Regulation and Utilization of Human Heat to Enhance Comfort, Safety, and Survival in Routine and Emergency EVA Situations

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Rationale

- Regulation of heat of astronauts during EVA or planetary surface exploration is highly important for safety and survival

- One strategy is to utilize the heat thermodynamic within the individual and from the individual to the group
  - to regulate this process during emergency situations

- A number of analogs are examined to enhance safety through sharing of heat
  - Individual: between body zones,
  - Collective : two persons or larger groups

Approach

A multi-compartment liquid cooling/warming garment with tubing bypasses enables the economic management of heat and energy in emergency situations

Physiological Design of EVA Cooling/Warming Garment

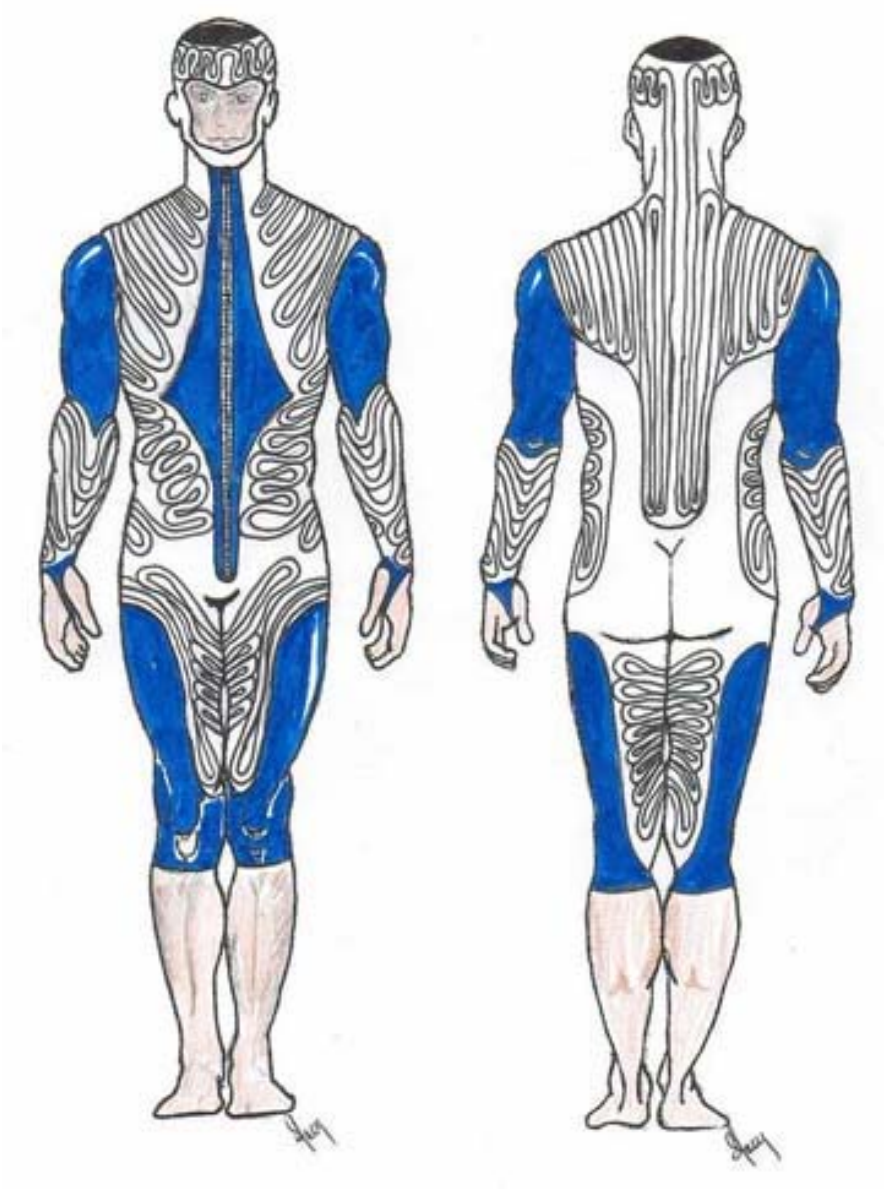
- Biological tissues are different in their profile of thermal conductivity
- Blood circulatory processes are highly effective for transporting heat to the body periphery
- The body surface has highly effective zones to transfer heat, therefore providing quicker normalization of heat exchange and comfort

