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An Exploration and Reconsideration of Normal Body Temperature in Healthy Adults

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AN EXPLORATION AND RECONSIDERATION OF NORMAL BODY TEMPERATURE IN HEALTHY ADULTS

BY

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DISSERTATION

Submitted in Partial Fulfillment of the
Requirements for the Degree of

Doctor of Philosophy

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The University of New Mexico
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DEDICATION

This dissertation is dedicated to my parents, Bob and Harriet Jones, my sister, Betty Jones, my children, Jennifer Kelley and Molly Mayo, and my dear friend, Peg Wangensteen. Without you, none of this would have been possible.

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ABSTRACT

The human body temperature generally considered normal by medical professionals and the lay public and believed to be an important referent in diagnosing illness and determining its severity is 98.6^0 Fahrenheit (F). The initial work establishing 98.6^0 F published over 140 years ago may be flawed; and, even if correct, may not reflect the present normal body temperature. To investigate mean body temperature in adults ages 21-100 who regarded themselves as “well,” an observational descriptive study was undertaken to measure body temperature using two commonly used measurement methods, oral and tympanic. 1000 adults comprised the non probability non randomized sample and were drawn from four metropolitan areas, 250 from each: Portland, OR, Minneapolis/St Paul, MN, Hartford, CT, and Albuquerque, NM. Temperatures were taken from 8 AM – 8 PM. Data on covariates as suggested from extant literature were collected. The mean oral temperature was 98.3^0F. The mean tympanic temperature was 97.9^0F. Both means were statistically different from 98.6^0F ($p < .001$). There was only moderate correlation between thermometer measurement methods (R^2 .35). Multiple regression analysis identified age, gender, and time of day temperature was taken as statistically significant covariates ($p < .001$ for all), but together they accounted for less than 18% of the variance regardless of measurement method. Public health implications are discussed. The referent of 98.6^0F should be replaced with 98.2^0F for most adults in evaluating oral temperature. When tympanic measurements are taken, a lower "normal" of 97.9^0F should be considered.

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CHAPTER 1

INTRODUCTION

Purpose

The purpose of this research is to determine the “average” or “normal” body temperature of healthy adults. These terms are used interchangeably in common usage and are understood to refer to human body temperature of 98.6^0 Fahrenheit (F), 37^0 Celsius (C). Although circadian rhythms affect temperature, 98.6^0F continues to be thought of as “normal” temperature (Fauci, et al., 2008). The original work establishing 98.6^0F was done over 100 years ago using instruments not calibrated to today’s standards, and in addition, many physiologic parameters have changed over that length of time. Anecdotal observation as well as published reports suggests normal body temperature is lower than 98.6^0F. It is hypothesized that human body temperature is not 98.6^0F, and further, that it is lower.

This chapter will present the history of the development of human body temperature measurement in order to understand the context from which 98.6^0 F came to be determined as normal body temperature. Past perspectives regarding evaluation of body temperature, the development of the clinical thermometer, and the work leading to the conclusion that 98.6^0 F is normal body temperature are discussed.

History of Assessment and Understanding of Body Temperature

From the earliest known times body temperature has been regarded as a measure of health or illness. The first written references to body temperature date from the sixth century BCE and are found in Akkabian cuneiform inscriptions (Mackowiak, 1998b). Detailed accounts of illness in the fifth century BCE include references to "fever" and although fever was not defined, it was generally understood to be an abnormal and elevated body temperature. Many of these accounts were collected in the Hippocratic *Corpus* (Castiglioni, 1947; McGrew, 1985; Smith, 1981).

The *Corpus,* also called the *Cannon,* is a collection of approximately 70 early medical texts. Attributed to Hippocrates and others, the accounts were compiled from multiple sources and collected in the Alexandrian Library in the third century BCE (Castiglioni, 1947; Mackowiak, 1998a; Smith, 1981). The seven part *Epidemics* (*epidemiae* means visits to cities), part of the *Corpus,* include many references to fever: "People in fevers whose urine is disordered like a mule's have headaches or will get them…. Philistis, wife of Heraclides, began to have acute fever….About the fourth day a burning fever developed…" (Smith, 1981, pp. 8, 17).

Fever was attributed to an excess of yellow bile – one of the four humors of blood, phlegm, black bile and yellow bile. Elevations in temperature were observed by patient presentation – sweating, shivering, and flushing – and by evaluating skin warmth with touch (Castiglioni, 1947; McGrew, 1985; Smith, 1981). Although not specifically proscriptive, the detailed observations and descriptions of illness contained in the Hippocratic *Corpus* influenced the practice of medicine through the second century CE.

Galen of Pergamum, born around 129 CE (various dates are given), was strongly influenced by *Corpus.* Trained as a philosopher, mathematician, and physician and later called "The Father of Medicine," he was drawn to scientific principles of observation reflected in the *Corpus*. Galen strongly supported the use of the *Corpus* as a guiding template for medical observation and used it as a basis for many of his works including *De febrium differentiis* (Galen, National Library of Medicine [NLM], n. d.; Smith, 1981). Fever continued to be attributed to an excess of yellow bile, and imbalances in the four humors continued to be regarded as the sources for disease.

