Development of Optimal Heat Distribution Strategies for Cold Water Diving Using Direct Regional Calorimetry

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ABSTRACT

Background: In cold water, without adequate heating strategies, divers will experience reduced performance and possibly cold injury. A gap exists in our understanding of the safest and most efficient means of applying heat to the diver, particularly when the power supply is limited. Evidenced-based heating strategies (i.e. quantity and spatial distribution of heating) that can be incorporated into current and future thermal protection systems can fill this gap.

Materials and Methods: A diver thermal protection system using a tube suit with six independent zones has been developed and tested; however, further differences in heating requirements exist within these zones. To more accurately characterize these differences, this project will develop a regional calorimeter by modifying the tubesuit to include 25 regions.

Results: With the six-zone thermal protection system, heating required to maintain divers' core and skin temperatures within safe limits in a wetsuit in 10°C water was 166±78W and was split 4%, 22%, 22%, 14%, 25%, 13% for head, torso, arms, hands, legs and feet, respectively. To refine the spatial distribution, 25 regions have been identified, with temperature sensors positioned accordingly. Within the six primary zones the regions per zone are as follows: head (1), torso (4), arms (8), legs (8), hands (2), and feet (2). The tubesuit temperature monitoring system is a modified 1-Wire temperature string (T32, INW), allowing measurements for all 25 regions in a package worn under a dry suit. Fluid flow will be measured for each region and heat exchange calculated based on the temperature differential from each region.

Summary: A refined 25 region calorimeter designed to measure heat loss/gain during diving operations will be developed. The calorimeter will be used to measure heat exchange in divers, resulting in a better understanding of the placement and quantity of heat required for cold water diving missions.

BACKGROUND AND SIGNIFICANCE

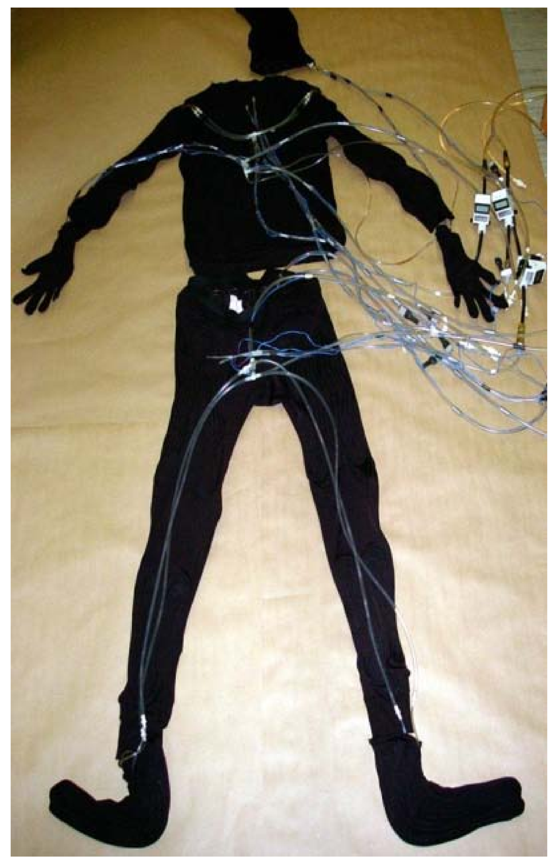
- Recreational, scientific, or military diving operations are often conducted in cold water temperatures that, without adequate thermal protection, dictate the mission scenario, or predispose divers to diminished cognitive and physiological function, cold injury, hypothermia, and even death
- Though new heat generation/delivery technologies continue to be researched, a clear gap exists in our physiological understanding of the safest and most efficient means of applying heat to the diver
- Heating systems with arbitrary or minimal evidence-based heat distribution strategies may be inefficient at best, and in some cases have even been shown to be unsafe and counterproductive by causing greater reductions in core temperatures than in trials when no heat was applied
- Regional and whole-body heat exchange is more complex than often acknowledged, and clear, evidenced-based heating strategies (i.e. quantity and spatial distribution of heat) that can be incorporated in current and future thermal protection systems are needed
- A greater understanding of the mechanisms of regional heat transfer (gain/loss) and new heating technologies are needed to ensure optimal regional and total body heating during extended duration missions with a limited power supply

OBJECTIVE

The broad objectives of this investigation are to 1) develop a novel research tool (regional calorimetry) for advanced underwater thermoregulatory analyses and 2) determine empirically-derived heat distribution strategies that can be incorporated into current and prospective heating systems for cold water diving