Design Strategies

- Tubing system should be positioned on body areas with maximal physiological ability to transfer heat in and out of the body

- Shunts minimize or redirect a cooling/warming loop of the garment for emergencies depending on the environment and activity

Prototype of MACS-Delphi Garment with Ventilation System

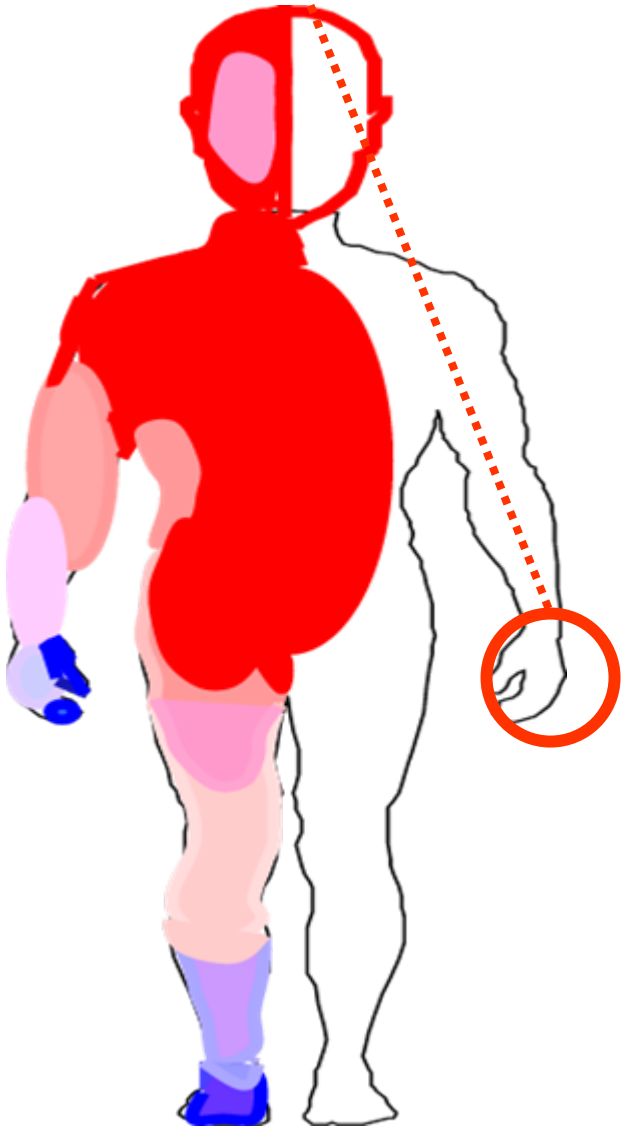


Hypothesis

A head/hand bypass conserves heat that is constantly dissipated from the head

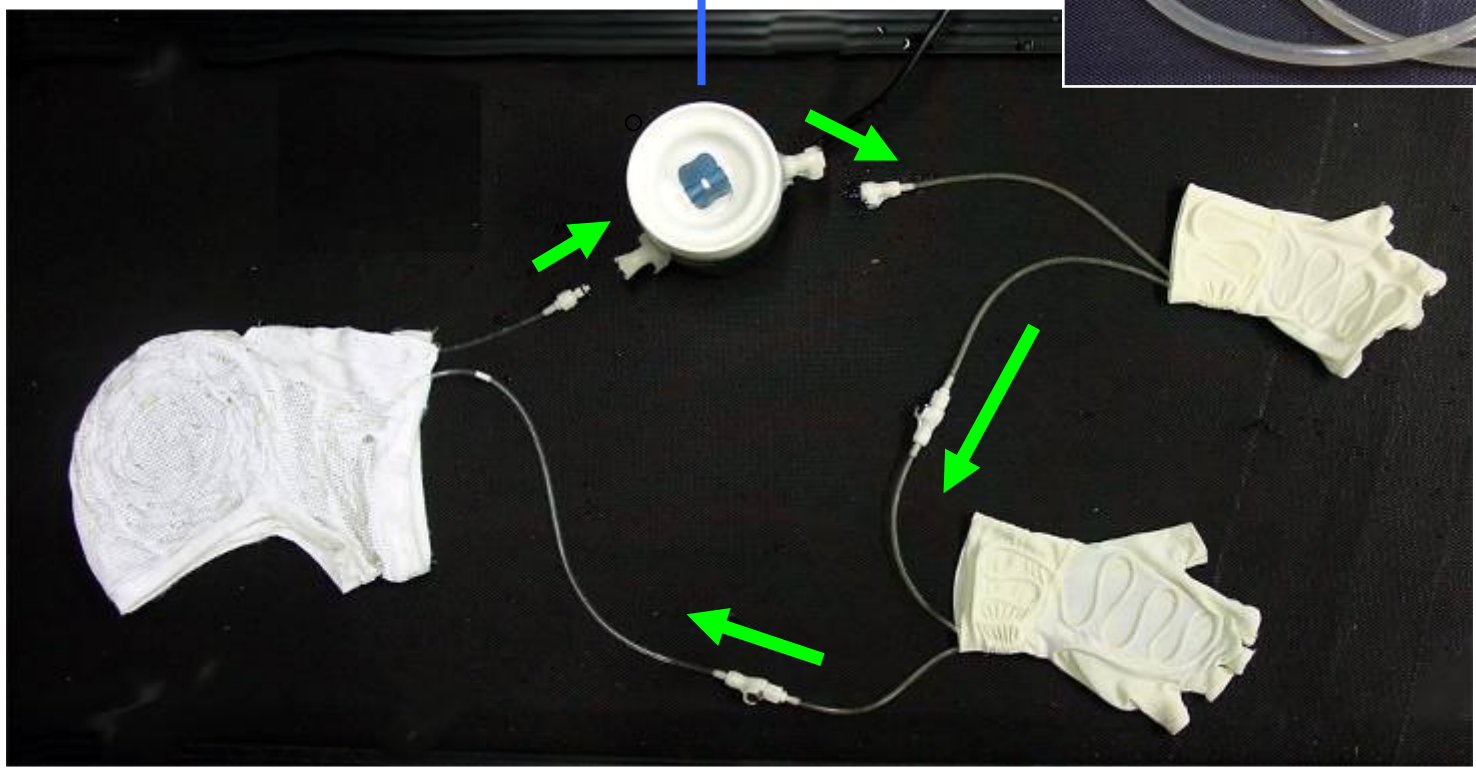
Core/Limb Thermal Fields

Bypass



BYPASS
Head and Hands

Between a hood and a glove



Head-Hands Bypass

Method
Rest Condition

- Stage 1. comfort stabilization - garment inlet water temperature 33°C
  - water in loop 23°C;
- Stage 2. body cooling – garment inlet water temperature 20°C;
- Stage 3. rewarming - garment inlet water temperature 45°C.