In addition to Galen, the Iranian Abu Ali al-shaykh al-Rais, also called Avicenna, was also influenced by the *Corpus.* Considered the dominant medical scholar of the Medieval Ages (Ibn Sina, n. d.), his publication *Kitab al Qunoun fi Al Toubb* (The Book of the Canon of Medicine) was written circa 1020. A 1593 copy published in Rome by the Medical Press still exists. In it, Ibn Sina emphasized the need to identify the causes of disease and ill health as well as to identify characteristic and diagnostic symptoms. He also offered an important definition of fever that demonstrates recognition of the importance of elevated body temperature:

> Fever is extraneous heat, kindled in the heart from which it is diffused to the whole body through the arteries and veins, by means of the spirit and the blood, reaching a heat in the body itself which is sufficient to injure natural functions.
>
> Smith, 1981, p 21

Galen's observations and extensive writings combined with those of Abu Ali al-shaykh al-Rais, called "Prince of Medicine" and "Prince of Physicians," formed the basis of assessment and treatment for alterations in health states (Avicenna, n. d.; Ibn Sina, n. d.) and significantly influenced concepts regarding fever and the practice of medicine for the next several centuries. Despite rapid advances in the natural sciences and in medicine that occurred beginning in the late 16^{th} century, fever remained an entirely subjective matter until the invention and later, the widespread use, of clinical thermometers (Ackernecht, 1968; McGrew, 1985; Mackowiak, 1998b).

Development of Temperature Measurement Devices

Although there are reports of very early attempts to measure body temperature by placing stones on a febrile person, no measurement devices for any sort of temperature determination were available until the late 1500s. Galileo Galilei and Santorio Santorio, colleagues at the University of Padua, are both credited with the invention of temperature measurement devices called thermoscopes. They did not measure temperature *per se* but could indicate differences between temperatures. However, since they were unsealed they were sensitive to fluctuations in air pressure (McGrew, 1985; Ring, 2006, 2007).

Santorio, in 1612, is credited as being the first to recognize that the human body has a normal temperature and that temperature could be followed in the course of a disease. He was also the first to apply a scale to his thermoscope. The term "thermometer" first appeared in his 1624 publication, *Recreation Mathematique*, and commented on the function of the instrument as useful to "test the intensity of the fever" (Mackowiak, 1997, p. 5). The first sealed thermometer was not invented until 1654 by the Grand Duke of Tuscany, Ferdinand II, who is credited with first sealed liquid-in-glass instrument (alcohol) (Mackowiak, 1994; Ring, 1998, 2007).

It was not until 1714, over 100 years since the inception of the thermoscope, that Gabriel Fahrenheit invented the mercury-in-glass thermometer, and later in 1724, calibrated it using the highest and lowest temperatures he could achieve in his laboratory – the freezing and boiling points of water - and specified them as 32 and 212 degrees respectively. Celsius, in 1742, also using the mercury-in-glass thermometer, devised another scale that used as referents 0 and 100 degrees for the freezing and boiling points of water. From the beginning, both the Fahrenheit and Celsius scales were used in common practice, a convention that continues to this day (McGrew, 1985; Mackowiak, 1997, 1998a, b; Ring, 2006).

Early Use of Thermometers

The presumption that thermometers might be useful in clinical practice was not, at first, widely held. Robert Boyle, in 1683, is quoted as complaining that the thermometer was "a work of needless curiosity or superfluous diligence" and held that determining temperature by touch was sufficient (McGrew, 1985). Other scientists disagreed and although thermometers were not in widespread use during the mid and late 1700s, those who did begin using them found them valuable and made observations about fever and other observed physiology.

Boerhaave, in his 581st Aphorism observes, "Velocior cordis contractio, cum aucta resistentia ad capillaria, febris omnis acutae ideum adsolvit" [An increase in the rapidity of the heart's contraction, and as increased resistance of the capillaries, complete our idea of every acute fever.] (Wunderlich, 1868, Woodman Translation, 1871, p. 20).

Boerhaave's student, Von Swielen, describes the use of a thermometer in *Commentaries on Boerhaave's Aphorisms* (1745),

> Omnium ergo certissima mensura habetur per thermoscopia, quualia pulcherrima habentur, et portalia quidem, fahrenheitiana dicta a primo inventore: accuratissima, imprimis illa sunt, quae argentums vivem loco alterius eujuscunque liquidi continent. Tali thermometro, prius mensuratur calor hominis sani, et plerumque in indice affexio ille gradus notatus est; deinde hoc cognito, si idem

