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Historical Development of Heat Stroke Prevention Devices in the Military

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Abstract— **Understanding of core body temperature, heat stress and heat stroke developed progressively over the centuries. Soldiers involved in military operations have a higher risk to develop heat stroke, and to not survive following the onset. This paper follows the evolving understanding of heat stroke and development of counter measures. At certain times in history, incomplete understanding of the causes of heat stroke led to the development of devices that did not lower the risk. As understanding improved, development of improved methods and devices became possible. In the present day, several designs for garments that can lower core body temperature or brain temperature have been developed, and would reduce the risk of heat stroke. These cooling devices include a vest and collar system. Further refinements of these designs to make them more practical would allow wider deployment.**

I. Introduction

Excessive core body temperatures induce physiological stress and may lead to heat stroke. Heat stroke may lead to medical impairment or even death. Soldiers in certain military operations have both an increased occurrence of heat stroke and increased mortality rate after the onset. A misunderstanding of the factors that contribute to higher risk of heat stroke would be reflected in any methods that may have been utilized to prevent or reduce the risk of heat stroke.

Through military history, the understanding of the effects of excessive heat upon performance and survival of soldiers has evolved, as well as methods and devices that were developed to minimize the risk of heat stroke. This example of the historical development of devices to minimize the risk of heat stroke supports the pattern observed in many fields that improvement in the understanding of the physiological mechanisms leads to the developments of methods and devices that have improved effectiveness in alleviating the problem. Methods to minimize risk of heat stress developed for military applications may also be suitable for civilian applications.

II. Background

A. Basis of Heat Stress and Stroke

Heat stress increases the risk of heat stroke that may lead to a fatal medical condition. Heat stress results from a mismatch between the supply and release of heat, due to insufficient dissipation of excess heat within the body to environment [1].

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Both internal and external sources contribute to the supply of heat. Metabolism generates heat internally (occurs continually within all cells) and dramatically increases during bouts of physical exertion. External supply of heat derives from the environment having temperatures above body temperature, or sources in the environment transferring heat to the body by conduction, convection or radiation. The sun can act as a heat source either directly as sun rays hitting the body, or indirectly by warming up nearby objects. Other sources include fuel combustion and high temperature equipment.

Release of heat from the body to the environment may occur through conduction, convection, or radiation from a higher body temperature to a lower environment, or through evaporation [2]. Chemical phase changes may absorb heat, such as the evaporation of water. Sweat and respiration of breathing are physiological mechanisms enabling evaporation at body surfaces, release of vapor to the environment, and dissipation of heat from the body. High body temperatures induce an increase in sweating, and physical exercise induces an increase in respiration. Factors that reduce dissipation of heat include higher external temperatures and higher humidity that reduces evaporation rates. Protective clothing, such as armor or hazard (nuclear, chemical or biological) safety suits, reduces both heat transfer to the environment and evaporation rates due to elevated temperature and humidity inside the suit.

Heat stress occurs when core body temperature is above normal physiological range around 37° C. Heat stroke may be induced when core body temperature is at or above 41° C [2, 3]. Following the onset of heat stroke, the rate of blood flow becomes insufficient to provide oxygen to vital organs. This reduced blood flow further diminishes dissipation of heat. Complications of heat stroke include renal and hepatic failure, disseminated intravascular coagulation, rhabdomyolysis and respiratory distress syndrome, and death [4]. Heat Stroke is estimated to result in death about 20% of the time [3].

B. Heat and Soldiers

Soldiers have a higher risk of developing heat stress and heat stroke [3, 5]. Four factors increase the risk: exacerbating aspects of military operations, environmental extremes, heat production extremes, and clothing extremes [6]. Soldiers frequently operate in environments that include combinations of heat, sun, and/or humidity.

The purpose of military training is to increase both operational effectiveness and chance of survival for the soldiers during combat. Survival enables future episodes of operational effectiveness. This purpose is usually supported by the basic attitude that the training should push them toward and even beyond the physical limits of their minds and bodies, which in the end will make them stronger. This involves intense exercise and heat stress. However, if this intense training induces heat stroke, then the purpose of the training is thwarted, in that permanent neural damage [7, 8] or even death may result. A more balanced approach would push the soldiers toward their limits, but use devices and techniques to monitor [9] and, if necessary, cool core body temperature below the level that may trigger heat stroke.