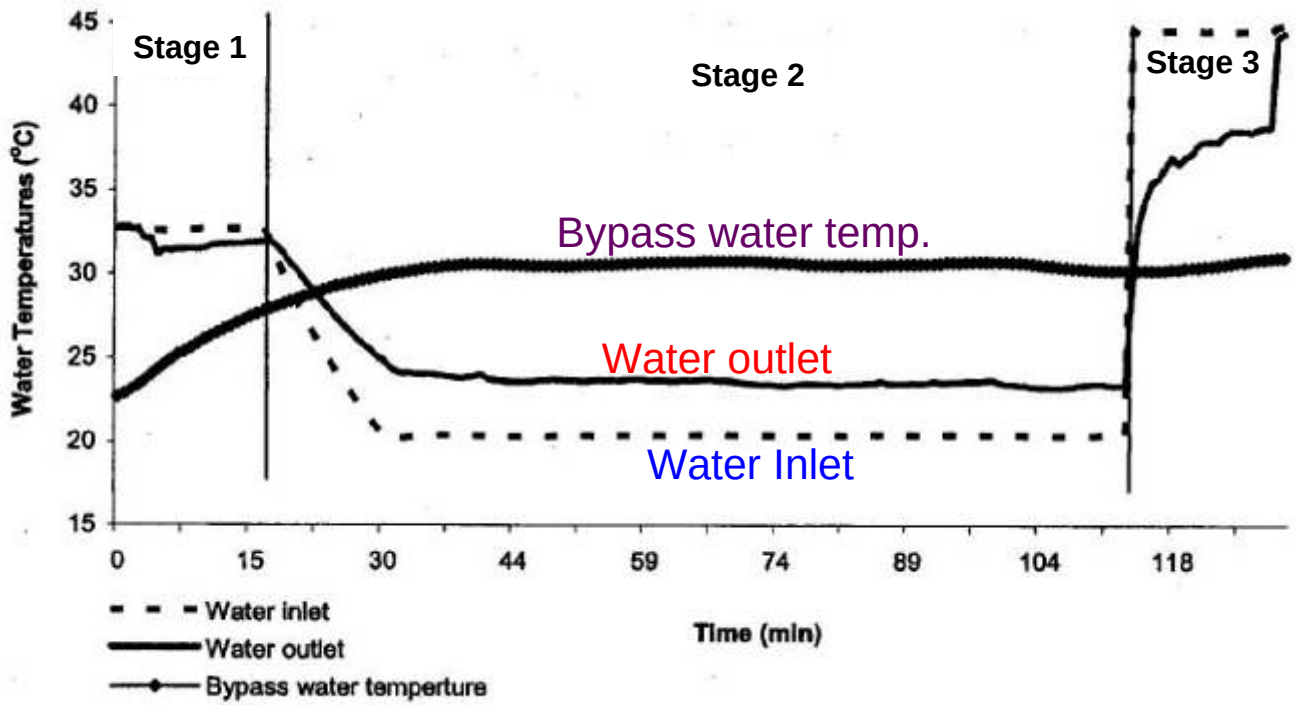