> thermometrum a febricitante aegro manu teneatur, velbulbus ejus ori immittatur, vel nudo pectori aut sub axillis applicetur per aliquot minuta horae, apparebit pro varia altitudine ascendentis argenti vivi, quantum calor febrilis excedat naturalem et sanum calorem. [By far the most accurate measurements of heat are by thermometers, which are now to be had both elegant and portable, and are called after Fahrenheit, the first inventor of them. Those which contain quicksilver instead of other fluids are the most accurate. When such a thermometer, first used on a healthy man, and marked accordingly on the scale, is either held in the hand of a fever patient, or the bulb placed in his mouth, or laid on his bare chest, or in his axilla, for some minutes, the assent of the mercury to different elevations will show how far the fever exceed the natural and healthy.]
>
> Wunderlich, 1868, Woodman Translation, 1871, p. 21

Another famous student of Boerhaave, Anton de Haen (1704-1776) is credited as introducing thermometry in the practice and teaching of medicine. He published a number of observations around 1760 that were later criticized by Wunderlich. "His method of thermometry was very peculiar, because he was accustomed to leave the instrument seven and a half minutes in situ, and then add 1^0 or 2^0 F. to the temperature registered, because he had found that the mercury would rise as much if left longer" (Wunderlich, 1868, Woodman Translation, 1871, p.22).

An important work by James Currie appeared in 1797. Titled *Medical Reports on the effect of water, cold and warm, as a remedy in fever and other diseases*, it included systematic temperature measurements and documented the effects of warm and cold baths, digitalis, opium, alcohol, and restricted diet on temperature. Although it was favorably reviewed it was not influential, perhaps because of a stilted translation into German. It was not until mercury-in-glass instruments became somewhat more available the early 1800s that thermometers began to be written about as being used in clinical practice (Wunderlich, 1868, Woodman Translation, 1871).

There were a number of publications documenting temperatures in humans and animals in the early 1800. In 1842, another systematic investigation of temperature in health and disease was published by Gierse, an important treatise was authored by John Davy of England, and in 1850-51, two Germans are credited with initiating a new phase in medical thermometry. Barensprung conducted a series of observations praised as comprehensive, well-constructed, and complete. Traube's work focused on the practical use of the thermometer in defining disease. Unfortunately, neither attracted much notice. However, their work attracted the attention of one Carl Reinhold August Wunderlich, a professor at the University of Leipzig, St James University Hospital. His seminal work was to influence ideas about body temperature for over the next 140 years (Wunderlich, 1868, Woodman Translation, 1871; Wunderlich & Seguin, 1871).

The Work of Wunderlich

Carl Reinhold August Wunderlich (1815-1877), published his groundbreaking work, *Das Verhalten der Eigenwarme in Krankenheiten* (*Medical Thermometry and Human Temperature*), in 1868, with a second edition following in the same year. *Das Verhalten der Eigenwarme in Krankenheiten* was translated in an abridged version into English by the American Edward Seguin (to whom it was dedicated) from the first German edition published in Leipzig, by Wigand Publishers (1868), and in its entirety by British physician W. Bathurst Woodman (1871) from the second edition, also 1868.

Woodman translates the title as *On the Temperature in Diseases: A Manual of Medical Thermometry*. The Woodman translation contains considerably more detail and he translates directly from the original without the frequent comments Seguin includes regarding his own research. Both translations will be referenced in the following discussion.

Wunderlich (Wunderlich & Seguin, 1871) himself tells us when he began using thermometers: “Ever since October 1851, I myself, induced by Traube’s spoken recommendations, have introduced the use of the thermometer in my clinic” (p. 9). He credits Taube for having observed that temperature rises in advanced age, that body temperature is influenced by external temperature and by exercise, that there is diurnal variation in temperature, and that temperature is elevated during concentration, alimentation and seasickness (p. 7). His research, conducted over sixteen years, supported most of Traube’s findings.

Wunderlich primarily used axillary temperature measurements; however rectal, vaginal, bladder, surgical incision sites, and oral temperatures are also reported (Wunderlich & Seguin, 1871). Temperatures were measured in patients who presented to his Leipzig clinic and who were hospitalized or attended at home in Leipzig. Temperatures were taken by him and by numerous assistants, some of whom are thanked by name in the Preface to the first edition. Interestingly, Wunderlich was involved with the separation and improvement of facilities for psychiatric patients, and published *Pathology and Therapy of Illnesses of the Nervous System* in 1864. It seems reasonable to speculate that many of the patients he saw were psychiatric patients.

In any case, Wunderlich conducted an extensive study of measured temperature ranges. He was convinced (and convincing) that there was value in temperature measurement and that it was an essential consideration for the medical practitioner:

> In actual every-day life there are numerous occasions on which it is necessary, or at least desirable, to ascertain whether a particular person is really ill, or at least indisposed. Taking the temperature, when it shows a deviation from the normal, is one of the most rapid means of ascertaining some disturbance in the economy.
>
> Wunderlich, 1868, Woodman Translation, 1871, p. 53

He extensively detailed the febrile course of many diseases: smallpox, measles, scarlatina, rubeolae, erysipelas, remittent fever, pneumonia, meningitis, pleurisy, lues, ganders and farcy, tuberculosis, cholera, trichinosis, tetanus, yellow fever, and many others (Wunderlich, 1868, Woodman, 1871). This remarkable data reflected the spirit of analysis and observation characteristic of the 1800s (Bynum & Nutton, 1981; Smith, 1981).

