nursing next fall. You are assigned to transport patients from the emergency department's trauma unit to the medical intensive care unit (MICU) when JD is admitted to the hospital. JD has been intubated and placed on a ventilator to protect his airway. His head and neck is still strapped down tightly to prevent any movement and so further damage, which indicates he likely has a spinal cord injury. You notice that JD's heart rate fluctuates between 35 and 50 beats per minute, which you recognize as bradycardia (a heart rate less than 60 beats per minute). You ask the nurse who you have established an educational relationship with what he thought was happening to the patient. The MICU nurse confirmed that JD had a spinal cord injury. There was concern that the patient may be suffering from spinal shock and possibly neurogenic shock, which affects the autonomic nervous system (ANS). You have not studied the ANS yet, but you have heard how important it is for survival. The nurse suggests that you review the ANS and visceral reflex arcs, and says he would be glad to discuss it with you on your next volunteer shift.

Objectives: Consider and Respond (Module 14.1 Overview of the Autonomic Nervous System)

After completion of this case, students will be able to understand and do the following:

- ***Describe the structural and functional details of the sensory and motor (autonomic) components of the visceral reflex arcs.***
- ***Discuss the physiological roles of each division of the ANS.***

1. You have been asked to review the ANS and visceral reflexes. Which of the following statements is *not* associated with the sequence of events that make up visceral reflex arcs?

  a. Sensory signals from the skin or viscera are transmitted to the brain or spinal cord by sensory afferent neurons.

  b. Incoming sensory information is integrated and an appropriate motor response is selected by the peripheral nervous system.

  c. Motor impulses from the CNS are transmitted by efferent neurons, which usually lead to autonomic ganglia.

  d. Impulses leave autonomic ganglia in efferent neurons, whose axons lead to a variety of target organs.

2. You want to be able to discuss the two divisions of the ANS on your next visit to the MICU. (a) Briefly discuss the anatomical features and functions of the sympathetic nervous system. (b) Briefly discuss the anatomical features and functions of the parasympathetic nervous system.

  a) The sympathetic nervous system is also known as the thoracolumbar division of the ANS because the cell bodies of preganglionic neurons originate in the thoracic and upper lumbar spinal cord. Short preganglionic axons travel with spinal nerves to synapse in the sympathetic chain ganglia that are found parallel to the vertebral column. Long postganglionic axons travel from these ganglia to a variety of target organs. This division is known as the "fight-or-flight" division, as it prepares the body for stress or physical activities.

  b) The parasympathetic nervous system is also known as the craniosacral division because its preganglionic cell bodies are located in the nuclei of several cranial nerves in the brainstem and in the sacral region of the spinal cord. Long

preganglionic axons synapse in ganglia near or within their target organs. Short postganglionic axons travel from nearby ganglia to the target organs. This division is also known as the "rest-and-digest" system because of its role in digestion and maintenance of homeostasis while at rest.

You recall that the sympathetic nervous system is responsible for the "fight-or-flight" response. It seemed like a cycling accident would trigger a strong response from this division of the ANS. However, bradycardia did not fit this picture; as a matter of fact it seemed like the opposite response you would expect from sympathetic activation. Was there something preventing the sympathetic nervous system from functioning properly? As you were leaving the MICU, you heard the medical resident ask the nurse to increase JD's intravenous fluid rate. She also asked the nurse to call the pharmacy to prepare a norepinephrine drip immediately. JD's blood pressure had become dangerously low, below the level that provides adequate blood flow to his brain and other vital organs. Wasn't norepinephrine a neurotransmitter associated with the sympathetic nervous system?

Objectives: Consider and Respond (Module 14.2 The Sympathetic Nervous System)
After completion of this case, students will be able to understand and do the following:

- ***Describe the neurotransmitters and neurotransmitter receptors of the sympathetic nervous system.***
- ***Describe the anatomy of the sympathetic nervous system.***
- ***Explain the effects of the sympathetic nervous system on the cells of its target organs.***

1. Understanding the anatomical features and locations where sympathetic nervous system structures are found is important for understanding JD's situation. Which of the following statements is *false* regarding the gross and microscopic anatomy associated with the sympathetic nervous system?

   a. The sympathetic chain ganglia extend from the superior cervical ganglion to the inferior sacral ganglia.

   b. White rami communicantes are small myelinated nerves that branch off of the spinal nerve and travel to the sympathetic chain ganglia.

c. **Gray rami communicantes carry postganglionic sympathetic axons from the sympathetic chain ganglia to collateral ganglia.**
d. Gray rami communicantes carry unmyelinated sympathetic postganglionic axons from the sympathetic chain ganglia to a spinal nerve that travels to the target organ.

