A Critical Appraisal of 98.6°F, the Upper Limit of the Normal Body Temperature, and Other Legacies of Carl Reinhold August Wunderlich

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Objective.—To evaluate critically Carl Wunderlich's axioms on clinical thermometry.

Design.—Descriptive analysis of baseline oral temperature data from volunteers participating in *Shigella* vaccine trials conducted at the University of Maryland Center for Vaccine Development, Baltimore.

Setting.—Inpatient clinical research unit.

Participants.—One hundred forty-eight healthy men and women aged 18 through 40 years.

Main Measurements.—Oral temperatures were measured one to four times daily for 3 consecutive days using an electronic digital thermometer.

Results.—Our findings conflicted with Wunderlich's in that 36.8°C (98.2°F) rather than 37.0°C (98.6°F) was the mean oral temperature of our subjects; 37.7°C (99.9°F) rather than 38.0°C (100.4°F) was the upper limit of the normal temperature range; maximum temperatures, like mean temperatures, varied with time of day; and men and women exhibited comparable thermal variability. Our data corroborated Wunderlich's in that mean temperature varied diurnally, with a 6 AM nadir, a 4 to 6 PM zenith, and a mean amplitude of variability of 0.5°C (0.9°F); women had slightly higher normal temperatures than men; and there was a trend toward higher temperatures among black than among white subjects.

Conclusions.—Thirty-seven degrees centigrade (98.6°F) should be abandoned as a concept relevant to clinical thermometry; 37.2°C (98.9°F) in the early morning and 37.7°C (99.9°F) overall should be regarded as the upper limit of the normal oral temperature range in healthy adults aged 40 years or younger, and several of Wunderlich's other cherished dictums should be revised.

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THE ORIGIN of the concept equating 37.0°C (98.6°F) with the normal temperature of humans is somewhat obscure but is generally credited to two different groups of 19th-century investigators.[1] Of these, Wunderlich[2] has been by far the most influential, owing to his 1868 magnum opus, *Das Verhalten der Eigenwarme in Krankenheiten*, in which he reportedly analyzed over 1 million axillary temperature readings from some 25 000 patients. In his book, Wunderlich[3] identified 37.0°C (98.6°F) as the mean temperature of healthy adults. He also pointed out that the range around 37.0°C extends from 36.2°C (97.2°F) to 37.5°C (99.5°F), reaching its nadir between 2 and 8 AM and its zenith between 4 and 9 PM.[4] Temperature readings in excess of 38.0°C (100.4°F), according to his work, are always "suspicious" and "probably febrile."[3] He wrote that women generally have slightly higher temperatures and exhibit greater thermal variability than men[4] and suggested that there might be racial differences in body temperature, that the first temperature taken after admission to a hospital is untrustworthy, and that "old people present a temperature 0.5°C = 0.9°F less than younger persons."[3]

Only a few studies have attempted to appraise critically Wunderlich's observations. Most were performed 40 or more years ago and involved either small numbers of subjects[1,5-7] or large numbers of subjects from whom only single temperature readings were obtained.[8,9] The present investigation represents a more comprehensive appraisal than any yet published of concepts promulgated by Wunderlich more than 120 years ago.

Subjects and Methods

Subjects.—One hundred forty-eight subjects (aged 18 through 40 years) participated in the investigation. These included 122 men (88 black, 32 white, one Hispanic, and one Oriental) and 26 women (17 black and nine white). All were healthy volunteers recruited from the community for nine different inpatient *Shigella* vaccine trials conducted at the Center for Vaccine Development, University of Maryland School of Medicine, Baltimore, between 1983 and 1987. We analyzed temperature observations recorded during a 2½-day baseline period prior to oral immunization with attenuated *Shigella* vaccine.