Prior to publication of *Das Verhalten der Eigenwarme in Krankenheiten*, temperature elevation was regarded as an illness *per se*. Hudson's *Lectures on the Study of Fevers* (1869), emphasized accuracy in measurement in that fever was "considered as an essential disease" (p. 162). Wunderlich's work was particularly groundbreaking in that he came to regard temperature elevation as a condition associated with an illness: "Then the question immediately occurs – what importance ought we to attach to the general condition of the system? And further, what are the general processes which are connected with the temperature?" (Wunderlich, 1868, Woodman Translation, 1871, p. 168).

While some aspects of his methodology are described in *Das Verhalten der Eigenwarme in Krankenheiten,* Wunderlich did not discuss his selection process, nor is much raw data presented although he reports that over 25,000 patients were included in over one million measurements. The only known original data is found in the Woodman translation (1871) and includes several temperature graphs from individual patients. There do not appear to be other surviving records of the data (P. Mackowiak, personal communication, September 10, 2007).

Temperature elevation was determined by comparison with the “average normal temperature of the healthy human body” measured in “the well-closed axilla” as 98.6^0 Fahr. “and a few tenths of a degree higher ($.5^0$-1 $½^0$ or 2^0 Fahr., $.7^0$ Fahr. average) in the rectum and vagina” (Wunderlich, 1868, Woodman Translation, 1871, p. 1). The Seguin translation is slightly different: “The average temperature taken at the axilla or any other artificial cavity is 98.6^0 F. $=37^0$ C; and higher by some tenth of a degree in the natural cavities” (p. 11).

The types of thermometers used by Wunderlich were “non- registering” – that is, they had to be read *in situ*. One of the thermometers believed to have been used for his measurements resides in the Mutter Museum in Philadelphia. Measured at 22.5 centimeters (8.9 inches), it required 20 minutes for temperature registration. Wunderlich, in Seguin, 1871, writes, “if the time be precious, the bulb may previously be heated, to about the expected heat, and then inserted, when three or five minutes will be enough for a correct estimate” (p. 27). When this instrument was compared with present-day thermometers calibrated by the National Bureau of Standards, it registered from 2.9 - 3.2^0F *higher* than the standardized thermometers. When compared with “four other 19^{th}-

century thermometers of similar design" (Mackowiak, 2001, p. 8), it also registered from 2.6 - 4^0F *higher* than those thermometers. And, it is important to note that Wunderlich reported primarily axillary temperatures.

Wunderlich also established what continues to be the accepted definition of fever – 100.4^0F (38^0C) (Boulant, 2001; Kistemaker, Den Hartog, & Daanen, 2006). He reports a number of temperatures in the 104-107^0F range, and several temperatures as high as110.7^0F (Wunderlich, 1868, Woodman Translation, 1871, pp. 326, 390). He does not specify the site of measurement in these extraordinarily high temperatures. Most thermometers in present-day use cannot measure any temperatures >107.6^0F (42^0C).

Wunderlich's data, when subjected to modern scientific rigor, is problematic: thermometers in use in the 1800s were not calibrated to today's standards; the sites of Wunderlich's temperature measurements are varied and unspecified; the study population, although apparently numbering over 25,000, is not defined and included both adults and children. Additionally, Mackowiak (2001) speculates that Wunderlich could not possibly have seen all of the data collected and that it was almost certainly not subjected to statistical analysis (1992; 1995). Despite these limitations, *Das Verhalten der Eigenwarme in Krankenheiten* has remained influential. 98.6^0 F has become fixed in our collective consciousness as normal body temperature.

Development of Clinical Thermometers

Ring (2006) claims that Wunderlich developed his own thermometer, however supporting primary source data is lacking. Edward Seguin (1871), American translator of *Das Verhalten der Eigenwarme in Krankenheiten*, did develop his own clinical thermometer and specifically differentiated between thermometers generally and *clinical* thermometers. His own thermometer assumed a normal temperature of 98.6^0 F (37^0C), looked for variance from normal temperature, and designated 0 – normal - as the referent.

Axillary temperatures were the preferred route for measurement through the 1800s. Specific instruction on the correct methodology for thermometer use in taking axillary temperatures is detailed in Hudson's *Lectures on the Study of Fevers* (1869). There is similar instruction in Wilson's *Fever Nursing: Designed for the Use of Professional and Other Nurses and Especially as a Textbook for Nurses in Training*, published in 1896.

Most thermometers available in the mid and late 1800 were made in England and were calibrated in fifths of a degree F. The measurement range was generally 90^0-115^0 F and they varied in length from 5-10 inches. It was advised that they be carried "upside down in the pocket" and compared with a "standard" thermometer (one owned by a metrological or philosophical society), once a year (Wunderlich, 1868, Woodman Translation, 1871, pp. 62 – 64).

