Hardwired For Shock: The Autonomic Nervous System

by Julie Aberger

EMT Objectives

After reading this article, the EMT will be able to:

- list the organizational divisions of the nervous system;
- define homeostasis;
- identify how the nervous system and the endocrine system are key to maintaining homeostasis;
- understand the difference between the somatic nervous system and the autonomic nervous system;
- differentiate between the sympathetic and parasympathetic divisions of the autonomic nervous system;
- discuss how the autonomic nervous system affects shock;
- describe how signs and symptoms of shock are due to sympathetic or parasympathetic innervation

Comfortable?

As you begin reading this article (perhaps sliding down into your armchair a bit), you are hardly aware of anything other than the words on the page. You may hear some music far away in another room, or feel slightly hungry, but your primary focus is concentrating on this article, taking the test, and getting the CEUs.

Meanwhile, thousands of discrete chemical actions are occurring inside your body, keeping you alive and well. Your internal machinery – life itself – never ebbs. The 24/7 biological circuitry is never dormant; it's more complex than a computer, efficiently regulating the body's inner chemistry to keep you in good working order. But you are not aware of it.

In this article, we will examine how the autonomic nervous system (ANS) – a system most EMTs know nothing about – regulates the inner body. Why should we do that? To better understand the mechanisms that produce the signs and symptoms of shock.

Shock occurs when the body fails to keep its physiologic balance: Without adequate perfusion, cells and tissues are deprived of oxygen and carbon dioxide accumulates. If the condition persists, cells, tissues, and organs die. So does the patient – sometimes right in front of us.

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To understand what happens to the body in shock, we must first uncover layers of nervous system organization. We must also acknowledge the endocrine system and understand how it works closely together with the nervous system to sustain viable life.

This article will focus primarily on the ANS and correct some of the oversimplifications EMTs may have been taught. When that is about to occur in a discussion, you will be alerted by the word *"Qualifier."*

But delving into this subject is not an easy task for the reader or the writer. This description is a brief overview of the nervous system and one particular sliver of it. To write about its entirety would take a book and an advanced degree in neuroscience.

Multiple Layers of Organization

Let's dig into the layers of the nervous system organization, starting at the top. The system is divided into two divisions. *(Figure 1)*

- The **central nervous system** (CNS) includes the brain and the spinal cord;
- the **peripheral nervous system** includes all nervous tissue outside the brain and spinal cord; it conducts impulses to and from the CNS. *Qualifier:* Even though the peripheral nervous system includes everything outside the brain and spinal cord, the 12 pairs of cranial nerves (CN I-XII) are part of the peripheral nervous system. Arising from the brainstem and forebrain, these nervous fibers convey impulses *to and from* the body's skeletal muscles *and* most of the visceral organs and glands. Thirty-one pairs of spinal nerves also carry impulses to and from the spinal cord. *(Figure 2)*

The peripheral nervous system comprises the sensory, or **"afferent"** division, and motor, or **"efferent"** division. This is based on the direction of the neural conduction to and from the brain.

- **Sensory**: responsible for conducting "afferent" impulses from the organ or muscle to the CNS. *You touch*

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a hot stove, the impulse travels from the hand to the your brain, "affecting" a reaction. Involuntarily you pull your hand off even before the sensation registers: HOT!

● **Motor**: responsible for conducting impulses from the CNS to "effectors," organs, muscles or glands. *You are walking through town when you spot a shiny quarter lying on the sidewalk. Being frugal, you quickly pick it up and pocket it.*

The **motor division** contains the **somatic** and the **autonomic functions**. One initiates voluntary activity, the other involuntary activity.

● The somatic nervous division regulates activities with which *you have* **voluntary** control, including almost all of your coordinated muscular activity. It conducts impulses from the CNS to the skeletal muscles providing movement. *A fly buzzes annoyingly over your head and you swat at it without success.* That's voluntary control.

Anatomically the somatic nervous division's **neurons**, or nerve cells, are found in the brain and spinal cord and their branches, called **axons**, extend to the skeletal muscles they serve. Simple.