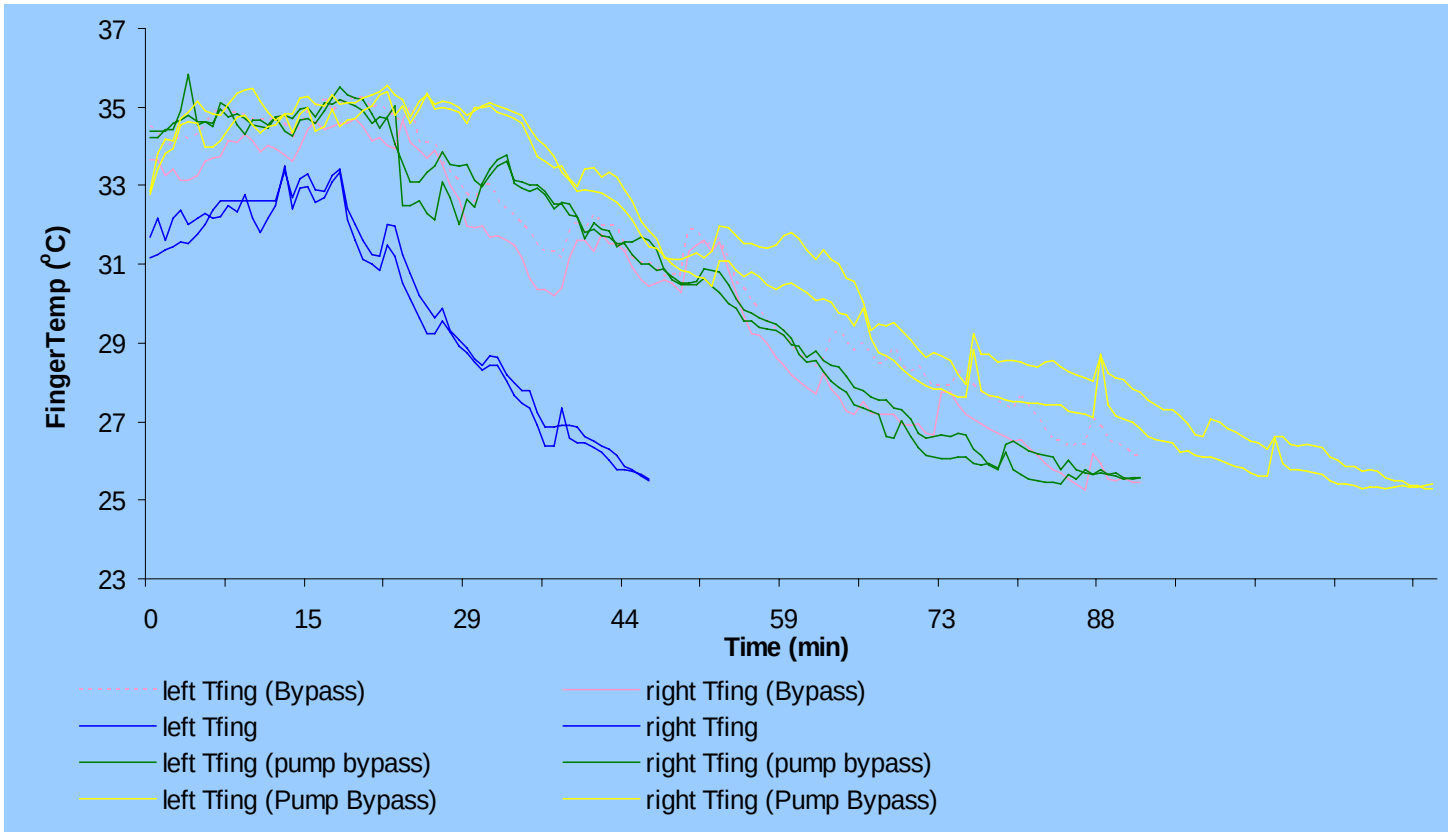