As the importance of temperature measurement gained professional and public recognition, the use of mercury-in-glass thermometers became more widespread. Oral and rectal routes eventually became more commonly used because they required less time to register temperature, and oral temperatures did not require undressing. Mercury-in-glass thermometers remained the most commonly used until the 1990s when digital technology came into use after a number of years in development. According to the US Patent Office (n. d.), the earliest application for a digital thermometer was in June, 1955, and the patent for the first digital thermometer used in clinical practice was filed in 1990.

The technology for thermal temperature strips was developed in the 1960s and "temp a dots" are still occasionally used to monitor temperature in children. According to the manufacturer, their accuracy is dependent on ambient air temperature and dry skin. Interestingly, one of the latest technologies, the temporal artery thermometer, measures heat from the temporal artery in much the same location as the thermal strip thermometer (Chan, Kung, Lam, & Yip, 1995; Kistemaker, Hartog, & Daanen, 2006; Pompei, 1999). All of the aforementioned devices measure temperature by conduction (Kurazumi, Tschikawa, Matsubara, & Horikoshi, 2004; Ring, 2006).

Temperature can also be measured by infra red technology. The tympanic thermometer uses infra red technology to measure heat reflected from the tympanic membrane. Blood supplying the tympanic membrane was assumed to share the same thermodynamic heat properties as the internal carotid artery; however, critics point out that other more superficial arteries also supplying the ear may play a part in reducing tympanic temperature to that below the core temperature. Ear anatomy and cerumen may also affect infra red sensing (Heusch, Suresh, & McCarthy, 2006; Pusnik & Drnovsek, 2005). Other infra red sensing devices are in use and the technology is advancing rapidly.

Mass screening using infra red instruments has been used recently in airports to detect fever and possible infection with SARS and bird flu (Ng, Kaw, & Chang, 2004). Passengers stand in front of a screening device and the temperature of the inner corner of the eye is measured. Parameters for further evaluation of a passenger are determined by a formula that assumes a lower skin temperature than body temperature. It is interesting that the authors explicitly state: "the skin temperature is lower than the normal 37^0C body temperature…" (p. 106). And conclude, "For the maximum eye region temperature to detect an adult aural temperature of 37.7^0C and above, a threshold temperature is selected and this allows for sensitivity of 85.4% and a specificity of 95%" (p. 108). It is interesting to note that important public health measures with potentially global implications are instituted under the assumption that "normal" body temperature is 98.6^0F.

The newest technology has been developed by the National Space and Aeronautical Agency (NASA) and Johns Hopkins University. Measurement of astronaut temperature has been a research parameter since the first orbital space flight of John Glenn. The "Results of the Second U.S. Manned Orbital Space Flight, May 24, 1962" includes a record of Scott Carpenter's vital signs pre launch and during flight and re entry. It is interesting to note that his core temperature (rectal) was 96.8^0F at the beginning of countdown, and was 98^0F at launch. Currently astronauts have their temperatures measured by an "ingestible" thermometer pill approximately the size of a penny. The readings are received and recorded by a remote control device. This technology is also being used by professional sports teams to monitor for hyperthermia during hot and humid workouts (NASA, n.d.).

The accuracy of devices that do not measure temperature by conduction has been questioned. Daanen (2006) compared tympanic and oral temperatures with esophageal temperatures (considered core temperatures) under several environmental conditions and found on average tympanic and oral measurements were $.7^0$F lower than core temperature. However, tympanic and oral measurements were more concordant with each other, differing by $.4^0$F. Others (Kosaka, et al., 2004; Knies, 2007; Lien 2003; Moore, Watts, Hood, & Burritt, 1999) have reported lower than core temperature readings for both thermometer types.

Discordant temperatures between conduction measurement devices and infra red devices are also reported in the sports physiology literature. Roth, Verdile, Grollman, and Stone (1996) concluded that tympanic thermometers significantly underestimated body temperature in marathon runners when compared with rectal temperatures. More recently, Ronneberg, Roberts, McBean, and Center (2008) reached the same conclusion using the temporal artery thermometer as compared with the rectal thermometer in collapsed marathon runners.

Clinical thermometers have changed considerably since their evolution from thermoscopes. While Wunderlich and others marveled at the accuracy of the instruments available to them, they could not have imagined the technology now available to the scientific community. But, regardless of whatever clinical thermometer type is used, there has always been a referent that defines “normal,” and elevations and depressions from that value have almost always been viewed in a clinical context.

Summary

Wunderlich presented 98.6^{0}F as an average number that represented the average of axillary and other temperatures from a population about which we know little as no raw data is known to be preserved. And, although a range is presented, he repeatedly referred to 98.6^{0}F as *normal* temperature, not as *average* temperature. This paper will use *normal* in the same manner as did Wunderlich – as a population average - and in the way it is employed in common usage; that is, 98.6^{0}F represents the expected temperature of an adult (an individual 21 years of age or older) when measured by a thermometer commonly in use – now, tympanic or digital – by a tympanic or oral route.