● The autonomic nervous system (ANS) regulates the body's vital functions without voluntary control such as digestion, blood pressure, heart and breathing rates, body temperature, and metabolism. Here impulses are conducted from the CNS to cardiac muscles, smooth muscles (the blood vessels, the gut) and glands. *(See Box:* **Muscle Review)** *As you sit in class, your breakfast is being digested (almost) noiselessly by your gut.* That's involuntary control; you are not consciously causing it to happen.

The autonomic nervous system, together with the **endocrine system**, run like a sophisticated computer that keeps the chemical balance of the internal body working at optimal condition. It works synergistically, combining different parts of the ANS to produce a neural action. Its design and operation is much more complex than the somatic nervous system.

It is both systems, however, that respond immediately to the body in distress/danger as well as relaxation/repose. We will return to this discussion later.

Homeostasis: Team Work

The body strives to keep a stable internal balance even in the face of continuous external changes. This is called **homeostasis**, a dynamic process occurring ***all*** the time, even as you sleep.

There is not a moment when your internal machinery, e.g., blood vessels, nerves, glands, etc., is not making active adjustments or fine-tuning itself to preserve homeostasis. Instantly, these mechanisms kick-in when a sudden change occurs to the body's internal or external environment. All systems participate, but as we said, the chief players are the autonomic nervous system and the endocrine system. The ANS provides a kind of highly specialized neural hardwiring while the endocrine system provides the hormonal juice.

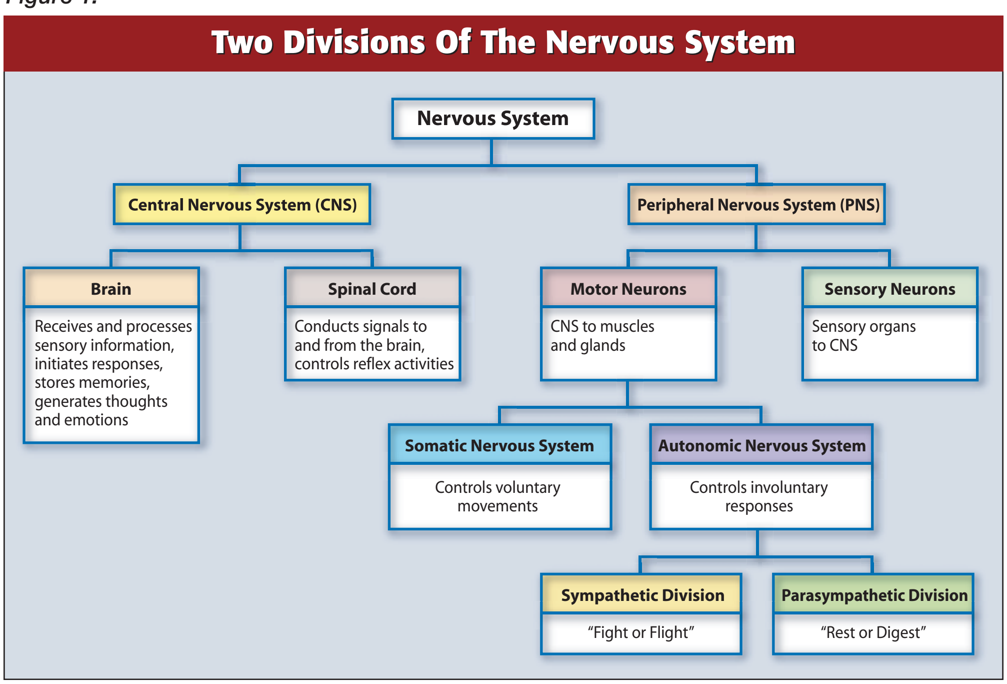
The body strives to keep a stable internal balance even in the face of continuous external changes. This is called homeostasis.

Do not think that neural responses are "either-or." Opposing impulses produce a constant changing response to stimulus, depressing or enhancing it, i.e., exciting or inhibiting like a "yin-yang," But nothing is completely yin or completely yang; they dampen each other's effects as needed. As one aspect increases, the other decreases to maintain overall balance of the whole. As we shall see, neural responses are continuously in play to maintain homeostasis.

As you run your fifth mile, your skeletal muscles tire and you need more oxygen to keep going. Through voluntary control, the somatic division keeps your legs and arms moving, albeit slowly. Without your conscious control, the autonomic division kicks in and speeds-up the heart rate and respirations to meet the needs of the muscle cells and supply their demand for more oxygen and glucose. What a team!