Thermometry.—Oral temperatures were measured one to four prescribed times each day. The actual time points at which measurements were taken varied among the nine trials included in the analysis. All measurements were performed by specially trained nursing personnel using the Diatek 500 electronic thermometer (Diatek Inc, San Diego, Calif). The thermometer's covered probe was positioned in the sublingual pocket until the final display tone was heard. This electronic thermometer has a range of 32.2°C to 42.2°C (90°F to 108°F) and a steady-state error of 0.05°C to 0.07°C (0.09°F to 0.10°F) over the range of 33°C

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to 41°C (91.5°F to 105.8°F).[10] Subjects were instructed not to eat, drink, or smoke for 15 minutes prior to each temperature measurement.

Data Analysis.—Data were analyzed using the SAS-PC program on an IBM PS/2 model 80 computer. Because initial descriptive analyses suggested neither strong kurtosis nor skewness for the 700 temperatures, no data transformation was applied.

We used *t* tests to compare mean temperatures between groups (ie, smoking, sex, race). To examine the simultaneous effects of several demographic factors on temperature, we ran a general linear model in which the dependent variable was temperature; the independent factors included in the model were age, race, smoking, all two- and three-day interactions among the previous three factors, day within study, and time of day. In SAS notation, the model was defined as:

Temperature = Sex Race Smoking Age Time Day
Sex × Race Sex × Smoking Race × Smoking

Comparisons of variance in temperature between days were made using F tests. Linear regression analysis was used to study the effect of baseline temperature on pulse and the effect of age on baseline temperature. Analyses of oral temperature used individual temperature readings as variates; analyses of diurnal temperature oscillations used patient-days as variates.

Results

The 700 temperature recordings from the 148 subjects had a range of 35.6°C (96.0°F) to 38.2°C (100.8°F), overall mean of 36.8°C±0.4°C (98.2°F±0.7°F), median of 36.8°C (98.2°F), and mode of 36.7°C (98.0°F); 37°C (98.6°F) accounted for only 56 (8.0%) of the 700 oral temperature observations recorded (Fig 1). The mean temperature varied diurnally, with a 6 AM nadir and a 4 to 6 PM zenith (Fig 2). The maximum temperature (as reflected by the 99th percentile) varied from a low of 37.2°C (98.9°F) at 6 AM to a high of 37.7°C (99.9°F) at 4 PM. Comparison of initial temperature recordings obtained on admission to the research ward with ones obtained the same hour the day after admission revealed no significant difference in variability (F tests for individual studies, $P>.12$). Age did not significantly influence temperature within the age range 18 through 40 years (linear regression, $P=.99$).

Women had a slightly higher average oral temperature than men (36.9°C [98.4°F] vs 36.7°C [98.1°F], *t* test, $P<.001$, $df=698$) but did not exhibit a greater mean diurnal temperature oscillation than male counterparts (0.56°C [1.00°F] vs 0.54°C [0.97°F]). Black subjects exhibited a slightly higher mean temperature and a slightly lower average diurnal temperature oscillation than white subjects (36.8°C [98.2°F] vs 36.7°C [98.1°F] and 0.51°C [0.93°F] vs 0.61°C [1.09°F], respectively); these differences approached but did not quite reach statistical significance (*t* test, $P=.06$, $df=698$). Oral temperature recordings of smokers did not differ significantly from those of nonsmokers (data not shown). Statistical analysis using a general linear model, as described in the previous section, yielded results qualitatively identical to those reported above (sex, time of day, $P<.001$; race, $P=.05$; age, smoking, and interaction terms, $P\geq.26$).

There was a statistically significant linear relationship between temperature and pulse rate (regression analysis, $P<.001$), with an average increase in heart rate of 4.4 beats per minute for each 1°C rise in temperature (2.44 beats per minute for each 1°F rise in temperature) over the range of temperatures examined (35.6°C to 38.2°C [96.0°F to 100.8°F]).