The work of Wunderlich and others represented remarkable advances in scientific observation. However, the methodology and conclusions of that time do not stand up well to scrutiny in the 21st century and the widespread belief that 98.6^0F is a referent that potentially divides health and illness may be incorrect.

CHAPTER 2

HUMAN BODY TEMPERATURE:

REGULATION AND IMPLICATIONS FOR RESEARCH

As scientific knowledge has increased, physiologic mechanisms are better elucidated and understood. This chapter will present the physiology of temperature regulation and will discuss implications for research.

Temperature Regulation

Temperature maintenance and regulation involve a complicated series of sensing and feedback loops that continually receive and send information. No single neural area is in command of body temperature. Some texts report that the hypothalamus controls body temperature, but this is a simplification. According to Boulant (2001), "…thermoregulation is controlled by a continuum of neural structures and connections extending from the hypothalamus and limbic system to the lower brainstem and reticular formation, to the spinal cord, and to the sympathetic ganglia" (p. 41). The preoptic region of the brain including the medial and lateral aspects of the preoptic area and the anterior and septal hypothalamus are very sensitive to temperature change and can initiate heat retention and heat dissipation (Boulant; Mackowiak, 1998a). Thermoregulatory mechanisms are part of a "phylogenetically ancient" network that maintains body temperature within a very narrow range (Buse, & Werner, 1985; Egan, et al., p. 5267).

Normal Temperature

In mammals, normal body temperature is maintained within certain limits that are genetically determined and are called set points. When temperature sensed in the preoptic region falls outside of the acceptable set point range, physiological mechanisms are activated to return temperature to genetically encoded set point parameters. Under normal conditions heat production and heat elimination are balanced (Pembrey, 1998).

Heat is continually produced by catabolism. Mitochondria convert adenosine diphosphate (ADP) to adenosine triphosphate (ATP) via oxidative phosphorylation, a heat producing process. The ATP molecule, in its cellular work, generates additional heat. Heat is also generated by catecholamines and hormones. Heat is dissipated by conduction, convection, radiation, and evaporation, and cutaneous circulation (vaso dilation). It is conserved by cutaneous circulation (vaso constriction), shivering, and non-shivering thermogenesis associated with brown adipose tissue. These on-going processes maintain temperature within genetically set set-points almost without conscious awareness until the balance is lost or the set point altered. There is normal diurnal variation in temperature corresponding to the sleep-wake cycle reflecting mitochondrial activity (Boulant, 2001; Brown, Choe, & Luithard, 2000; Cevoli, et al. 2002; Monk, & Carrier, 1998; Moore, Watts, Hood, & Burritt, 1999).

Failure of Regulatory Mechanisms

When temperatures drop below or exceed set point limits due to *thermoregulatory failure,* metabolic processes are compromised. Temperature reduction has been used therapeutically to decrease metabolic activity in heart surgery, spinal cord injury, and cardiac arrest and victims of drowning are reported to have survived prolonged immersion in very cold water (Van Dorn, 2000; Xu, Bergland, Cheuvront, Endrusick, & Kolka, 2004). However, below a certain temperature, metabolic derangement is irreversible and death ensues. Temperature elevations in which the body cannot compensate for environmental conditions, usually a combination of heat and humidity, can also be fatal. The deaths of athletes working out or competing in very hot conditions and of people unable to get to cool locations during heat waves are regularly reported. These conditions are not the result of a new temperature set point, but rather an inability of the body to regulate temperature in response to environmental stress. They are correctly called hyperthermia and hypothermia (Fujishima, et al, 2001; Goldstein, Dewhirst, Repacholi, & Kheifets, 2003).

Change in Thermoregulatory Set Point

When temperature set point is elevated in response to pyrogens it is called a fever (Cooper, 1971, 1995). Mackowiak (1998b) defines fever as "a pyrogen-mediated rise in body temperature above the normal range" (p. 1871) but points out that temperature elevation is only one component of the febrile response. While not fully understood, it is thought that exogenous pyrogens such as virus, bacteria, prions, and others, induce endogenous pyrogens such as Interleukin (IL-1, IL-1a, IL-1b, IL-6), tumor necrosis factor alpha, and interferon gamma, to elevate temperature set point by the inhibition of sensitive neurons (Boulant, 2001; Mackowiak, 1998a). IL-1 appears to increase prostaglandin. Antipyretic substances such as aspirin, indomethacin, and ibuprofen block prostaglandin and are effective in lowering temperature. Other endogenous substances, including hormones, may act as endogenous pyrogens and may also elevate set point. An example is the slight temperature elevation during the luteal phase of the menstrual cycle.