Qualifier: Complicating everything is the fact that nearly all spinal nerves and many of the cranial nerves contain both somatic and autonomic fibers. And some of your organs receive innervation from both systems. As your internal and external environment changes from moment to moment, your body integrates response patterns to both in split seconds!

Figure 1:



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Sympathetic? Parasympathetic? Huh?

But wait: We need to dig a little deeper.

As we have said, the ANS is responsible for either ***inhibiting*** or ***exciting*** neural activities. Thus, the system has two parts: the **sympathetic** and the **parasympathetic**, odd names for anatomical/physiological categories.

The term "sympathetic" came from Galen, (b. 130 AD) a prominent Greek physician, surgeon and philosopher in the Roman Empire. He believed that nerves were conduits for distributing the "animal spirits" in the body. By way of the nerves, the animal spirit would coordinate the activities of the body's organs, working in harmony, or in "sympathy" with each other. The reference stuck.

"Parasympathetic" refers to the groups of nerve cells, or ganglia, that lie near or within the organs they innervate. The prefix "para" means alongside of, beside, or near.

The sympathetic and parasympathetic divisions typically exert antagonistic, or opposing effects, on selected or "target" organs such as the heart and lungs, etc.

Qualifier: However, that is not always the case; some research authorities call this clean division "an oversimplification." Neither division is ever activated in its entirety. Both systems work together in a complex integrated manner, feeding the body what it needs to maintain its homeostasis whether in an emergency or not.

Sympathetic Cascade

The body's sympathetic division – dubbed the "fight or flight" system – reacts instantaneously to hazardous conditions such as fear or anger. It takes one second to respond to stress! It mobilizes the body for action.

Most motor neurons of the sympathetic division originate in the spinal cord segments T1 thorough L2. *(Figure 2)* Two long chains of axons provide the pathways from the brain to specific organs. Each chain link has many axons, or branches. The first chain is found in the brain or spinal cord and leads to the second chain, but does not directly connect. There is a space, or synapse, between them.

The hypothalamus mobilizes the sympathetic nervous system. There is no simple single explanation how that works.

Electrical signals provide pathways to specific organs in different ways. If you look at *Figure 3,* you see a huge number of varying effects of that innervation.

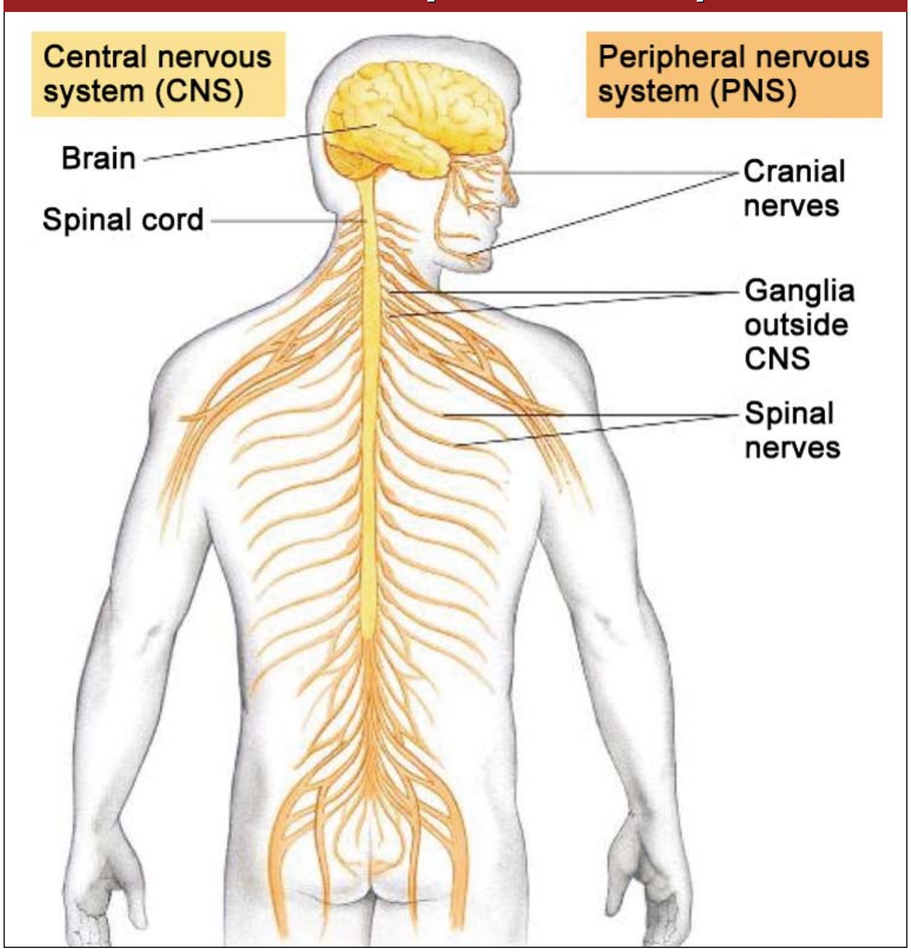
Neurotransmitters or **chemical "messengers,"** from the adrenal medulla and the hypothalamus, are released and transfer the signals to specific organs. Some neurotransmitters are dumped right into the bloodstream while others take a more circuitous route appearing in synapses, or minute spaces, between cells before the intended action occurs.