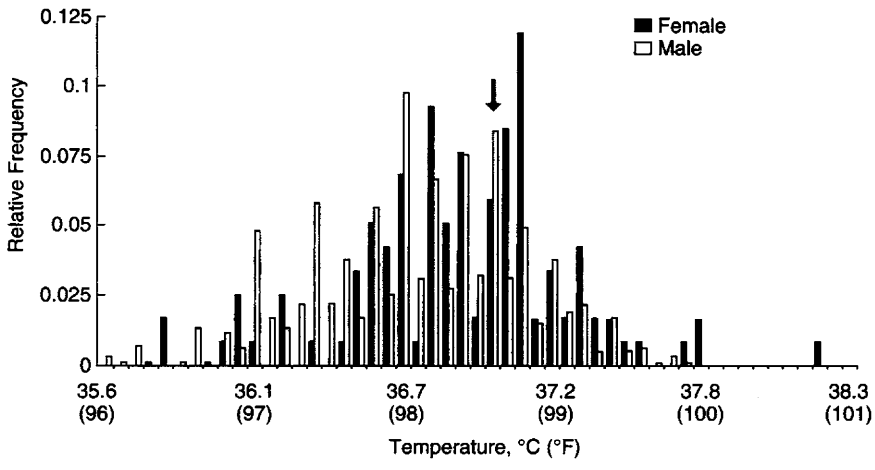

Fig 1.—Frequency distribution of 700 baseline oral temperatures obtained during two consecutive days of observation in 148 healthy young male and female volunteers. Arrow indicates location of 37.0°C (98.6°F).

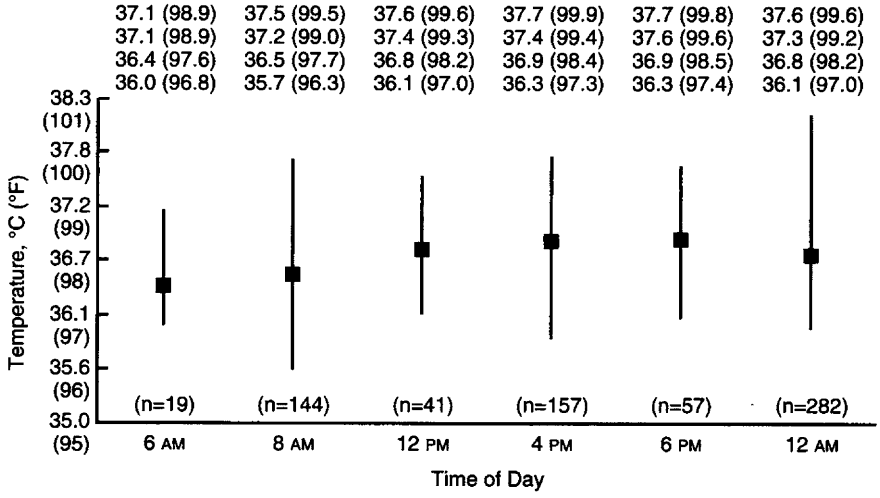

Fig 2.—Mean (solid squares) oral temperatures and temperature ranges according to time of day. The four temperatures shown at each sample time are the 99th percentile (top), 95th percentile (second from top), mean (second from bottom), and 5th percentile (bottom) for each sample set.

Comment

Thermometers used by Wunderlich were cumbersome, had to be read in situ,[11] and, when used for axillary measurements (Wunderlich's preferred site for monitoring body temperature), required 15 to 20 minutes to equilibrate.[12] Today's thermometers are smaller and more reliable and equilibrate more rapidly. In addition, the mouth and rectum have replaced the axilla as the preferred

sites for monitoring body temperature. Such differences provide at least a partial explanation for the discrepancies between our data and Wunderlich's. Whatever the full explanation, the differences between our findings and those reported by Wunderlich suggest that several of his observations may not apply to today's clinical setting.