Fever

Fevers rarely exceed core temperatures of 105.8^0F (41^0C) and most thermometers currently in use cannot measure any temperatures >107.6^0F (42^0C). This is particularly interesting in that Wunderlich reports a number of axillary temperatures in the $106\text{-}108^0$F in range in Typhus (Wunderlich & Seguin, 1871), and the *New Orleans Medical and Surgical Journal of September, 1878*, reports an axillary temperature of 115^0F taken 15 minutes before death that was verified with two thermometers (*British Medical Journal*, November 16, 1878).

Low Body Temperature

Low body temperatures are less studied although they are known to be "sub normal" in hypothyroidism and severe sepsis. In sepsis, it is unclear whether thermoregulation establishes a new low set point, or whether compensatory thermoregulatory mechanisms fail. In any case, thermoregulation is thought to be lost as a result of multiple organ failure and is an ominous sign. In hypothyroidism, a lower set point is established (Gentilello & Moujaes, 1995; Harding & Goode, 2003). Interestingly, at the time 98.6^0F was established as normal, axillary temperatures less than 96.8^0F (36^0C) were called "collapse" temperatures by both Wunderlich and Seguin (1871).

There is increasing interest in possible benefit associated with induced hypothermia. Marion and Bullock (2009) review recommendations for induced hypothermia and clarify recommended therapeutic ranges. They conclude that hypothermia of $32\text{-}33^0$ C for 24-48 hours is safe and beneficial in cardiac arrest, but the benefit is uncertain in traumatic brain injury. Polderman and Herold (2009) agree and but also conclude that hypothermia of 30^0 C or greater is safe and effective for fever management in brain-injured patients regardless of fever etiology.

Implications for Research

A number of current sources continue to cite 98.6^0F as normal temperature and a temperature of 100.4^0F and higher as fever. Yet, as previously discussed, although it is understood that normal body temperature represents a diurnal range, 98.6^0F remains a synonym for "normal" temperature in lay and scientific literature.

Respiratory Therapists are reminded that 37^0C is normal temperature (Wagner, Beckett, & Steinberg, 2006). Firemen in training are instructed to evaluate for temperatures that are not normal, 37^0C (Jaslow, 2008). Wright, Hull, and Czeiler (2002), studying the relationship between alertness, performance, and body temperature, state,"… we raised subjects' body temperature from the normal of 37^0C…" (p. R1357). In these instances, "normal" generally has little clinical relevance. However, other studies that assume 37^0C to be normal have considerably more consequence.

The most commonly used method for determining of time of death, *algor mortis*, body cooling, is based on body temperature taken in the rectum or the liver. Several formulas use calculations in which an assumed heat loss of 1.5^0C per hour is subtracted from 37.5^0C to arrive at a presumed time of death (Mann, Bass, & Meadows, 1990). A normogram devised by Henssge (1988) corrects for environmental temperature and assumes a normal temperature of 37.2^0C at death. Baccino, et al, (1996), comparing cadaver rectal core temperatures with tympanic measurement assumed a temperature at death to be 37^0C.

As previously mentioned, temperature screening has been used for mass screenings in airports to detect fever and possible infection with SARS and bird flu (Ng, Kaw, & Chang, 2004). Parameters for further evaluation of a passenger are determined by a formula that assumes a lower skin temperature than body temperature and the authors explicitly state: “the skin temperature is lower than the normal 37^0C body temperature…” (p. 106). Design of a micro-climate for astronauts is predicated on an assumed temperature of 37^0C (Koscheyev, Coca,, Leon, & Dancisak, 2002; Murakami, 2004).

Current protocols for cooling and re warming patients during open heart surgery are team specific and are dependent on the skill of the surgeon, perfusionist, and anesthetist. Tindall, Peletier, Severns, Veldman and de Mol (2008) have devised a mathematical model to guide therapeutic hypothermia. Their highly complex model assumes a body temperature of 37^0C at the start of cooling and 37^0C is the target for re warming.

Despite these assumptions, other reports suggest that body temperature may be lower. In a study of swimming performance, Martin, Neville and Thompson, (2007) found the average morning temperature in a coed group of swimmers (N=16) to be 35.14^0C: the evening temperature 36.73^0C. At Westfield State College (Biology, 1998-200), Professor Buzz Hoagland had his summer biology students participate in temperature evaluation research that is available on line. The temperatures were taken with oral thermometers and recorded every 15 minutes from 8:15 PM to 10 PM. The average evening temperature of 41 students was 36.6^0C.

As early as 1950, Horwath, Menduke, and Piersolto, published findings that oral temperatures varied between 97.8^{0}F and 98.2^{0}F. Dinarello and Wolff (1978), in a small sample of young men (N=9), found an average oral temperature of 97.9^{0}F. In 1991, Mackowiak, Wassermann, and Levine monitored the oral temperatures of 148 healthy men and women ages 18-40 and found that 98.6^{0}F was neither "the mean, the median, nor mode temperature and accounted for only 8% of the observations recorded" (p. 6).

