Thermoregulatory Physiology[1]

Man is a tropical animal. This means that in order to survive in temperate or polar environments (i.e. non-tropical) environments, man needs protection or insulation. Stated another way, the human body is designed to run within a narrow temperature range. Specifically, the body seeks to maintain the heart, lungs and brain (body core) at 98.6°F mean temperature. Mean temperature means that some people operate at a slightly higher temperature and some people operate at a slightly lower temperature. On average, the operating temperature of the core is 98.6°F (Figure 1).

Think of the body as an engine. It consumes food and converts it into fuel to fuel the muscles and feed the brain. The brain is in control of the body. It controls the nervous system and all of the organs. It has two major wants. It wants to be kept warm (i.e. 98.6°F mean temperature), and it wants to be fed sugar. When these two things occur the brain is happy. When these two things don't occur, the brain will take corrective steps to make it happen. It will go to extensive measures to make it happen. The discussions in this section and on hypothermia and hyperthermia illustrate how the body reacts to cold and heat stress.

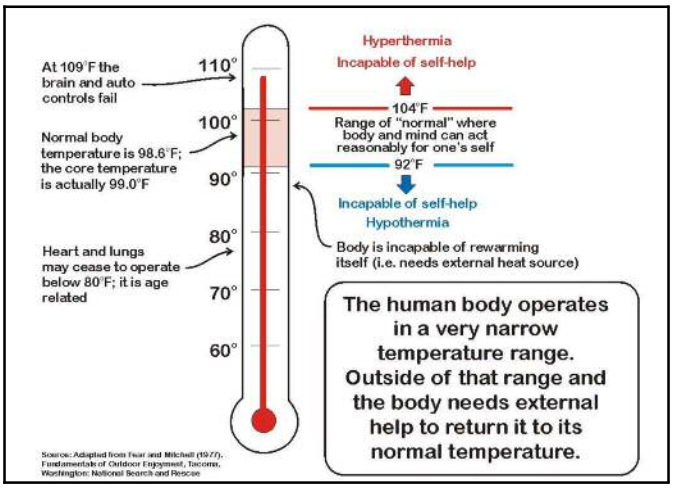

Figure 1: Operating temperature range of the body.

The muscles in the body provide mobility and bodily functions. The heart is a muscle that pumps blood throughout the body. Two major by-products of muscles working are heat and wastes. The heat generated needs to be dispersed and the wastes eliminated.

Thermoregulation of the Body – From a survival perspective, the first area of focus is on thermoregulation or maintaining the optimum temperature of the body. Thermoregulation involves the body's ability to dissipate heat and its ability to gain and reduce the loss of heat. There are four ways to transfer heat (Figure 2). These are conduction, convection, radiation, and evaporation.

Conduction is the transfer of thermal energy though a solid or between two solids in contact with each other. Touching radiator in Figure 2 transfers the heat in the radiator directly to the fingers touching it. Sitting on a rock at ground temperature (55°F), the person's buttocks will get cold. Actually, the body heat is lost through conduction to the rock or the buttocks is heating the rock.

Convection is the transfer of heat by the circulation of a fluid (e.g. water) or gas (e.g. air). The purpose of a convection current is to equalize the temperature differential between the hot and cold areas. The

[1] This section was written by Robert B. Kauffman who is solely responsible for its content. This article is copyrighted © Robert B. Kauffman, 2015. Robert B. Kauffman, Professor of Recreation and Parks Management, Frostburg State University, Frostburg, MD 21532. e: rkauffman@frostburg.edu.

greater the differential between the hot and cold areas, the greater the potential for the creation of a convection current and the stronger the current. In the radiator in Figure 2, the air is heated by the radiator. Since warm air is less dense, it rises and heats the room. In doing so, it cools. It becomes denser and sinks to the floor where it circulates back into the radiator where it is again reheated. In theory, the process continues until the temperature is the same throughout. The primary method to insulate against convection losses is to create dead air spaces which interfere with or prevents the circulation process.

