Dara Wittenberg

CVP

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A Review of Heat Stroke.

Introduction

Heat stroke (HS) occurs when the body's system of thermoregulation is overwhelmed to such a degree that a cascade of events can ultimately cause multi organ failure. Individuals will present with hyperthermia (rectal temp of > 40° C), plus symptoms ranging from mild heat edema, rash, and heat cramps to the more severe syncope, acute renal failure (ARF), disseminated Intra-vascular coagulation (DIC), hypotension, altered sensorium, encephalopathy, gastrointestinal hemorrhage, liver problems, possible anhidrosis, rhabdomyolysis, respiratory alkalosis and/ or metabolic acidosis, tachypnea, electrolyte imbalances, sinus tachycardia and other EKG abnormalities, erratic/irrational behavior, or possibly coma. The likelihood of death or permanent damage, especially neurological, is increased if treatment is delayed.

Classifications

There are two classifications of HS: classic, non-exertional heat stroke (NEHS) and exertional heat stroke (EHS). NEHS is typically is seen in sedentary, vulnerable (the very old/handicapped/chronically ill) or the very young who cannot move themselves), who have been exposed to high temperatures over successive days so much so that the thermoregulatory systems fail ([12]). The highest incidence of NEHS typically occurs during heat waves in areas that have not experienced such heat in many years. Another interesting subgroup of NEHS is pilgrims- those who are most often unaccustomed to long days in high environmental heat ([3]). These subjects will present with hyperthermia, hot and flushed skin, anhidrosis, and often coma.

EHS is most often observed in individuals engaging in strenuous activity in a hot environment for a prolonged period. Both types have a high mortality rate if therapy is delayed more than two hours. This paper will focus primarily on EHS and its effects on the cardiovascular system.

Every year more people are participating in ultra endurance events such as marathons, half iron and longer distance triathlons, and long distance (100+ miles) cycling events. Marathon participation has grown by some estimates as much as 67%([4]) in the United States alone since 1980. The USA Triathlon organization estimates that some 746,000 people participated in triathlons in 2007 and USA Cycling sanctions over 2500 events yearly with more than 300 participants in each[5]. Most of these events, triathlon especially, take place in the height of summer with temperatures most often in the 80 to 90 degree Fahrenheit range and humidity above 70%. In addition to this, global warming often causes surprisingly hot temperatures (90 degrees Fahrenheit and above) during the early and late season events, for which athletes, and more seriously race directors, may not be prepared. So not only are is there an increases in the occurrence of heat waves in previously unaffected areas (such as the heat wave in Northern Europe in 2004 that killed 3000 individuals in France alone), but there is also an increased incidence of higher than normal temperatures for more of the year in countries and areas heretofore unused to and unprepared for these temperature ranges([6]).

Aetiolology

To fully understand HS, the underlying mechanisms for thermoregulation must be outlined. The major systems involved in thermoregulation are the integument, autonomic nervous system, and the cardiovascular system, but of course heat gain and loss can be drastically effected by behavioral elements also (clothing, drug use, intensity of exercise, hydration and nutrition stratus). The human system can handle a wide range of environmental temperatures and maintain a constant body temperature of 37° C (98.6°F). The body gains heat from the environment via conduction, convection, and radiation (the same mechanisms that can cause heat loss, in addition to evaporation). Conduction causes heat gain/loss through direct contact depending on the thermal gradient, convection is heat transfer via a fluid (direction again depends on the temperature gradient), and radiation is heat transfer via electromagnetic waves. When the ambient temperature is high, conduction is the least effective mechanism for heat loss, while evaporation becomes the most important.

However, it is not simply the environment that causes heat gain in the system, but also the system itself. Human metabolism is only 25% efficient; the rest of the enery produced is released as heat into the environment.At rest, the human body will produce between 60 to 100 Kcals of heat an hour (which has the potential to raise body temperature by 1°C if the thermoregulatory system is not functioning), but with exercise this number can increase to as much as 1000 kcal/hr.

When the core temperature rises by as little as 1°C, the hypothalamus registers this and begins a series of heat dissipating events: blood flow is diverted to the skin via

cutaneous vasodilation, and the eccrine sweat glands are activated so that under the right ambient conditions heat maybe lost via evaporation. [Note: the production of sweat alone will not cool the body; sweat must evaporate, thus taking with it approximately 580kcal of heat per liter]. Additionally, if the ambient humidity is in excess of 75% evaporation cannot occur. It should be noted, that even under ideal circumstances (temperatures under 60°F and less than 50%RH), if exercise is continued for long enough heat gain will occur, and it is not possible to replace all the liquid lost through sweat and respiration to keep blood volume adequate to normal cardiac output ([7]). Herein lies one of the central components to the patho-physiology of EHS. The hotter it is, the more an individual will sweat, the greater will be the eventual depletion of blood volume, and when the remaining blood volume must be split between the exercising muscles, skin, heart, and brain a major problem could ensue.

Blood flow changes

Under normal circumstances, there is a shunting of blood that occurs during exercise that dramatically changes systemic blood flow. At rest, the brain and muscles receive 15 and 20% respectively of total blood flow, but during exercise the blood shunt adjusts this to 3-4% for the brain (the brain is still receiving the same amount of blood as cardiac output has increased) and 80-85% for exercising muscles. The rest of the body receives much less blood flow due to the vasoconstriction induced by the release of catecholamines from the sympathetic nervous system. When the core temperature rises, the combination of as much as 8L of blood per minute being re-directed to the skin, and the fluid and electrolytes lost through sweat is enough to dramatically alter cardiac output and increase further fluid loss.

