HEAT STORAGE AND BODY TEMPERATURE DURING COOLING AND REWARMING

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INTRODUCTION

Stores of body heat change daily, increasing with activity and meals, decreasing with sleep. They also decrease with strong cold exposure, as in cold water immersion. Body heat content (H_b) change is known from the difference between metabolic heat **(M)** and heat loss (ΣQ) over a period of time, as determined from indirect and direct calorimetry. Since direct calorimetry is **uncommon,** most people estimate ΔH_b from change in body temperatures, but the constants for the predictive equations are in dispute. They have not been tested experimentally during intentional body cooling. We measured **AH,,** rectal temperature (T_{re}) and mean skin temperature (T_{sk}) during strong cooling and subsequent rewarming.

METHODS

Continuous direct and indirect calorimetry gave values for **CQ** and **M** during various cooling procedures. The direct calorimeter was an insulated tubing suit [6], where mass flow of water times temperature change across the suit, plus small terms for respiratory heat loss and heat transfer through the insulation summed to give **EQ.** The suit was also able to cool and rewarm. In one set of experiments the calorimeter was the bath calorimeter at the Defence Institute of Environmental Medicine [4]. Indirect calorimetry was done with a ventilated full face mask, with measurement of air flow and gas analysis. During cooling, when **CQ** > M, the accumulated difference was $-\Delta H_b$; in rewarming **AH,** was the accumulated difference while M > ΣQ.

Calculation of change in mean body temperature **(AT,)** was:

$$\mathbf{AT,} = \mathbf{AH,} / m_b \cdot c_p \quad (1)$$

where m_b is the body mass (kg), and c_p is the specific heat of the body. Instead of using the single value of 3.47 $kJ \cdot kg^{-1} \cdot {}^\circ C^{-1}$, it was calculated from:

$$c_p = 1.88(fF) \ t \ 3.72(1-fF) \quad (2)$$

where fF is fat fraction and the constants are (in kJ) the specific heats of pure lipid and fat-free mass [5].

There were 5 different cooling procedures. In Bath calorimeter subjects stayed immersed to the neck for 1 hour in 24°C water, or 40-60 min in 18°C water. In Swim submereed subjects swam with fins underwater against a counterweighted trapeze in water at 5, 10 and 15°C, wearing a thin rubber *dry* suit without added insulation. 3 procedures employed suit cooling. In Cool with exercise subjects were overcooled while pedalling a cycle ergometer with a load of 50 W. In Suit cooling they were overcooled while seated at rest. In Cool and hold subjects were overcooled, then held at that level of heat deficit for 1-2 hours until T_{re} had been steady for an hour. Rewarming followed all 5 cooling procedures, using the tubing suit. The end of rewarming was the restoration of the heat previously lost (**AH,** = 0).

RESULTS

Heat losses for the 5 procedures varied on average from -464 to -1038 j, with individual values ranging from -335 to -1600 **kJ.** $-\Delta T_b$ showed values (averaged by procedure) from -1.9 to **-4.0°C,** with individual values ranging from -0.5 to -6.0. Body temperatures were: for **T,,** from -0.8 to -1.4°C averaged by group; for T_{sk} they were from -5.4 to -11.2°C.

The low point for T_{re} was the end of afterdrop, because that represents the full cooling effect on internal temperature. We saw in Cool and hold that there was a normal afterdrop despite the long delay before rewarming. Also, in the 2 procedures with exercise (Swim submereed and **Cool with exercise**) T_{re} rose during most of the cooling period and fell finally during the rewarming, when exercise had stopped.

To relate ΔT_b to body temperature change, we used experimental data to solve Burton's [1] equation:

$$\text{AT,} = a(\Delta T_{re}) - (1\text{-}a)(\Delta T_{sk}) \quad (3.1)$$

where "a" is a weighting coefficient, or, rearranging terms:

$$a = (\Delta T_b - \Delta T_{sk}) / (\text{AT,} - \Delta T_{sk}) \quad (3.2)$$

The resulting values for "a" in the 5 procedures were mostly between 0.74 and 0,76, for both cooling and rewarming. The grand mean for 119 determinations was 0.75 ± 0.01 (s.e.m.). Thus for major cooling and rewarming:

$$0.75(\Delta T_{re}) + 0.25(\Delta T_{sk}) = \Delta T_b \quad (4)$$

and to calculate heat loss or gain one would use eq. 1 rearranged

$$\text{AH,} = \text{AT,,} \cdot m_b \cdot c_p \quad (5)$$

DISCUSSION

The derivation of Burton's "a" in our study was remarkably free of variability, compared to earlier studies under much milder thermal conditions [e.g. 2, 3]. Published values for "a" have ranged from 0.5 to 0.9, with the higher values tending to be in warmth. Using afterdrop to define the change in T_{re} was essential to securing the low variability in our study.

Estimating heat loss from body temperature using eq. 4 & 5 is specifically for situations where there is rapid cooling. It may not apply to heat exposure or exercise, where the 2-compartment model may be inappropriate.

CONCLUSION

Body heat loss during cooling from cold water may be estimated with the weighting coefficients 0.75 for AT, (including afterdrop) and 0.25 for ΔT_{sk}.

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