Fig. 2. Thermal profile of circulating water in the bypass connecting the hood and the shortened gloves (n = 7).

Duration of Decline in Finger Temperature to 25ºC Criterion



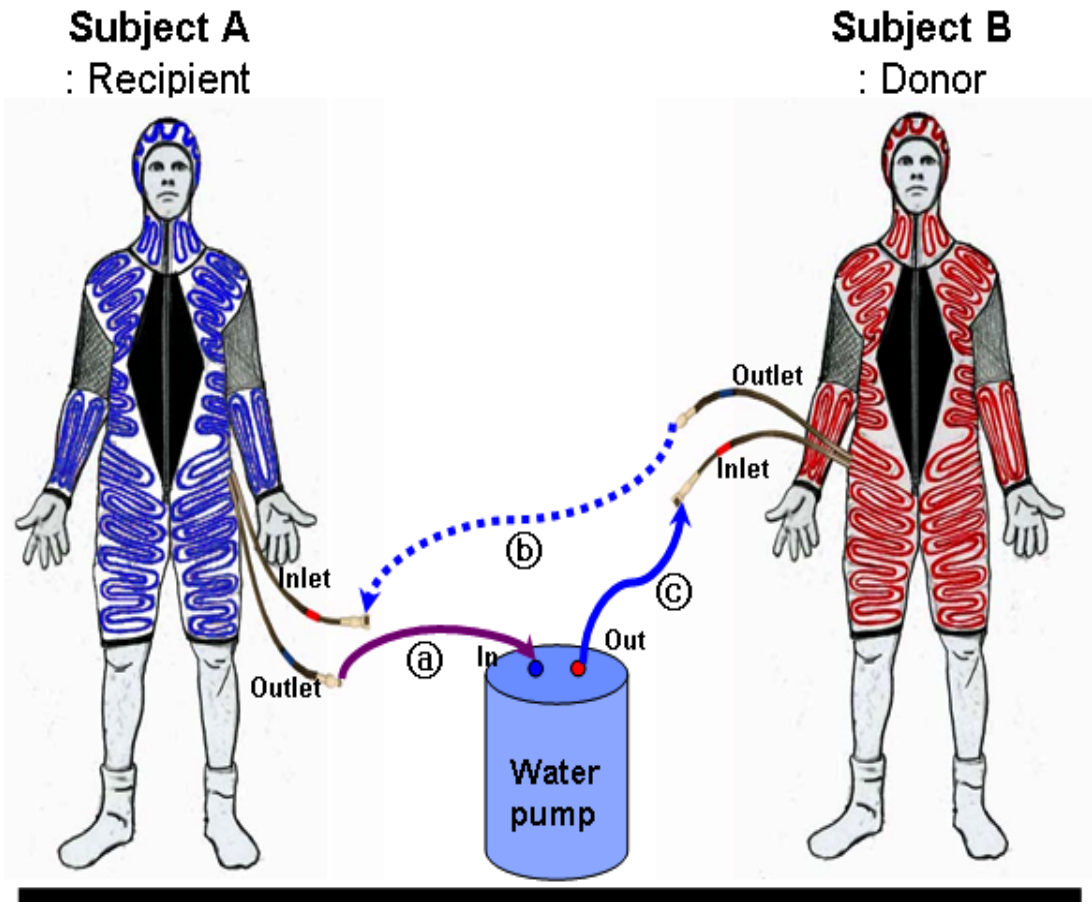
Heat Sharing Between Two People

System Failure Scenarios

- 1. One person has a support system not working well and a body heat deficit of 100-120 kcal
  - Other person at thermal comfort level