In addition to intense physical exertion and hot environments, soldiers must sometimes wear clothing that hinders heat dissipation from their bodies, including armor [10] and hazard safety suits. Armed conflict occurs in many extreme environments, including desserts and tropical regions having prolonged periods of high temperatures. Soldiers have a high risk of experiencing heat stress and of heat stroke.

III. Historical Development

The understanding of heat related ailments has grown over time. In antiquity, a sickness that seemed to be related to intense sun and heat was affiliated with the bright star Sirius that appeared to follow the sun during the summer. The term siriasis developed from this belief, and is still sometimes used to refer to sunstroke. In 24 BC, the first records of excessive heat causing military casualties were made for the military campaign of Aelius Gallus in the modern day Middle East. The heat “caused his men great distress, so that a large part of the army perished” [2]. Even though heat was known to greatly hinder army objectives, no records of efforts to prevent siriasis were found, including the Middle Ages. Nevertheless, the concept that the sun could cause heat stress seemed to be generally understood. Evidence includes old depictions in paintings or pottery of workers in tropical rice paddies wearing wide brimmed hats, or travelers through desserts on the silk road or in the middle east wearing flowing robes including head coverings.

A more formal consideration of siriasis and heat stroke began in the 17th century within the British Empire, where thousands of troops had been sent from their homeland in the British Isles colonies that may have had dramatically different climates. Many of the soldiers stationed in India did not adjust well to the hot summers and many could not withstand the heat. In 1693, Blancard’s Physical Dictionary defined certain of the key concepts based on contemporary understanding. Siriasis was defined [2] as “an inflammation or rather heat of the brain or its membranes occasioned by the heat of the sun.” Heat stroke, was defined as being caused by the rays of the sun penetrating the skull and spine. Thus, methods of prevention focused on ways to protect the skull and spine from sun rays. In 1744, French army surgeon De Meyserey believed that by wearing helmets with white leather, sun rays could be prevented from passing through and affecting the brain and spinal cord, and thus heat stroke could be prevented [2].

Evidence of a deeper understanding of body heat and methods of cooling were shown in the late 18th Century. At that time sweating was considered to be a method to dispense with ill humors [2]. Then, studies conducted by Blagden and Fordyce showed that sweat actually cooled the body and acted to stabilize body temperature [2]. Later in 1858, physiologist Claude Bernard undertook animal experiments that helped develop a better understanding of the causes of heat stroke. Core body temperature and symptoms of heat stroke were monitored while the animals were in a heated environment. These studies showed that an increase in core body temperature induced heat stroke independent of sun rays [2].

In spite of these contemporary findings, the prevailing view of the day was that heat stroke was caused primarily or exclusively by harmful sunrays that were referred to as actinic rays. These actinic rays were understood to directly attack the nervous system with an influx of heat. This understanding of the underlying mechanism led those in the military to think that heat stroke would be prevented if the brain and the spinal cord could be protected from the actinic rays of the sun. Many national armies, especially those of the British Empire, developed clothing articles designed to protect both the brain and the spine from the sun rays. Designs for protective gear in the latter half of the 19th century did not necessarily focus on thickness or permeability, but rather on color and location. In British and American armies, a combination of orange and red was regarded as the best color for blocking the actinic rays of the sun [2]. In 1908, Andrew Duncan and Colonel Maude of the American Army believed that the effects of the sun could be averted by lining helmets and the back of the coats of soldiers with this coloring [2]. The helmets of soldiers would be lined with this color if they were stationed in hot climates.

Fig. 1: Spinal cord protector used by the British army during the Boer War in South Africa. The purpose was to protect the brain and spinal cord from sun rays that were thought to cause sun stroke. The protector has been preserved in the Royal Regiment of Fusiliers Museum, London.