The primary sympathetic neurotransmitters are epinephrine (adrenaline) and norepinephrine.* They transfer signals to sympathetic receptors in the smooth muscle walls of blood vessels, the bronchioles, the sweat glands and muscles of the skin. The result: You feel a huge surge as vasoconstriction of the blood vessels in those structures increases blood pressure and heart rate; constricts circulation in the skin; dilates the bronchioles to improve oxygenation; increases metabolism; increases release of glucose to mobilize stored energy to the brain. It also dilates the pupils to improve eyesight, particularly at night.

Qualifier: Another neurotransmitter– acetylcholine (ACh) – is also a neurotransmitter for both the sympathetic division and the parasympathetic division. And that is why these two divisions of the ANS cannot be seen as having separate, clearly defined roles.

Figure 2:

The Central and Peripheral Nervous Systems



*The difference between the norepinephrine and epinephrine is their chemical structure, which makes them to act slightly differently as they connect to receptors in the muscles and nervous system.

Lie Down & Relax

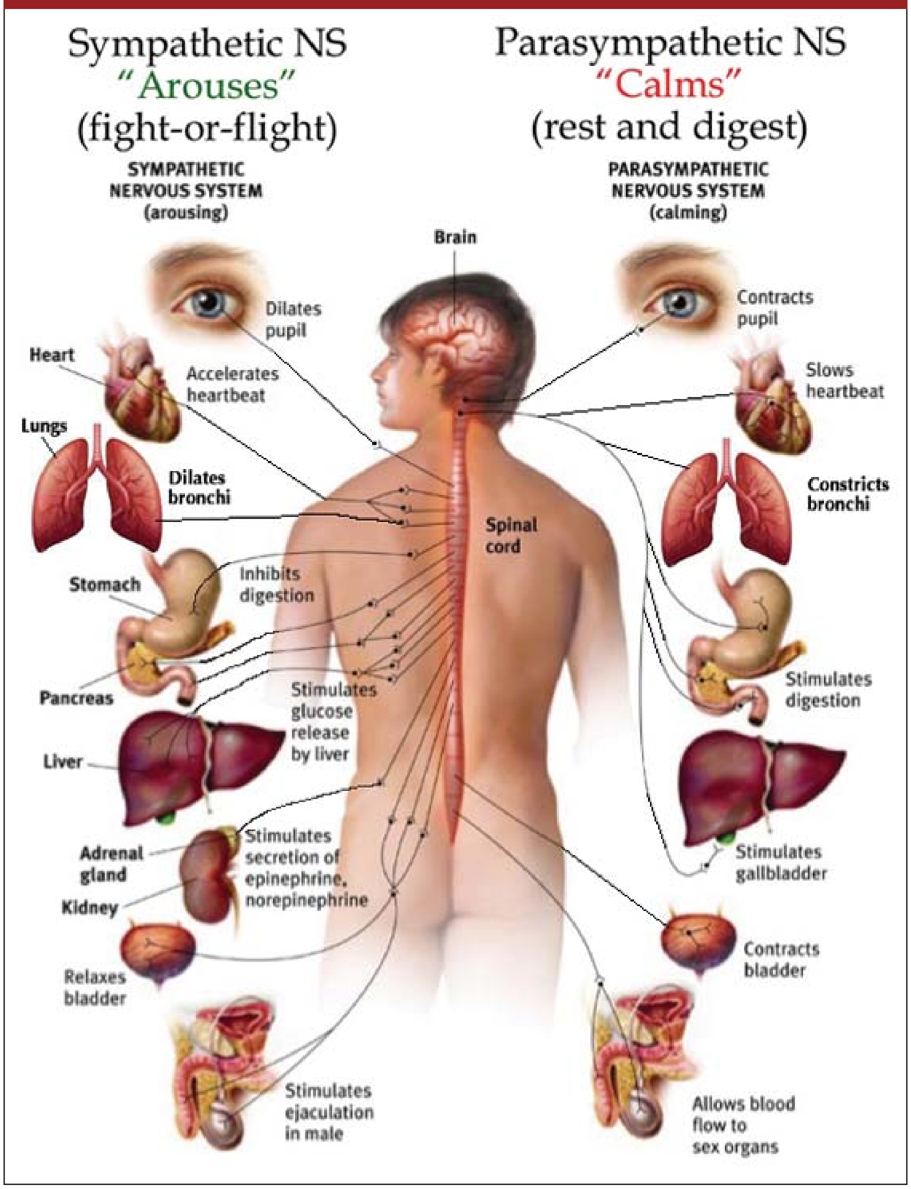
● In contrast, the parasympathetic division, commonly known as the "feed & breed," or "resting & digesting" division, is most active when the body is at rest, e.g., lying down for a nap, relaxing with a book, lying on the beach. It conserves body energy for later use. Think of it as the body's daily housekeeping system: digesting food and excreting wastes like feces and urine. *You're just about to drop off to sleep but you suddenly feel the urge to urinate. With great effort, you roll out of bed and head for the toilet. As you urinate your bladder empties and you feel relief.* You were made aware that you had to urinate by parasympathetic innervation.

