COOLING VEST SYSTEM TO ASSIST REGULATION OF CORE BODY TEMPERATURE

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ABSTRACT

Body area networks can be utilized to monitor and maintain core body temperature for individuals with impaired thermoregulation. An imbalance between heat gain and dissipation may lead to higher core body temperature. Heat stress caused by abnormally high body temperature increases the risk of heat stroke that may lead to tissue damage, neuronal impairment and potentially death. Thermoregulation may become impaired due to neurological dysfunction resulting from spinal cord injury, head injury, disease, cancer treatments or old age. This project developed a prototype of a scaled down (10:1) model of a cooling vest system. Sensors of core body temperature would be utilized by a microcontroller module to regulate the perfusion of water within a cooling vest. Water was pumped from a reservoir, perfused through a vest, and returned back to the reservoir. A thermoelectric cooler (Peltier device) transferred heat between the water in the reservoir and atmosphere air. An experimental test of the ability of the cooling vest system to lower the temperature of saline in a bladder in the chest of a teddy bear model was conducted. The pre-warmed saline was cooled more during the 4 minute test if the cooling vest system was on the bear compared to when the vest was not on the bear. Testing on a larger scale model will be necessary for further development of the system.

Categories and Subject Descriptors

J.3 LIFE AND MEDICAL SCIENCES

General Terms

Design, Human Factors

Keywords

heat stress, heat stroke, thermoelectric device, Peltier device, core body temperature, thermoregulation

1. INTRODUCTION

Regulation of core body temperature is an important control point of physiological homeostasis in mammals. Periods of hyperthermia, having excessive core body temperatures, induce physiological stress and may lead to heat stroke [4]. Hyperthermia results from a mismatch between the supply and release of heat, due to insufficient dissipation of excess heat within the body to the environment. Environmental temperature correlates with incidence of heat stroke [14-15]. Thus, global warming would be expected to increase the risk of heat stroke.

Heat stress occurs when core body temperature is above the normal physiological range of around 37° C. Heat stroke may be induced when core body temperature is at or above 41° C [7, 16-17]. Following the onset of heat stroke, the rate of blood flow becomes insufficient to provide oxygen to vital organs and tissues. This reduced blood flow further diminishes the ability to dissipate heat. Complications of heat stroke may include renal and hepatic failure, disseminated intravascular coagulation, rhabdomyolysis and adult respiratory distress syndrome [1, 7, 16, 21]. Heat Stroke is estimated to result in death about 20% of the time [17].

Release of heat from the body to the environment may occur through conduction, convection, or radiation from a higher body temperature to a lower environmental temperature, or through evaporation. Chemical phase changes may absorb heat, such as the evaporation of water. Sweat and respiration of breathing are physiological mechanisms that enable evaporation to occur at body surfaces, release of the vapor to the environment, and thus dissipation of heat from the body. Physiological negative feedback mechanisms respond to hyperthermia by inducing changes in both autonomic systems (increased blood perfusion to skin regions, increased sweating and reduced metabolism) and volitional behavior changes (adjustment of garments, body position, drinking of cool fluids and other behavior) that work together to cool the body. Thermoregulation may become impaired due to neurological dysfunction resulting from spinal cord injury, head injury, disease, cancer treatments or old age [9-10, 18-20]. The neurological damage that impairs thermal regulation may also impair motor function and mobility, resulting in affected individuals relying on a wheelchair for locomotion.

Components of the homeostatic system that may become impaired include 1) detection of core body temperature, 2) identification of a state of hyperthermia, 3) activation of autonomic systems to cool the body, and 4) arousal of conscious awareness of being in a state of hyperthermia and inducing changes in behavior that would cool the body.

Body area networks with electromechanical systems could assist thermal regulation [12]. Electronic temperature sensors can be placed in body locations to detect temperatures that reflect core body temperature [13]. One location that may be suitable for chronic monitoring of temperature would be on the skin near the axillary artery located near the underarm. The temperature detected at this location is considered to reflect core body temperature. Once a state of hyperthermia has been detected by the electronic control system, actuators could be utilized to directly cool the body, and to issue an alert to the individual or caregiver encouraging changes in behavior (garments, position) that would assist cooling. One way to directly cool the body is a cooling vest system [3, 7]. Cooling vests have been developed

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and tested on athletes (pre and post activity) [5, 22]. Both able bodied and disabled athletes have utilized cooling vests [22]. Cooling vests have also been developed and tested on helicopter pilots [2], bull dozer operators [6], standing surgeons [11] and those undergoing physical exercise within nuclear biological chemical suits [8].

In this project, we are designing and testing subsystems for a cooling vest system for chronic use by mobility impaired individuals, such as on a stationary bed, chair, or wheelchair. A prototype of a system for a scaled down version of a body, vest and heat exchanger was developed and tested. Results of the testing of this prototype will be useful toward potential development of a cooling vest system for individuals with impaired thermoregulation, who would otherwise be at risk for hyperthermia.

2. MATERIALS AND METHODS

A cooling system positioned near a stationary bed or chair, or mounted on a wheelchair would cool and perfuse fluid through a vest, when a condition of hyperthermia was detected. If the cooling system does not adequately restore normal body temperature, an alert would be issued to the individual or caregiver.