2. The MICU team has increased JD's intravenous fluid rate and has ordered a norepinephrine drip for hypotension, or low blood pressure. (a) Define what an adrenergic receptor is, then describe where each of these adrenergic receptor subtypes are located in the body. (b) Describe what you would expect to happen when norepinephrine binds to α_1 receptors in the cells of the blood vessels found in JD's skin. (c) Which adrenergic receptors would you expect norepinephrine to bind to increase the force of contraction in the heart and heart rate?

a) **Adrenergic receptors are neurotransmitter receptors that bind the neurotransmitters norepinephrine and epinephrine. The following are the adrenergic receptor (alpha and beta) subtypes associated with the sympathetic nervous system:**
   - **Alpha-1 (α_1) receptors are found on smooth muscle cells of blood vessels in the skin, gastrointestinal (GI) system, and kidney, among others.**
   - **Alpha-2 (α_2) receptors are found on the plasma membrane of preganglionic neuron cell bodies.**
   - **Beta-1 (β_1) receptors are found in cardiac muscle cells, some kidney cells, and adipose tissue.**
   - **Beta-2 (β_2) receptors are found in smooth muscle cells lining the airways of the lungs, skeletal muscle fibers, smooth muscle cells in the urinary bladder and skeletal muscle blood vessels, liver and pancreas cells, and salivary gland cells.**
   - **Beta-3 (β_3) receptors are found in adipose tissue and smooth muscle cells in the walls of the GI tract.**

b) **When norepinephrine binds to α_1 receptors found on smooth muscle cells in blood vessel walls in the skin, the response is vasoconstriction, which helps to direct more blood flow to the heart, brain, and skeletal muscle fibers in preparation for a "fight-or-flight" situation.**

c) **β_1 receptors are found on the plasma membranes of cardiac muscle cells. When norepinephrine binds to β_1 receptors on these cells, they respond with increased force of cardiac muscle contraction and increased heart rate.**

JD was in shock, specifically neurogenic shock. The MICU nurse who asked you to read about the ANS was explaining this condition to another nurse. Apparently, the sympathetic nervous system can be affected if the spinal cord is damaged, especially when the injury involves the cervical or upper thoracic region. That made sense when you considered the anatomy of the sympathetic nervous system. This disrupts the balance between the two divisions of the ANS, allowing the parasympathetic nervous system to exert too much control over many vital systems.

The administration of intravenous fluids (sometimes referred to as a fluid challenge) and norepinephrine therapy had stabilized JD's blood pressure for the time being, but his heart rate continued to fluctuate. The nursing staff had administered several atropine injections according to the MICU protocol for severe episodes of bradycardia. Atropine seemed to work, but its effects were only temporary. Your nursing mentor implied that atropine was a drug that took advantage of the receptors associated with the ANS. He has asked you to research the medication atropine and its mechanism of action associated with the parasympathetic division of the ANS.

Objectives: Consider and Respond (Module 14.3 The Parasympathetic Nervous System)
After completion of this case, students will be able to understand and do the following:

- ***Identify the roles of the parasympathetic nervous system, and explain how it maintains homeostasis.***
- ***Describe the anatomy of the parasympathetic nervous system.***
- ***Describe the effects of the parasympathetic nervous system on its target cells.***

1. Atropine blocks acetylcholine from binding to muscarinic receptors. Which of the following statements explains how the drug atropine can be used to treat bradycardia?

   a. **When atropine blocks the binding of acetylcholine to cardiac muscle cells, it prevents parasympathetic activity that decreases heart rate. This allows the heart rate to increase.**

   b. When atropine blocks the binding of acetylcholine to muscarinic receptors, it prevents sympathetic activity that increases heart rate. This allows the heart rate to increase.

c. When atropine blocks the binding of acetylcholine to muscarinic receptors on cardiac muscle cells, it increases parasympathetic activity that decreases heart rate. This allows the heart rate to increase.

d. When atropine binds to muscarinic receptors on cardiac muscle cells, it increases parasympathetic activity that decreases heart rate. This allows the heart rate to increase.

2. The physician from the neurology service determined that JD's spinal injury was at the first thoracic level of the spinal cord (T_1). (a) Explain anatomically how a spinal cord injury in the cervical-thoracic region has affected the sympathetic nervous system while sparing the parasympathetic nervous system. (a) Which subdivision of the parasympathetic nervous system could be affected by a spinal cord injury? (b) Describe the effect that parasympathetic activation has on cardiac muscle cells. If sympathetic stimulation of the heart was eliminated, what response would you expect?

a) The parasympathetic nervous system is also known as the craniosacral division. Preganglionic axons travel with cranial nerves that originate superior to the spinal cord in the brain. Damage to the spinal cord does not affect the cranial portion of this division. However, the sympathetic system is greatly affected by cervical and thoracic spinal cord injuries, as their preganglionic axons must travel with spinal nerves that exit from these regions. The sacral portion of the parasympathetic division would be affected as preganglionic axons exit from the spinal cord with the sacral nerves where they form the pelvic splanchnic nerves that innervate the segments of the large intestine, urinary bladder, and reproductive organs.

b) Parasympathetic stimulation reduces the heart rate, which reduces blood pressure. Parasympathetic activity would proceed unchecked without sympathetic activity, leading to bradycardia and low blood pressure, as the two divisions have the opposite effect on cardiac muscle cells.