Parasympathetic neurons arise from the brain stem where the cranial nerves originate, and from the vertebral – S2-S4 – region of the spinal cord. Cranial nerves III, VII, IX and X serve different organs in the body.

The vagus, CN X, has many responsibilities, but its primary one is as a parasympathetic innervator, slowing or shutting down the activities of many organs, e.g., heart, lungs, liver, stomach, spleen, intestines, bladder and genitalia. CN X comprises the only cranial nerve to extend beyond the head and neck into the thorax and belly, but one of three cranial nerves to carry parasympathetic properties.

Figure 3:

The Autonomic Nervous System: Cranial Nerves And The Organs They Serve



The vagus, CN X, has many responsibilities, but its primary one is as a parasympathetic innervator, slowing or shutting down the activities of many organs.

(The third cranial nerve, for example, stimulates the pupils to constrict.) As we have said, CN X has both motor and autonomic properties, e.g., provides skeletal muscle activity and enhances responses of certain visceral organs. It also transmits nervous impulses from viscera in the thorax and abdomen back to the CNS.

The parasympathetic neurotransmitter or "messenger" is acetylcholine (Ach), another neurohormone that also plays a minor role as a sympathetic neurohormone. Together the two systems – sympathetic and parasympathetic, often closely aligned – continuously send out discrete messages that coordinate the function of every cell!

An interesting fact: Destruction of the vagus nerve would quickly lead to death because the sympathetic division, which mobilizes and accelerates vital body processes, would operate unopposed and the body's internal balance would quickly go into overdrive – hyperglycemia, increased metabolic rate, rapid heart beat, palpitations, hypertension, intense nervousness and sweating – and crash. Just like a car with a jammed gas pedal.

You can see from *Figure 3* that both divisions are at work in most organs: the reproductive; the cardiovascular, the GI, the pupils, etc. Most organs are innervated by both divisions and are obviously called "doubly-innervated organs." The heart, for instance, has both sympathetic and parasympathetic receptors that can cause its rate and force of contractions to increase or decrease.

There are three basic patterns of sympathetic or parasympathetic innervation:

- dual innervation that is oppositional; a sympathetic effect increases the heart rate; a parasympathetic

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effect slows it down. The lungs have dual reception either constricting or dilating the smooth muscle of the bronchioles.