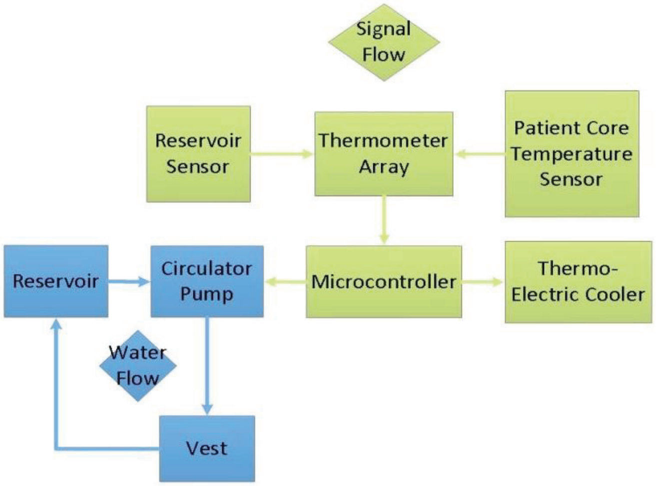

Figure 1: Block diagram of the cooling system. Water flows through the vest, reservoir and pump. The microcontroller receives input from the sensors and outputs signals to control the pump and thermoelectric cooler (Peltier device).

In the developed prototype model of a scaled down (10:1) system, heat was transferred from the body to the air by pumping water between a vest being worn over the chest area to a reservoir. Figure 1 shows the system block diagram. Water is pumped from the reservoir, through the vest and returns to the reservoir. The returning water was made to flow over a thermoelectric cooler (Peltier device) upon entry to the reservoir. The system transferred heat from the body to the atmosphere air through conduction and convection.

A teddy bear was used as a scaled down model of the body. The stuffing in the chest cavity was removed and replaced with a bladder of saline to simulate the body fluids and tissue in the body. During test trials, the temperature of the saline in the bladder was pre-warmed be above target body temperature (above 37^{o} C), and thus would need to be cooled by the system. A vest, with internal perfusion of water, was placed around the chest of the bear. The cloth and fur of the bear between the inner bladder and external cooling vest would partially simulate some of the thermal resistance of the layers within the body forming the outer surface of the chest cavity, and potentially clothes being worn between the skin and the cooling vest. A water pump perfused water between a reservoir and the vest.

For the dissipation of body heat, heat would be transferred from the bladder of warm saline to the water being perfused through the vest. The warmed up water would carry heat to the reservoir, and there exchange the heat with atmospheric air. The heat exchange from the reservoir to the air would be driven by a thermoelectric device, a Peltier device that has one surface in contact with the reservoir, and the other surface in contact with air (a fan increased air flow over the surface exposed to the air). Voltage applied from the control system to the thermoelectric device generated a thermal gradient that was cooler on the side contacting the reservoir, and warmer on the side contacting the air. Thus heat was transferred by the system from the body cavity to the atmosphere air.

Figure 2: Image of the scaled down (10:1) model of the body and cooling system using a teddy bear, with the stuffing in the chest replaced with a bladder of saline to simulate fluids and tissue of the chest. A vest around the chest was perfused with water to transfer heat from the chest area of the bear to the reservoir.

A microcontroller module had outputs that controlled the water pump. Sensors to the microcontroller module indicated temperature of the saline within the bladder, and of the reservoir.

Table 1: Test Results (with or without the cooling vest). The test lasted 4 minutes between the start and end temperature.

	Trial	Temp. start (℃)	Temp. end (℃)	Change in Temp. (℃)
With Vest	1	38.38	29.59	8.79
	2	37.4	28.12	9.28
	3	37.4	30.08	7.32
No Vest	1	37.4	35.94	1.46
	2	37.89	35.45	2.44
	3	36.43	33.5	2.38

The ability of the cooling vest system to lower the temperature of the bladder of warmed saline in the chest of the bear was tested. The bladder was filled with pre-warmed saline and positioned within the chest cavity of the bear. Temperature of the saline in the bladder was monitored for the next 4 minutes. For some trials, no cooling vest was placed around the bear. For other trials, the cooling vest was placed around the bear, and water was perfused through the vest to the reservoir with the thermoelectric device.

3. RESULTS

Table 1 shows the results of the 4 minute test of monitoring the temperature of the pre-warmed saline in the bladder in the chest of the bear that either wore or did not wear the cooling vest. A plot of the changes in temperature of the saline in the bladder in the bear is plotted in Figure 3. Without the cooling vest, temperature in the bladder only cooled about 2^{o}C. With the cooling vest, temperature in the bladder cooled about 8^{o}C.

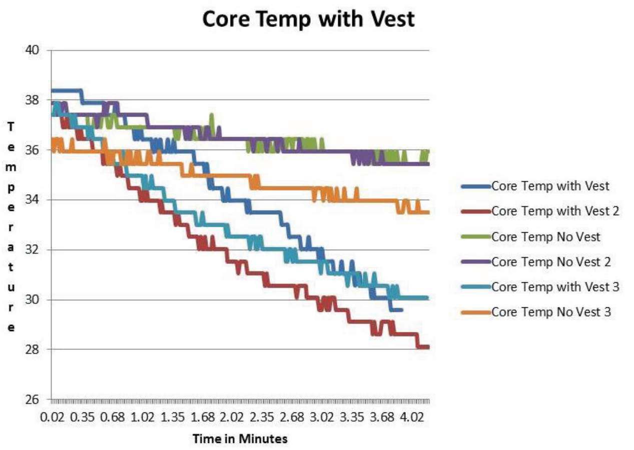

Figure 3: Temperature of the saline in the bladder in the chest of the bear during the 4 minute duration of the test. For each trial, the bear either was or was not wearing the cooling vest. Temperature was measured in Celsius.

4. DISCUSSION AND FUTURE DIRECTIONS

The scaled down prototype system was able to cool the temperature in the bladder during the 4 minute test. Further testing with larger models closer to the dimensions of a human body will be necessary for further development and testing of the design. The ability of the system to maintain stable core body temperature with fluctuations in internal heat will need to be assessed. A system that would help maintain stable core body temperature would improve the health and quality of life of individuals with impaired thermoregulation.

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