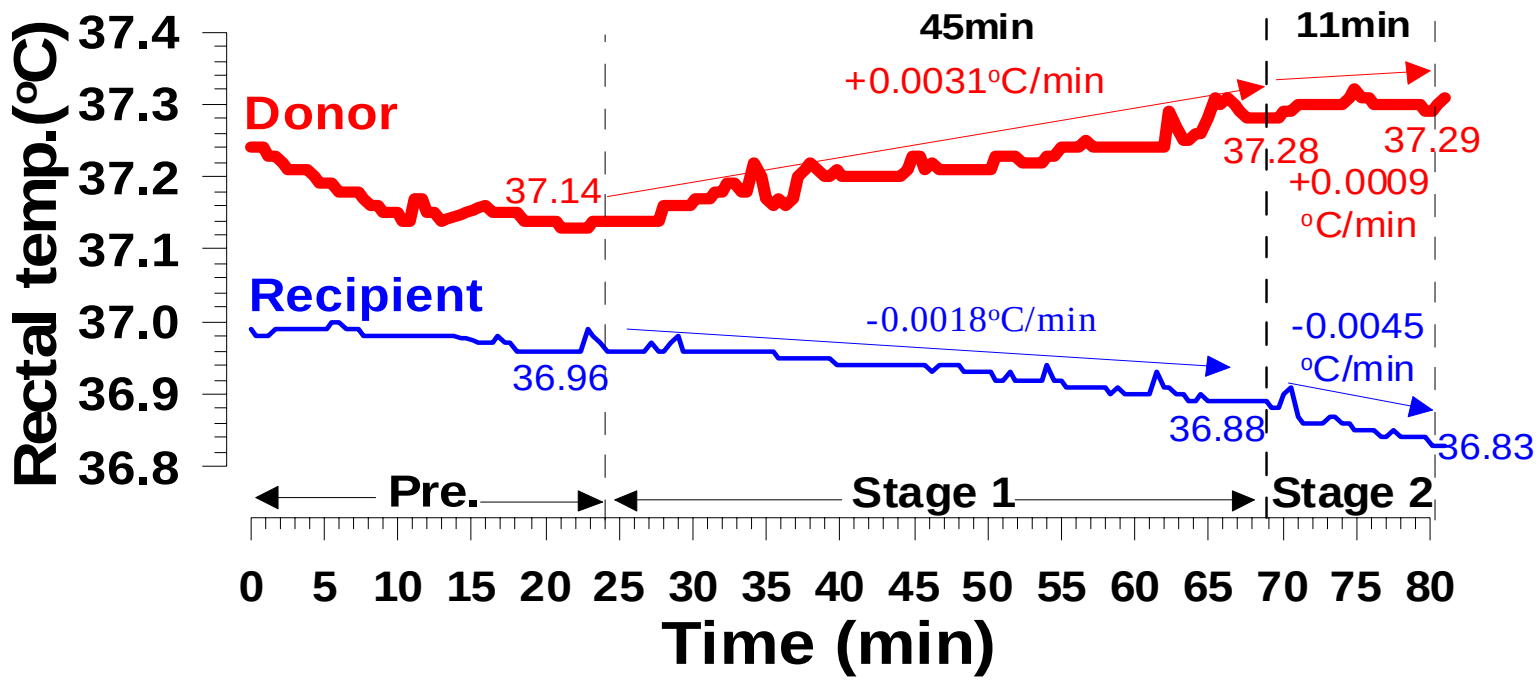
2. One person overcooled due to system failure
   - Other person mildly overheated