The Acute Phase and the Inflammatory Response

As the core temperature increases, changes occur at the cellular level such that proteins are denatured (due to the high core temperature) and cell membranes are destroyed. A number of inflammatory cytokines and heat shock proteins are released in an attempt to protect the system from damage([8]). To compound the inflammatory response, the gut may release endotoxins. As blood is shunted to the periphery for heat loss, other areas of the body such as the stomach and kidneys may become ischemic (as these regions due not possess the metabolites that would override the sympathetic nervous system's –SNS- release of the vasoconstriction producing catecholamines of norepinephrine –NE- and epinephrine -E). This increasing core temperature and ischemia cause the gut to become hyper-permeable and to release endotoxins into the circulation ([9],[10]) which can cause "hemodynamic instability and death" ([11]).

These inflammatory and impaired coagulation responses can also lead to DIC as there is damage to the endothelium which may cause multiple organ failure due to intravascular coagulation and then surprising bleeding (as all the platelets and clotting factors are used up) .

Catecholamines

Along with the ischemia produced by catecholamine induced vasoconstriction, EHS subjects may have persistent sweating (unlike NEHS, with presents with anhidrosis) as the release of catecholamines will be higher with exertion in the heat. As more NE and E is released the use of carbohydrates as a substrate for energy production increases, and therefore there is an increased production of hydrogen ions

which in turn increase the acidity of the blood and muscles. However, due to hypovolemia the muscles are poorly perfused and the lactate is not cleared, so there is both an increased rate of lactic acid production and a decreased clearance. In an attempt to compensate for this acidosis, the breathing rate increases (explaining the symptom of tachypnea in HS) causing respiratory alkalosis so often seen in EHS also. This is usually transient in EHS.

Rhabdomyolysis, electrolyte imbalances, and ARF

The increased core temperature, hypokalemia (stemming from potassium loss in sweat) and the poor perfusion rate of muscle can cause rhabdomyolysis. Electrolyte imbalances ensue as skeletal muscle breaks down: hyp*er*kalemia can now stem from the potassium that leaks out of damaged muscle cells, and hypophosphatemia comes from the increased rate of glucose phophorylation. The damaged muscle also loses myoglobin which the kidney has to filter. There may also be hypercalcemia from hemoconcentration. These factors contribute to ARF along with the increased level of cytokines, the release of endotoxins and the development of DIC.

The Change from a Hyperdynamic to Hypodynamic state

A patient with HS may initially be in a hyperdynamic state with tachycardia (the heart rate increases to try to increase cardiac output despite a decreased blood volume which decreases stroke volume), low systemic resistance due to vasodilation and the blood shunt to the skin for cooling. When and if this shifts to a hypodynamic state, cardiovascular collapse could be imminent. This hypodynamic state would be reflected in a high systemic resistance as the thermoregulatory system is completely

overwhelmed and instead of sending blood to the skin, blood volume is so low that all blood is now diverted to the brain and heart to maintain life. Therefore almost universal vasoconstriction causes an increase systemic resistance. The extreme hypovolemia also diminishes cardiac output, blood pressure and intravascular volume.

EKG changes

The electrolyte imbalances brought about by HS may cause conduction defects such as (right bundle branch blocks, or intra-ventricular conduction delays), prolongation of the QT interval and nonspecific ST segment changes(10,3). Typically, unless there is underlying cardiopathology, these changes are transient. Myocardial dysfunction could also stem from the obvious: thermal stress, which may cause "dysrythmias and/or pulmonary congestion and edema" (10).

Treatment

- IMMEDIATE Cooling: evaporative (fanning), whole body immersion in cold water, or internal (gastric or peritoneal lavage)
- Fluid replacement (but this needs to be done carefully and slowly as with additional blood flow to the muscles, the lactic acid that was trapped there due to low perfusion may now be released worsening metabolic acidosis. Additionally, if the low BP was due to the blood shunt to the peripheral vascular bed, then the addition of intravenous fluid may cause pulmonary edema (2).
- The treatments for DIC, Myocardial infarction, EKG abnormalities, CNS dysfunction, rhabdomyolysis, ARF, electrolyte imbalances, and/or coma are beyond the scope of this paper.

Risk factors for EHS (as distinct from NEHS)

- Exercise/Exertion in high heat with excessive clothing
- Exercise or exertion when the temperature is greater than 35°C and the RH is > 60%
- Prolonged exercise at too high an intensity in the heat
- Lack of acclimatization
- Fatigue or lack of sleep
- A preceeding viral infection
- Existing dehydation
- Use of drugs such as ephedra
- Inappropriate hydration strategies (too much water or water with no electrolytes in it induces hyponatremia, or too little liquid will increase dehydration)
- Previous history of heat related injury

Prevention

- Acclimatization (systematic training in the heat) takes about 7-10 and will induce several very beneficial effects:
    - Increased plasma volume
    - Increased training in the heat will increase efficiency so that less heat energy is created
    - Weight loss? Less heat created!

- As the body becomes heat acclimatized it can produce more sweat for cooling (2-3L an hour in a trained subject, vs 1L/hr for an untrained subject)
- Lower the set point in the hypothalamus for an earlier onset of sweating, so heat is lost sooner.
- Improved evaporative efficiency of the sweat itself as the sweat is not as salty (also decreased electrolyte loss)
- Follow a tested hydration strategy!

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