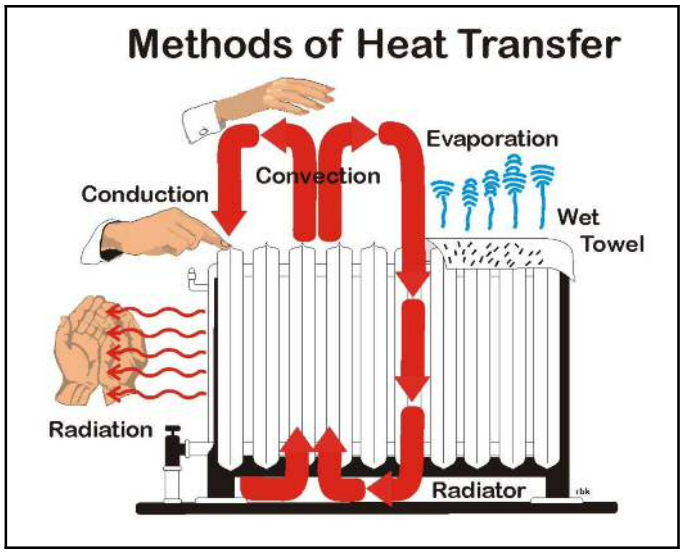

Figure 2: How the body gains and loses heat.

Consider the following example as illustrating the differences between convection and conduction heat transfers. There is a cubic foot of goose down, and a cubic foot of fine steel wool. Which is the better insulator? It could easily be argued that their ability to insulate against convection losses is the same. Remember, both materials create small dead air spaces that resist circulation or movement of the air. One could argue that goose down creates dead air spaces more effectively than steel wool, but you get the point. It is the ability to impede the circulation process associated with convection currents.

In contrast, there is no question regarding conduction losses. Steel is an excellent conductor of thermal energy. Comparatively, goose down is a poor conductor. Thermal transfer of energy through the steel is many time greater than through the goose down. Regarding insulation, steel is a poor insulator against conduction losses. Goose down is much better. The point is that the same material can have different abilities to retard heat transfer and to insulate against heat transfer.

Radiation is energy that is transferred through waves radiating from the emitting substance. The radiator in Figure 2 is the emitter. The waves cause the molecules in the object being heated to vibrate. The friction from their vibration generates heat in the object being heated. Microwaves cook food using this method. People sitting around a campfire are heated by the heat radiating from the campfire. Dead air spaces or even a vacuum has no effect on stopping or retarding radiating heat. The radiating energy passes through a dead air space or vacuum. The sun radiates energy that travels through the vacuum of space and heat the earth.

Evaporation is the conversion of a liquid to a gas. In order to do so, the liquid needs to absorb energy to convert it to a gaseous state. The energy is absorbed from the environment which results in cooling the environment. Evaporation of sweat is the method used by the body to cool itself and keep it within its proper operating temperature. Evaporation plays an important role in how the body cools itself which is discussed in its own section.

The body attempts to maintain its core temperature (heart, lungs, brain) at a mean operating temperature of 98.6°F. It performs a balancing act between using heat generated by the operation of the body, gaining heat from outside sources, and retaining body heat with insulation. The body generates heat through its

operation. This heat can be used to maintain the operating temperature of the body. Shivering is the classic example of the body generating heat to heat itself. These processes will be discussed in more depth in the next section as well in the hypothermia and hyperthermia sections.

The body changes the mix of these three options to maintain its core temperature and to be comfortable. It does this through a combination of voluntary and suggested choices by the brain and the autonomic nervous system changing body functions. First, the body can gain heat from outside sources. Or it can lose or dissipate heat from the body. If the body is cooling down, a person can step directly into the sun's rays from the shade and feel the heating effect of the sun. The body gains the radiating heat from the sun. Conversely, if the body begins to overheat, a person can step into the shade to cool off by no longer receiving solar radiation. A step to the right into the sun's rays and the person begins to overheat. A step to the left back into the shade and the person's body begins to cool off.

In a second example, a person standing in a room is heated by the heating system that heats the room. If the thermostat is set at 70°F, there is an equilibrium established where the convection losses from the body to the room are offset by the production of waste heat by the body. The person feels comfortable. Turn the thermostat down to 65°F. Now, the convection losses from the body to the room become stronger. The equilibrium is upset. The body becomes uncomfortable. If the thermostat isn't turned back up to 70°F, the body has two choices to reestablish this equilibrium. It can increase heat production or it can increase its insulation. A person may stand-up and walk around the room temporarily generating additional waste heat which temporarily warms the body.

The third alternative is that the person could increase their insulation and put on additional layers of clothes. Since 20% to 30% of the body's heat is lost through the head, putting a hat on provides considerable insulation. Most people will add a sweater or sweat shirt to provide sufficient insulation in an effort to readjust the equilibrium. The clothes add insulation. It retards convection losses to the environment, and it maintains the equilibrium between the heat lost to the room and the body's production of heat. The body is again comfortable and the body's core temperature is easily maintained at 98.6°F. The brain is happy and goes on to other things.

The Sweating Process – Under normal situations, the sweating process is the primary method the body uses to cool itself. It should be noted that the body can lose heat through other functions including respiration, urination, and defecation. Of these, respiration can often become a significant contributor of heat loss.