Thermal Bypass and Direction of Tubing Between Two persons – Donor and Recipient



Method
Seated Condition

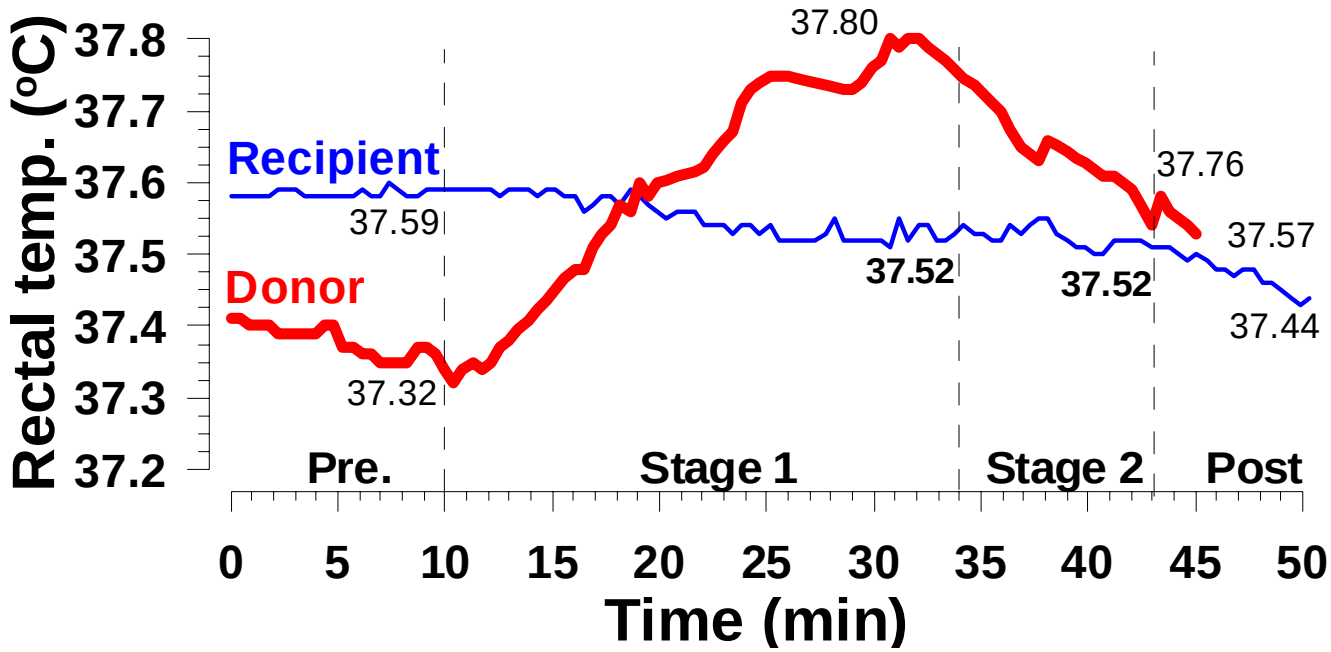
- Stage 1 – recipient chilled (15^{o}C); donor warmed (33^{o}C) until recipient finger temperature at 26^{o}C
- Stage 2 – tubing from donor garment connected to recipient's garment through a water bath
  - Water is circulated through the bypass loop between the two people
- Experiment terminated when water temperature in bypass loop reaches a plateau



Rectal temperature (T_{re}) dynamic of Recipient and Donor across stages seated side by side.

Method
Exercise Condition

- Stage 1 – Recipient chilled (inlet water 15^{o}C)
  - Donor in treadmill run until Tre at 38^{o}C or Recipient Tfing at 26^{o}C
- Stage 2 – garment tubing from Donor connected to garment tubing of recipient
  - Water is circulated through the bypass loop between the two people – both seated
- Stage 3 – termination following plateau in water temperature in the bypass link



T_{re} of Recipient and Donor across stages. Stage 1 – Donor exercise, Recipient rest; Stage 2 – heat exchange.

Collective Heat Exchange

- Group protection against cold following life support system failure

- Group heat storage and utilization through optimal body positioning of people
  - Regulation of heat dissipation among crew members
- Mutual support through sharing a heat/cold water file among crew members

Conclusions

- It may be possible to support the thermal status of crew members in difficult environmental conditions by appropriate heat/cold regulation
  - Individual bypass loop connecting different body zones
  - Person to person sharing of tubing files
- Regulation of collective heat to provide safety for entire group in harsh environments