- dual innervation that is complementary; for instance, the parasympathetic function controls the erection of the penis but ejaculation is sympathetic.

- single innervation by either the sympathetic or parasympathetic division. The blood vessels, for example, are controlled exclusively by sympathetic nerves.

Each organ has a certain "tone" or resting state that accounts for its day-to-day status. For instance, parasympathetic effects dominate the heart and smooth muscle of digestion and urinary tract organs. Therefore, these organs exhibit "parasympathetic tone." However, the sympathetic can override the parasympathetic when the body is in distress: the heart rate increases and the gut shuts down.

Almost all the body's vasculature – its blood vessels – is regulated by the sympathetic division and, therefore, has "sympathetic tone," i.e., the blood vessels are kept in a continual state of partial constriction. When you are suddenly frightened, for example, the sympathetic fibers in the vascular system tighten further, the smooth muscle embedded in the walls of the blood vessels constricts, thereby increasing blood pressure and decreasing perfusion to organs (like the skin which becomes pale) that don't require continuous perfusion. When the need is no longer there, the sympathetic tone declines, the smooth muscle relaxes and the blood vessels dilate. Aaaahhh...

Almost all the body's vasculature is regulated by the sympathetic division.

Putting It Together

Now let's put it together: how the autonomic nervous system affects shock. Shock throws the body into an autonomic call-to-arms!

Your crew is called to 35 Library Place for an overdose. You arrive at an upscale residence to find an agitated 23-year old male who admits to frequently injecting cocaine; he has "tracks" on the inside of both arms. He is now experiencing crushing chest pain that began a half hour ago. He is conscious and oriented, but looks real bad. He is wide-eyed, ashen, cool and sweating profusely; he's extremely agitated and rates the pain 11 out of 10. His heart rate is 162, his respiratory rate is 30, and he is laboring to breathe. His blood pressure is difficult to get, but finally you obtain 184/106. He is nauseous and begins to vomit, then passes out. You ask yourself, what is causing this distress and what must I do first?

What is the chief complaint and what might be the cause? Crushing chest pain, most likely a myocardial infarction (MI) brought on by cocaine use.

Why do people use cocaine? The reason is found in the ANS: The drug acts on the neurotransmitters (epinephrine and dopamine, etc.), allowing them to repeatedly stimulate the "pleasure center," or receptor cells, which produces prolonged euphoria, and an increase in sexual appetite.

You know from pharmacology that "coke" is a stimulant that can trigger chaotic heart rhythms; accelerate the heart and breathing; and increase blood pressure and body temperature. Long-term use (and sometimes only once!) can also cause chest pain, nausea, fever, muscle spasms, convulsions, coma, and death. Cocaine-related cardiovascular death is due to acceleration of the heart and increased blood pressure. (By the way, cocaine is not an opioid, so Narcan® is ineffectual on a cocaine overdose.)

First & Foremost: The A-B-Cs. The patient obviously needs a patent airway, oxygen, and swift transport to the hospital. You quickly position him on his side on the gurney, cover him, open his airway, suction and insert an oral airway (OPA), then head-out. You put him on a non-rebreather but are ready to ventilate with the bag-valve-mask if he goes into distress.

What's going on? The patient is in cardiogenic shock whereby the pumping of the heart is not adequate and perfusion cannot be sustained. Cardiogenic shock is the leading cause of death in acute MI.

Let's look at your patient's signs and symptoms and see how the ANS responded to his weak and damaged heart muscle.

● Why is the patient ashen, diaphoretic and cold? For a time, the sympathetic division diverts the blood flow from the skin (and the abdominal viscera) to the vital organs, e.g., heart, lungs, liver, kidneys. Lack of circulation (or hypoperfusion)

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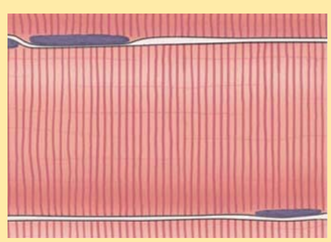
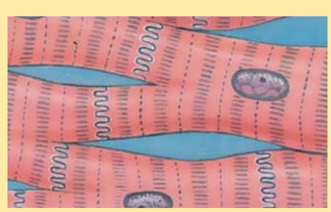
Muscle You Can't See

As you may remember from EMT anatomy & physiology, there are three types of muscle found in the body: skeletal, cardiac and smooth.