PRELIMINARY RESULTS

- A diver thermal protection system using a tube suit with six independent zones has been developed and tested; however, further differences in heating requirements exist within these zones
- Divers in a wetsuit in 10 °C water required 166 W
  - Head – 4%
  - Torso – 22%
  - Arms – 22%
  - Hands – 14%
  - Legs – 25%
  - Feet – 13%
- To more accurately characterize these differences, this project will develop a regional calorimeter by modifying the tubesuit to include 25 regions



CALORIMETER SETUP

- The six zones of the tubesuit will be further divided into 25 monitored regions:
  - Head (1)
  - Hands (2)
  - Feet (2)
  - Torso (4)
  - Arms (8)
  - Legs (8)

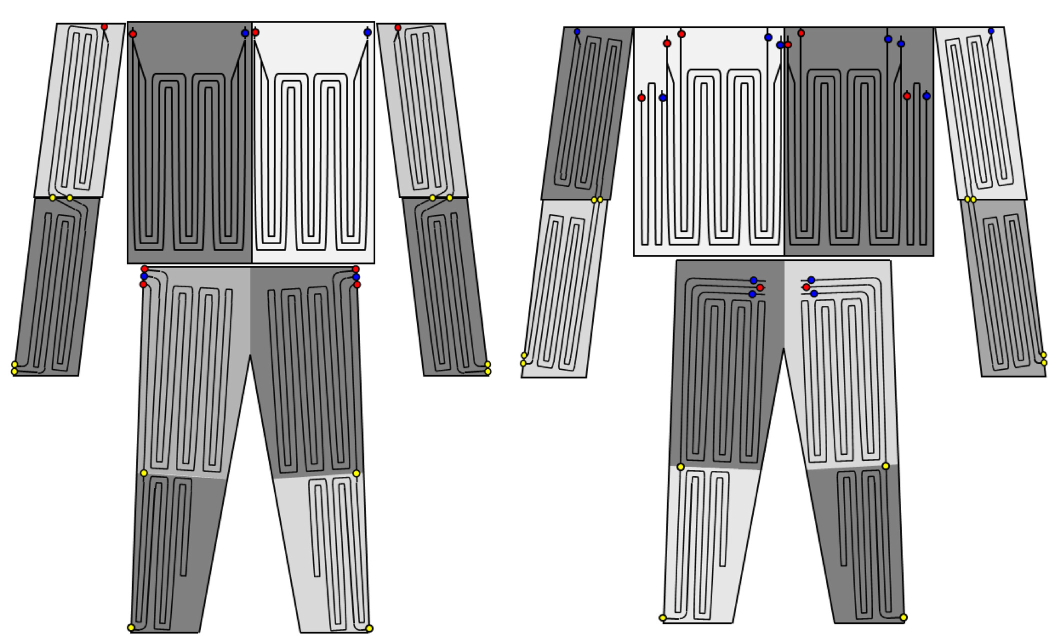


Figure 1. Tube flow path in current tubesuit. Tubes are represented by black lines. Shading distinguishes separately measured regions. Locations of thermistors measuring inlet and outlet water temperature are represented by colored circles (red = Region inlet thermistor, measures Tin; blue = Region outlet thermistor, measures Tout; yellow = Thermistor between region sharing a common flow path, measures Tout for one region and Tin for the next region).

- The inlet and outlet tubesuit water temperature will be measured for each of the 25 regions
- The 60 tubesuit temperature sites will be measured using a modified INW 1-Wire system
- Fluid flow will be measured for each region after sensor installation
- Heat exchange for each region will be calculated based on temperature differential and water flow

MANNED TESTING

- Initial experimental optimization will be performed using three subjects to determine optimal tubesuit (calorimeter) perfusion (72, 86, or 100 °F) and ambient water temperatures (35, 50, or 65 °F) for the regional calorimetry testing
- Regional calorimeter testing will be performed with subjects at rest, wearing dry suits, fully immersed for 2-3 hours
- Based on the results from regional calorimeter testing, preliminary regional heating strategies will be tested
- A redesigned tubesuit will be developed to better match desired anatomical regions and to refine the spatial resolution of the calorimeter
- Further human testing will be performed to investigate regional heating strategies for various conditions including diver physical activity, dry suit undergarment insulation, water temperature, and power availability for active heating

GOALS/MILESTONES

FY11 Goal – Complete and validate a refined regional tubesuit calorimeter
Initial manned calorimeter testing

FY12 Goal – Conclude manned calorimeter testing
Complete preliminary regional heating testing
Preliminary regional heating guidance
Develop and validate optimized regional calorimeter

FY13 Goal – Complete manned heating testing for various conditions, including exercise
Technical Report and Peer-reviewed journal article(s)

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