According to Wunderlich, "when the organism (man) is in a normal condition, the general temperature of the body maintains itself at the physiologic point: 37°C=98.6°F."[3] Although several investigations since Wunderlich's have recorded mean temperatures of normal adult populations closer to 36.6°C (98.0°F),[1] Wunderlich's intimation that 37.0°C (98.6°F) is the most normal of temperatures persists to this day, not only in lay thinking but in medical writing as well.[13-17] The special significance accorded to 37.0°C (98.6°F) is perhaps best illustrated by the 1990 edition of *Stedman's Medical Dictionary*, which defines fever as "a bodily temperature above the normal of 98.6°F (37°C)."[17]

Our data suggest that 37.0°C (98.6°F) has no special significance vis-à-vis the body temperature of healthy adults when such temperature is measured orally using modern thermometers. In our study population, 37.0°C (98.6°F) was not the overall mean temperature, the mean temperature of any of the time periods studied, the median temperature, or the single most frequent temperature recorded. Furthermore, it did not fall within the 99.9% confidence limits for our sample mean (36.7°C to 36.8°C [98.1°F to 98.2°F]).

Wunderlich regarded 38.0°C (100.4°F) as the upper limit of the normal body temperature range and, by extrapolation, any temperature greater than 38.0°C (100.4°F) as fever.[3] Modern medical textbooks differ in their definition of the upper limit of the normal oral temperature. Published values include 37.1°C (98.8°F) and 38.0°C (100.4°F) in textbooks of physiology,[18,19] 37.2°C (99.0°F) in *Harrison's Principles of Internal Medicine*,[20] and 37.4°C (99.4°F) in a recently published monograph on fever.[21] As noted above, a widely used medical dictionary defines this same upper limit as 37.0°C (98.6°F).[17]

The source of the confusion over what constitutes the upper limit of the normal body temperature, we believe, derives from individual variability that limits the application of mean values derived from population studies to individual subjects and from the fact that the maximum oral temperature, like the mean temperature, exhibited by any population varies according to time of day. Because of such variability, no single temperature should be regarded as the upper limit of normal. In our study population, 37.2°C (98.9°F) was the maximum oral temperature (ie, the 99th percentile) recorded at 6 AM, whereas, at 4 PM, the maximum oral temperature observed reached 37.7°C (99.9°F). Thus, our data suggest that, when modern thermometers are used to monitor oral temperatures in young or middle-aged adults, fever is most appropriately defined as an early morning temperature of 37.2°C (99.0°F) or greater or an evening temperature of 37.8°C (100°F) or greater.

Wunderlich wrote that temperature "oscillates even in healthy persons according to time of day by 0.5°C=0.9°F."[3] He also wrote, "The lowest point is reached in the morning hours between two and eight, and the highest in the afternoon between four and nine."[4] Modern authorities have generally concurred with Wunderlich's observations on such matters.[14,20] However, Tauber[15] has recently suggested that the amplitude of diurnal variation might be as high as 1.0°C (1.8°F). Our observations are more consistent with Wunderlich's view. Nevertheless, our subjects exhibited considerable individual variability, with some having daily temperature oscillations as wide as 1.3°C (2.4°F) and others having oscillations as narrow as 0.05°C (0.1°F).

According to Wunderlich, women have slightly higher normal temperatures than men and often show greater and more sudden changes of temperature.[3] Dinarello and Wolff,[7] in a study of nine healthy young adults (six men and three women), corroborated both observations. In the present investigation we were able only to corroborate Wunderlich's former observation.

Wunderlich did not personally study the influence of race on body temperature. Instead, he deferred to the observation of "Livingstone, *Travels in South Africa*, p 509 [showing] temperatures of natives 1.8°C=2°F [sic] greater than his own."[3] In the present investigation there was a trend toward higher temperatures among black subjects than among white subjects, with the differences approaching statistical significance (t test, $P=.06$; general linear model, $P=.05$).

In view of the data presented and the work of several other investigators,[1] we believe that 37°C (98.6°F) should be abandoned as a concept having any particular significance for the normal body temperature. In the early morning, 37.2°C (98.9°C) and, overall, 37.7°C (99.9°F) should be regarded as the upper limits of the oral temperature of healthy adults 40 years of age or younger, and several of Wunderlich's other cherished dictums should be revised.

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