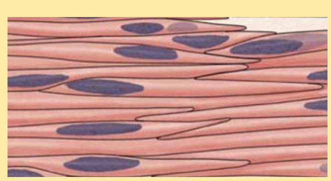
• **Skeletal** muscle is the voluntary muscle that provides movement; you consciously control the contraction and relaxation. ▶



• **Cardiac** muscle is an extremely specialized form of involuntary muscle tissue that pumps blood throughout the body. You have almost no control over the contraction of your heart. ▶



• **Smooth** muscle is the invisible muscle encircling the walls of hollow organs such as the gut, the walls of the circulatory system such as arteries and veins, and the walls of the bronchioles. This muscle constricts or tightens and relaxes and dilates or loosens without your conscious control. Neural fibers line the walls of the muscle and cause it to relax or constrict. It is fundamental to blood pressure, airway patency, and digestion. Without it, muscle ain't muscle. ▶



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leaves the skin cold and colorless. Diaphoresis, or heavy sweating, is due to the sympathetic discharge into the sweat glands that cools the skin to release heat. If you're fighting or fleeing, you need to keep cool; the body does that by sweating.

- Why is he tachycardic and hypertensive? This is a sympathetic response. The heart is beating faster in a desperate attempt to move blood to the cells – perfusion. Blood vessels are constricting for the same reason.
- Why is he breathing so fast? He needs more oxygen to keep up with his increased heart rate. His blood is circulating faster to meet the demands of his faltering perfusion. One of the main ingredients of blood is oxygen! The sympathetic response helps insure that airways are wide open and the vital capacity of the lungs increase.
- Agitation? Remember one of the most sensitive organs in the body that requires a constant supply of oxygen? The brain. When it is shorted of its O2 supply, the patient becomes irritable, agitated and sometimes combative. Your patient is "coke-fueled."

Hypovolemic Shock

Your patient is a 15-month old boy who has had a stomach flu for three days. You are called to the house for "altered mental status." His mom says the baby has had diarrhea and vomiting since the illness began. Today his diapers are dry.

The baby looks bad: pale, listless, not crying, and when you pick him up, his extremities are flaccid. He has a thready, rapid pulse. His skin is cool and diaphoretic. He is unresponsive.

What is causing this critical condition? ***Hypovolemic shock.*** The baby has an inadequate volume of blood in his circulation because of a massive loss of fluid following three days of diarrhea and vomiting. Both contain water that is lost when the conditions persist for a prolonged period. Inadequate fluid = inadequate blood volume. This condition is especially deleterious to infants and children.

- Rapid pulse? The sympathetic response increases the heart rate and strength of pumping attempting to perfuse the cells with a limited amount of blood.
- Thready pulse? Because there is a loss of blood volume, the pulse is thready, i.e., weak and difficult to feel. There is not enough circulating blood to produce normal pulses.
- Skin cool and diaphoretic? Again, the sympathetic nervous system has constricted the smooth muscles lining blood vessels in the skin to increase perfusion to the vital organs. Diaphoresis is a sympathetic reaction as we described in the previous scenario.
- Dry diapers? The child has no more fluid to urinate and kidney function is critical; he is in hypovolemic shock.
- Muscles flaccid? There is significant organ systems' failure here that has decreased metabolism and energy production.

This child is critically ill. Insert an oral airway and ventilate, call ALS, position him properly on the litter, and move as quickly, but safely, as possible. Be prepared to do CPR. His life depends on it.

Fight the Battle, Win the War

Having seen the significant and complex amount of control and regulation the autonomic nervous system exerts in the body, the reader can easily understand the signs they see when a patient becomes "shocky." The ANS is readying the body to fight for its very own life.

The outcome of that battle may depend upon you. You must immediately recognize the signs and symptoms of shock and realize their significance. Provide an airway, give oxygen, stop bleeding, call ALS, and get going! Do not delay rapid, but safe transport.

Julie Aberger *is an EMT instructor and an active member of the* ***Pennington First Aid Squad.*** *Julie is also the editor emerita of* The Gold Cross.

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