PREDICTION OF SURVIVAL TIME FOR COLD EXPOSURE

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INTRODUCTION

Exposure to cold can be life-threatening to the ill-equipped or unprotected individual. To help facilitate planning and to **be** better prepared for contingencies, prediction of survival time (ST) in the cold is essential, although this task is difficult to achieve due to the lack of controlled and reliable data of deep hypothermia. Controlled exposures are limited to mild levels of hypothermia and accidental exposures are insuffcently documented for detailed analysis. However, controlled data can be used as the basis for the development of a model that is subsequently calibrated with accidental cases. This study describes such a development for the prediction of ST under sedentary conditions in the cold (see Ref 1 for greater detail).

METHODS

The model is based on steady-state heat conduction in a single cylinder comprised of a core and two concentric annular shells representing the fat plus skin and the clothing plus still boundary layer, respectively. Emphasis is placed on the prediction of central body temperature and not of the extremities. The core radius and fat plus skin thickness are based on the individual's anthropometric dimensions and fatness level. The clothing plus still boundary layer is based on the combined insulative value and the effect of wind is taken into account. The ambient condition can **be** either air or water, the distinction is made by assigning different values of insulation to the still boundary layer. Heat loss and body temperatures are predicted using the steady-state bioheat equation and body heat loss is determined by the difference between heat production and heat loss.
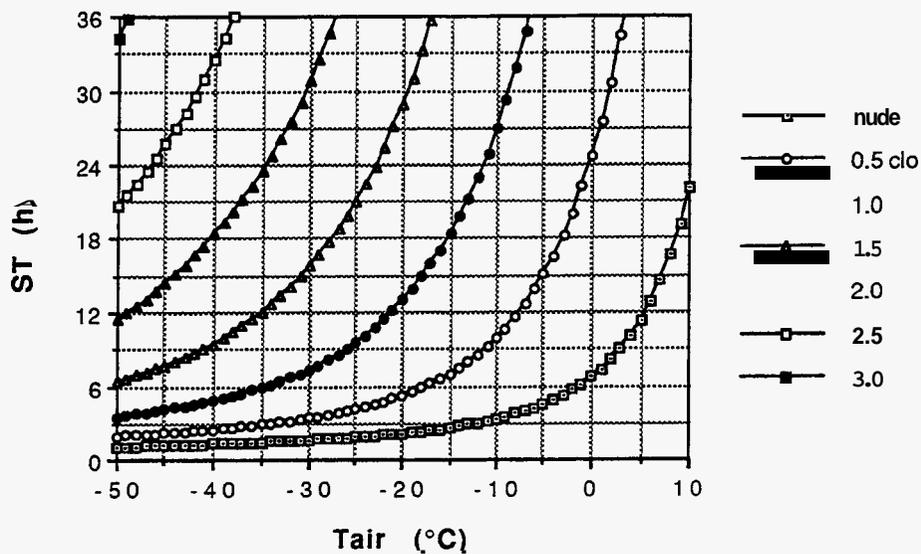
Metabolic heat production due to shivering (M_{shiv}) is predicted by temperature signals from the core and skin (2). Where the cold exposure is sufficiently severe such that heat loss overwhelms total heat production, ST is largely determined by the heat conduction characteristics of the model. Where a balance occurs, ST is governed by the depletion time of the energy reserve for shivering. This energy reserve is based on the glycogen depletion model of Wissler (3) normalized to body size. M_{shiv} is attenuated using hyperbolic cosine functions when central core temperature (T_c) drops below 32°C and when the shivering energy reserve is depleted. The attenuation is 100% when T_c reaches 30°C and 50% when the shivering reserve is exceeded by 50%.

End of survival is declared when T_c reaches 30°C although the model is capable of predicting lower body temperatures. Calibration of the model began with cold water survival reports. To obtain predictions of ST close to or between those reported by Molnar **(4)** and Veghte (5) for immersion in water from 0 and 20°C, it was necessary to i) choose a model radius that was 50% larger than the mean radius of the body and ii) attenuate the shivering intensity as described above. Further testing was conducted for air exposure under thermoneutral conditions (nude and 1 clo at 28 and 21°C, respectively) and for nude exposure to 5°C. In each case, predicted metabolic rates and body temperatures at steady-state were in reasonable agreement with observed values.

RESULTS

A sampling of ST predictions for nude exposure in relatively calm (1 km/h wind) cold air of an average healthy male are the following: 3, 5, 10, and > 24 h for -20, -10, 0, and 10°C, respectively. With 2 clo of insulation in a 10 km/h wind, STs are 7, 10, 17, and > 24 h for -50, -40, -30, and -20°C. The figure below shows predicted STs for various levels of insulation from nude to 3 clo and for exposure to air from -50 to 10°C **at** 2 km/h. See Ref. I for a more complete listing of STs.

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DISCUSSION

The following summarizes the limitations of the model:
    i) applicable for sedentary activity,
    ii) assumes full exposure (i.e., standing or immersion),
    iii) does not take solar radiation into account,
    iv) assumes the energy reserve for shivering is based on glycogen depletion, and
    v) ST predictions have **not** been verified.

The predicted STs must be weighted against the extrapolative nature of the model. At present, it would be prudent to **use** the predictions in a relative sense, that is, to estimate the benefit **of** increasing one's insulation in terms of the percentage increase in ST. For example, increasing insulation from 1 to 2 clo is predicted to extend ST by about 400% in air at -30°C under a **2** km·h^{-1} wind condition. Clearly, model predictions are subject to change as more information becomes available for calibration. This is especially true with respect to the endurance time of long-term shivering.

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