The sweating process works as follows (Figure 3). Heat is produced by the body. It needs to be dissipated. The warm blood is shunned to the skin for cooling. The skin secretes water through the sweat glands. The water evaporates. In order to evaporate, the water absorbs energy. The energy is absorbed from the skin cooling the skin and cooling the blood in the capillaries. The cooled blood is transported back to the body's core or muscles where it becomes reheated. The process is repeated.

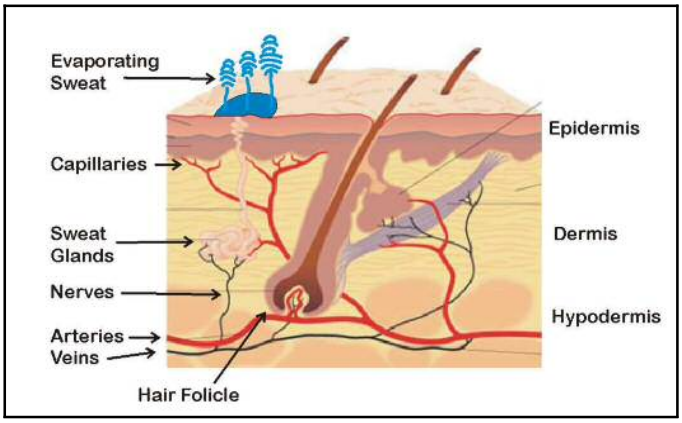

Figure 3: The skin sweating.

For water to evaporate, it needs to gain energy from its surroundings to transform it from a liquid to a gas state. It absorbs this energy from the skin. The result is that the temperature of the skin is lowered and the blood in the capillaries is cooled. Sweating can consume large amounts of water. In a hot environment the body can easily lose 1.5 quarts a day and over five quarts a day with heavy exercise. If this water is not replaced, it can quickly lead to dehydration. Dehydration is discussed in more depth in its own section.

Clothes and Shelter – Shelter is defined as anything that protects the body. In terms of the thermoregulation process, shelter can include clothes, campsite, car, the home, etc. Shelter can be viewed on a continuum extending outward from the body. The clothes worn is a form of shelter surrounding the immediate body. A home is a more remote shelter. Shelter is discussed in more depth under its own unit.

Compensatory and Decompensatory – The thermoregulatory process described so far is a compensatory process. *Compensatory* is when the body seeks to compensate and readjust to the stresses placed on the body, in this case the thermal stresses of hot and cold. As noted, it does this by increasing its heat production, by increasing or reducing energy received from outside sources, and/or by adding or subtracting insulation. Technically, the body seeks *homeostatus*. "Homeo" means "like" and "status" mean "state." The process just described is a process by which the body readjusts to changes in temperature and reaches homeostatus.

The body seeks to compensate. When the body is no longer able to compensate and maintain homeostatus, it shuts down. The shutting down process is *decompensatory*. In terms of thermoregulation, heat exhaustion and shivering are compensatory processes. Heat stroke and hypothermia are decompensatory. These processes are described sections discussed under separate cover titled *Hypothermia* and *Hyperthermia*.

Summary – Thermoregulation is the body's process of attempting to maintain its operating temperature at a mean temperature of 98.6ºF. Normally, it is a compensatory process where the body seeks homeostatus. The body gains and loses heat through conduction, convection, radiation and evaporation. Using these process, the body uses one or all three methods to maintain its optimum operating temperature. It can increase heat production. Exercise and shivering are examples of heat production. It can gain or lose heat due to external sources. Sitting in front of a campfire is a method of gaining an external source of heat. Or the body can change the amount of insulation surrounding the body. This can be as simple as putting on or removing a hat or sweater as needed.

References:

Fear, G., and Mitchell, J., (1977). Fundamentals of Outdoor Enjoyment, Tacoma, Washington: National Search and Rescue.

Kauffman, R., (2005). *The Accident Process - How to Effectively Use the Video 'Cold, Wet and Alive to Teach Risk Management and the Accident Process*. Quantico, Virginia: Paddlesport Leadership School and Encampment, Prince Williams Forest Park, August 1-2.

Kauffman, R. (2004). *A new use for the movie* Cold, Wet, and Alive. Paper presented at the meeting of Association of Experiential Education, Norfolk, VA., November 2-4.

Kauffman, R. (1995). *Boating Fundamentals: A Manual of Boating Safety*. Arlington, Virginia: National Recreation and Park Association, 126 pp.

SOLO's 2010 Wilderness First Responder Review. P.O. Box 3150, Conway, New Hampshire: SOLO.