EMPIRICAL MODEL OF TEMPERATURE RESPONSE TO COLD WATER IMMERSION

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INTRODUCTION: Linear extrapolation and the Texas Human Thermal Model (1) are widely used to estimate core temperature during cold water immersion. The purpose of this study was to examine the validity of both techniques by comparing estimates with human data obtained from cold water immersions lasting up to 360 minutes.

METHODS Rectal temperature (T_{re}) data were obtained from cold water immersion studies conducted in Finland and Norway (F) (2) and the United States (US) (3) over the past 9 years. Two types of garments were used in these studies, constant wear anti-exposure coveralls with vapor-permeable membranes (Gore-Tex) (CW-F, CW-US) and neoprene quick-don anti-exposure coveralls (QD-F). Water temperatures for the CW-F and QD-F studies were 1°C and 7°C for the CW-US study. Maximum exposure durations for the CW-F and CW-US were 120 minutes and for the QD-F it was 360 minutes.

The actual T_{re} data was compared with linear extrapolations and T_{re}'s predicted from Texas model simulations. Linear curve fitting was performed on the data for given intervals of time (e.g. 90, 120, 180, 240, 300, and 360 minutes). Comparisons of the correlation coefficients and predictive accuracy were based upon both the curves generated from individual trials and from pooled data. The QD CLO values input into the Texas model were assumed to be equivalent to previously reported values (immersed regional CLO values ≈ 0.9-2.6, mean=1.2) (4). Overall CLO values were available for the CW-US (immersed CLO ≈ 0.8) and insulation of the CW-F was assumed to be equivalent. Garment CLO values accounted for the water thermal boundary layer. Anthropometric data from individual subjects was input into the model during simulations. A temperature offset was used to correct for differences in initial temperatures between actual data and simulations. Model fidelity was analyzed by directly comparing actual human T_{re} data (T_a) with model estimates (T_e) and by comparison of the estimated changes to actual changes in T_{re} relative to the initial T_{re} (T_o). Paired-t tests were used to compare data and significance was determined at a $p=0.05$ level.

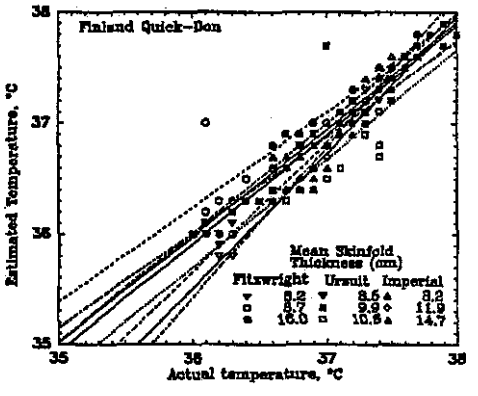

Figure 1. Relationship of estimated T_{re} to actual T_{re} for QD-F.

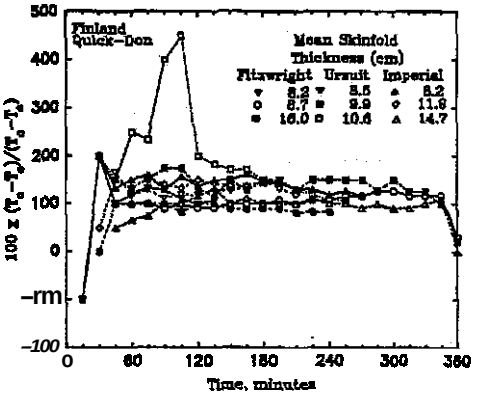

Figure 2. Percent difference between actual change in T_{re} versus time and estimated change for QD-F.

RESULTS: Linear Estimates: Linearity can be demonstrated throughout the extended trials (i.e., >180 minutes), but the slopes change significantly ($p<0.05$) over time.

Texas Model: Model simulations of the **QD-F** were fairly reliable throughout most of the exposure period. **As** seen in Figure 1, the slopes of the regression limes representing the correspondence of actual and estimated T_{re} did not significantly vary from 1.0.

The percent difference between the estimated and actual change in T_{re} had means ranging from 86% to 198%, with the mean *of* the means of 122%(SEM±11) (Figure 2). **As** no data was available past 360 minutes, it was not clear whether the over-estimation *of* T_{re} observed among the final values **was a** transient phenomena.

Simulations *of* the CW trials were less reliable. The CW-F simulation regression line slopes deviated significantly from a slope *of* 1.0 ($p<0.01$) (Figure 3). The percent difference between the estimated and actual change in T_{re} had a mean of the means of 203%(SEM±36, range *of* 116% to 325%) (Figure 4). While the percent difference in T_{re} in the **CW-US** simulations had a mean *of* the means *of* 96% (SEM±11, range *of* 39% to 139%), considerable variation was noted for both **CW** studies. The regression line slopes obtained **from** the CW-US simulations did not significantly differ from 1.0.

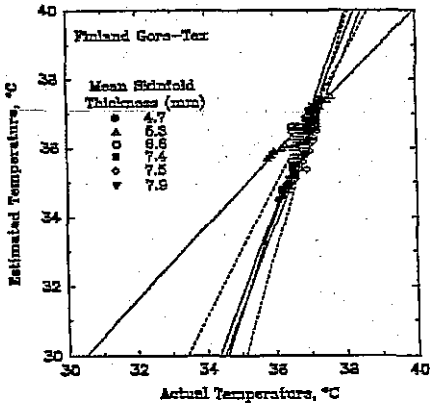

Figure 8. Relationship *of* estimated T_{re} to actual T_{re} for CW-F.

CONCLUSIONS It appears that linear extrapolation of T_{re} for extended periods based only upon short term responses (i.e., <120 minutes) **will** be inaccurate. The Texas model provides a reasonable simulation of human Tre responses to cold water immersion under some conditions. The cause of the deviation of estimates from the simulated studies with the actual T_{re}'s is unclear. It is likely that **use *of*** regional CLO values would have improved the accuracy of the estimates for **the** CW studies. Additional validation studies of the Texas model **using** other garments and environmental conditions appears warranted.

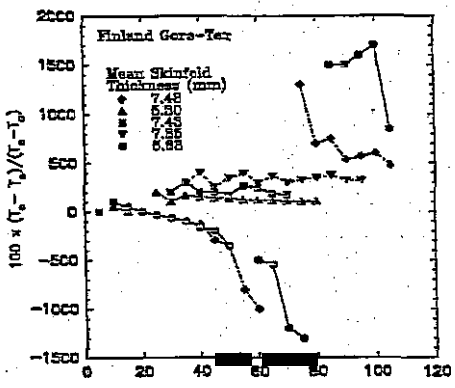

Figure 4. Percent difference between actual change in T_{re} **versus time and estimated** change **for CW-F. Missing data is due to division by zero.**

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