One example of a spinal cord protector has been preserved in the Royal Regiment of Fusiliers Museum of London (Fig. 1). During the late 19th and early 20th centuries, this spine protective cloth armor was issued to soldiers during the Boer War where the British soldiers were operating in South Africa. This protective device was designed to hang around the neck and shoulders to cover the spine, and thus prevent actinic rays from reaching the spinal cord. Based on their understanding of the causes of heat stroke, such a device seemed like a reasonable method to reduce the risk of heat stroke.

Demonstrating a growing realization of the multifaceted nature of heat stress, sun ray protective clothing was not the only heat stroke prevention measure. Regular application of cool water began to be mandated by the military under certain situations [2]. Pouring water over one’s head, chest, and back was understood to be a way to cool the body and lower the risk of heat stroke. This method was also reported to be used as a treatment for curing fevers, but garnered only limited support [11]. Even at the end of the 19th century, heat stroke still seemed perplexing and was misunderstood.

At the turn of the century, heat, or specifically a rise in core body temperature, was identified as the primary risk indicator of heat stroke. In 1905, experiments conducted by John S. Haldane showed that human core body temperature was related to the temperature of the environment that surrounded the body, and not only related to the sun [2]. He also showed that humidity was an important variable in the risk of developing heat stroke. He developed a wet bulb test, which was similar to a thermometer but was influenced by humidity. The values from this wet bulb test more closely correlated to an increase of the core body temperature compared to values of just temperature from a dry bulb thermometer that disregarded humidity [2]. This idea was further developed in 1908 when a Briton named Rogers observed correlations between the numbers of hospital admission for heat stroke, the season of the year, and values for humidity. This growing understanding was a breakthrough because it discerned that multiple factors were involved in heat stroke, not just sun rays.

Less than a year after Roger's observation of a correlation between the impact of seasons and humidity upon incidence of heat stroke, the British Army Medical Corps distinguished heat stroke and sunstroke as different medical conditions. But, this distinction was not universally accepted, as over 50 years later the U.S. Army during the Civil War still defined all heat-induced medical illnesses as sunstroke [6]. Nevertheless, this distinction by the British reflected observations of the impact of exercise upon soldiers. They observed that troops had increased core body temperatures when they underwent drills and marches. They also observed that evaporation of sweat was a method of the body to abate the surge in core body temperature and return temperature back toward the normal level [2]. An appreciation that the capacity for cooling by evaporation of sweat was affected by humidity and wind velocity was reflected in new rules concerning army exercises. In order to allow sweat to evaporate from the skin and cool the body, troops were to have open jackets while marching. The degree of difficulty of troop marches or other exercises were to be progressively expanded or diminished based on indicators related to heat stress. A new recommendation by the Manual of Elementary Military Hygiene even said to watch and limit the consumption of alcohol prior to exercises, because excessive alcohol intake would dehydrate the body and reduce the amount sweating needed for cooling.

In 1914, C.F. Wanhill did a study to test the effectiveness of the colored linings in the helmets that were thought to block the actinic rays. The conclusion was that no difference in body temperature could be detected whether the helmets had or did not have the red-liners [2]. This finding was compatible with the growing understanding that heat, not just sun rays contributed to the risk of heat stroke. Thus, more methods were needed to reduce heat, not just clothing to shield the sun rays. Though some still promoted the use of red-lined helmets and spinal protection devices as late as World War II (WWII), more and more realized that heat stroke was caused by an inability to lower core body temperature by releasing heat into the environment. The U.S. Army changed the classification of heat-related illness from sunstroke during the Civil War to excessive heat during the Spanish-American War [6].

During the World Wars, heat stroke prevention techniques were carried out by troops stationed in oppressive climates. Heat stroke stations were instituted throughout the Middle East. Many soldiers attended lectures on ways to prevent heat stroke and other heat related conditions. Soldiers were usually supplied with water to drink and to cool down. By WWII, many nations adopted guidelines for their soldiers regarding limits in conducting exercises [2]. These principles were often based on the wet bulb tests that considered humidity. Post-WWII research has revolved around the idea that the factors contributing to heat stroke can be understood and methods to minimize the risk are possible. This increased understanding was reflected in the more refined classifications by the U.S. military during WWII of heat-related illnesses into three categories: heat stroke, heat exhaustion, and ill-defined effects of heat [2]. Interest grew in developing devices to help lower core body temperatures for those undergoing heat stress.