It is quickly apparent that alterations in the balance between the divisions of the ANS can have life-threatening consequences. JD has had hypotension and bradycardia, both which severely limit the amount of blood being delivered to his vital organs. For the time being, intravenous fluid and a continuous infusion of norepinephrine has stabilized JD's blood pressure, and atropine has had some limited success stabilizing his heart rate.

JD's situation was not completely hopeless. The respiratory therapist that monitored JD's ventilator data indicated that he was having spontaneous breathing movements, which meant that it might be safe to remove him from the ventilator once he was more stable.

Objectives: Consider and Respond (Module 14.4 Homeostasis Part II: PNS Maintenance of Homeostasis)

After completion of this case, students will be able to understand and do the following:

- ***Define sympathetic and parasympathetic tones. (Module 14.4)***
- ***Explain how the nervous system as a whole regulates homeostasis. (Module 14.4)***

1. The sympathetic and parasympathetic divisions have opposite, or antagonistic, effects on many different organs. Which of the following statements is true regarding autonomic tone?

   a. To maintain a viable balance, each division of the ANS is active to some degree within a given target organ, with one division usually exerting dominance over the other.

   b. Only one division, either sympathetic or parasympathetic, is active within a given target organ while the other division remains dormant.

   c. Both divisions of the ANS are equally active within the target organs that both innervate.

   d. To maintain a viable balance, each division of the ANS is inactive within a given target organ, where neither division exerts dominance over the other.

2. The normal function of both divisions of the ANS is critical for homeostasis. (a) Use the concepts of autonomic tone and dual innervation to explain why JD has bradycardia. (b) Describe what you would expect to happen to JD's heart rate if his spinal cord was uninjured but his vagus nerve (CN X) was damaged?

   a) The heart is innervated by both divisions of the ANS, a phenomenon called dual innervation. Under normal conditions parasympathetic tone and sympathetic tone are maintained in a balance that keeps the heart rate and blood pressure within their normal set ranges. If a spinal cord injury occurs, parasympathetic tone would be unchecked by sympathetic tone, so this balance would be lost. Parasympathetic tone would be uninhibited, leading to a reduction in heart rate and bradycardia.

b) **If JD's spinal cord was uninjured, the sympathetic nervous system link to his heart would be intact. The parasympathetic nervous system link would be severed, however, if his vagus nerve was damaged. This would lead to an imbalance where sympathetic nervous system activity was unchecked by parasympathetic tone. The result would be an increased heart rate, or tachycardia.**

WRAPPING UP THE CASE

The police report indicated that JD was the unfortunate victim of a hit-and-run accident. He was wearing a helmet, which did protect his head, but he suffered severe impact injuries to his neck and upper back that damaged his spinal cord. He would most certainly have died at the scene if the second bicyclist had not been riding down the same road that day.

Unfortunately, no one was able to locate any family or friends that could identify JD. The local bike shop was contacted, but the bike model JD was riding was popular. The shop owner did not recognize the description of JD, but he was sure that they would be able to link the serial number of his bike to a customer's name. Hopefully JD was the original owner.

Neurogenic shock is a condition that occurs after an acute injury involving the cervical or thoracic regions of the spinal cord. Sympathetic preganglionic axons that travel with spinal nerves to the sympathetic chain ganglia are damaged, which leads to a reduction of sympathetic output to target organs. Decreased sympathetic activity also occurs due to the disruption of descending sympathetic tracts, where otherwise intact sympathetic ganglia found below the level of spinal injury are affected, and control of these ganglia is lost due to the spinal injury. The main symptoms of this condition are hypotension and bradycardia due to the loss of sympathetic tone at cardiac muscle cells leading to unchecked parasympathetic activity. These clues plus neurologic dysfunction and warm, dry skin should increase clinical suspicion of neurogenic shock. Neurogenic shock is different than spinal shock, which is a condition that involves the loss of spinal nerve reflexes. The severity of the neurogenic shock is related to the level of the spinal cord damage, where a higher level of damage results in more severe symptoms. Although the spinal cord may be permanently damaged, the symptoms of neurogenic shock usually resolve after 3 weeks.