Prototypes of cooling devices have recently been developed that could be worn by soldiers. Several of these inventions have undergone successful tests and trials [3]. These devices are much improved from the orange colored helmets and spine protectors of the late 19th century, but considerations of practicality limit their implementation [3].

A primary goal of cooling devices is to enhance dissipation of heat from the body. Heat dissipation is increased by contact between the skin and heat sinks, such as cool water, ice packs or gel substances that absorb the heat into chemical reactions. To manage this process, a vest has been employed to hold the heat sink close to the skin. The location of the vest around the chest and abdomen has several advantages. The heat transfer is close to the "core" in a noninvasive manner, and the arms, legs and head are unhindered to perform functions that may be essential to the operational mission. Cooling vests are an effective way to lower core body temperature [12] and lessen the risk of heat stroke [13]. However, vests and the associated cooling systems add weight that may hinder operational effectiveness. One approach is to only use the cooling vest before and after a bout of exercise, such as a sporting event [14, 15, 16]. Compared to defined sporting events, military operations have a longer and less predictable duration, so pre- and post-cooling strategies do not seem suitable. Another approach is for when one is exposed to a heated environment on a vehicle. The vehicle carries the load of the cooling system. One cooling vest system was developed for helicopter pilots [17], and another for armored combat earthmover drivers [18]. These vehicle applications would have the users in a sitting position. Another application was for a surgeon working in a standing position [19].

Cooling vests may help reduce heat stress for people wearing hazard (nuclear, chemical or biological) safety suits [12]. Due to the rising threats from nuclear, chemical or biological weapons or accidents, soldiers are increasingly at risk and may need to wear appropriate hazard safety suits for extended periods of time. These suits typically reduce ventilation between the body and environment and increase heat stress, especially if one were physically active in a warm environment. The increased risk of heat stroke for people wearing hazard safety suits has been shown to be reduced by a cooling vest that utilized ice packs as the heat sink [12].

Neck cooling devices have also been developed and tested for ability to reduce the risk of heat stroke [3]. This strategy is based on excessively high brain temperature being a primary factor inducing heat stroke. During aerobic exercise, the brain is estimated to generate more heat than at rest [20], and have a higher temperature than core body temperature [21]. Blood perfusion through the brain is the primary method of heat dissipation, since the brain is surrounded by skull, craniofacial structures and upper neck region. During periods of heat stress, core body temperature, and thus blood temperature increase. This lower temperature gradient decreases heat dissipation even more from the brain to the blood. The onset of heat stroke compounds the problem by having a lower cardiac output that decreases perfusion through the brain [7], and further decreases heat dissipation from the brain.

The carotid arteries supply the brain with blood flow. Cooling of the carotid arteries in the neck region, such as with ice packs or a cooling collar, has two positive impacts that enhance dissipation of heat from the brain to the blood [3]. First, the blood in the arteries going into the brain would have a cooler temperature that would increase the temperature differential and heat dissipation from the brain. Second, the cooling of carotid artery induces dilation of the arteries and increases perfusion of blood flow through the brain [20, 22]. Local cooling of the carotid arteries during exercise has been reported to lower brain temperature [21-24], which would lower the risk of heat stroke.

Improvements in cooling devices, such as vests or collars, may result in wider application. A practical cooling device for a soldier in the field would need to minimize weight and movement restrictions, and maximize the heat sinking ability.

IV. CONCLUSION

From ancient time until now, a progressive evolution for heat stress and heat stroke has occurred in the 1) recognition of the problem, 2) the factors that contribute to the problem, and based on the understanding of the factors 3) methods or devices to counter the factors and lower the risk. Heat stroke was first associated with the sun. Based on a theory that the sun rays penetrated into the brain and spinal cord to induce heat stroke, clothing and coverings, some having specific colors were developed and utilized. As understanding of the primary factor switched from the sun to heat, new methods and devices were developed. Soldiers involved with military operations have a higher risk to develop heat stress, and have a higher risk of mortality after the onset of heat stroke. Devices to assist with cooling of core body temperature or more specifically brain temperature have been developed and tested. Further refinements in design to make the systems more practical for soldiers in the field would enable wider application.

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