Sund-Levander, Forsberg and Wahren (2002), conducted a systematic review of articles related to body temperature indexed in CINAHL and MEDLINE from 1935 to 1999 and manually searched reference lists from those articles. They state, "Although there is a general acceptance of normal body temperature as a range rather than a fixed value today, there is a widespread confusion concerning the definition of normal body temperature in adults" (p. 122). Their aim was to "investigate the range of normal oral, rectal, tympanic and axillary body temperature related to gender in health men and women" (p. 122). They included for review only articles that had clearly described study populations, and had descriptions of thermometer types and calibration data. They conclude from summarizing studies with strong or fairly strong evidence reported ranges as follows: oral 33.2-28.2^{0}C: rectal 34.4-37.8^{0}C: tympanic 35.4-37.8^{0}C: axillary 35.5-37.0^{0}C. They found slight differences between men and women. They were: men oral 35.7-37.7^0: women oral 33.2-38.1^{0}C: men rectal 36.7-37.5: women rectal 36.8-37.1: men tympanic 35.5-37.5: women tympanic 35.7-37.5. They conclude, "…the ranges of body temperature need to be adjusted, especially for the lower values" (p. 126).

There are other reasons to question whether 98.6^{0}F represents normal temperature in the 21st Century. Both physiology and environment have changed (Bogin & Rios, 2003; Hoppe, 1997; Wells, 2000; Yasukouchi, 2005). The *Albuquerque Journal*, July 16, 2007 reports a University of Michigan study that finds European men are, on average, 5.5 inches taller now than in the 1800s. We are heavier. The average daily calorie *consumption* in England in 1850 was 2525 calories (Allen, 2005) compared with approximately the same number now; however, the average calorie *requiremen*t, based on activity and metabolic requirements for a male in 1850 was approximately 3300 calories. There is data that correlates temperature with body weight and size (Hibino, Nadamoto, Fujisawa, & Fushiki, 2003; Holmback, et al., 2003; Fidanza, 2003). Onset of puberty is earlier for both males and females. Life expectancy has dramatically lengthened in the last 150 years (Berent, 2005; Brooks, 1966; Floud, 1994).

Ongoing Questions

If 98.6^0F is truly normal temperature, why do people report chills, shivering, and feeling ill when their temperature is “normal” or “sub normal”? Based on what is known about thermoregulation, these compensatory mechanisms for heat conservation should not be engaged until the body is trying to reach a new set point, or has a “fever,” in the range of $100+^0$F.

Maximum body temperature in fever as measured by “core temperature,” is now reported to be at the highest 107.6^0F. If this is so, how were axillary temperatures of 106^0F and higher measured? An oral temperature will be higher than an axillary temperature and a core temperature is higher yet. And, as previously mentioned, Mackowiak (1998a, b) describes the difference observed between the calibration of Wunderlich’s thermometers and those calibrated to today’s standards. A temperature of 98.6^0F recorded prior to 1868 could register anywhere from 94.6-96^0F on today’s thermometers. Considering all these things, it is reasonable to theorize that normal body temperature is lower than 98.6^{0}F.

The persistent belief that 98.6^{0}F is a referent that potentially divides health and illness may prevent earlier identification of febrile states associated with lethal emerging viruses (SARS, bird flu, hemorrhagic fevers), bioterrorism (anthrax, small pox, plague, tularemia), and diseases well known to present with “low grade” fevers (leukemia, lupus, Graves disease, pernicious anemia, among many others) (Fong & Alibek, 2005; Stewart, 2006).

Despite Wunderlich’s volume of measurements, it is unlikely that “normal” temperature ever was truly known. The small sample sizes that previously found lower normal temperatures have not made their way into literature in a way that currently affects practice. It is hoped that by a further investigation of normal body temperature in a large adult population, this research will add to the expanding base of medical and nursing knowledge.

CHAPTER 3

DESIGN AND METHODOLOGY

This chapter presents research design and methodology to investigate the proposed research question and hypothesis:

Research Question

What is normal body temperature in well adults?

Hypotheses

Ho Normal body temperature in well adults is 98.6^0F

Ha Normal body temperature in well adults is not 98.6^0F

Design

A multi-site descriptive observational study using two commonly used thermometer types – oral and tympanic – was used to determine normal body temperature in a large convenience sample of community dwelling adults, ages 21-100, who regarded themselves as "well today."

Institutional Approval

Permission to conduct this study, #09-312, was granted by the University of New Mexico Health Sciences Center Human Research Review Committee (HRRC) on July 2, 2009, and renewal approval was granted on June 17, 2010. The study protocol, consent forms (Appendix A), and recruitment information were approved by the HRRC in advance of beginning the study. Three study sites required additional approval from their institutional review boards prior to participant recruitment. Permission to be on site and to recruit was granted by Normandale Community College on January 15, 2010: Metropolitan State University on January 12, 2010: the University of Connecticut on December 2, 2009.

Methods

Setting

The study population was recruited from four large metropolitan areas: Portland, Oregon; Minneapolis-St. Paul, Minnesota; Hartford, Connecticut; and Albuquerque, New Mexico. These sites represented North-South and East-West populations and were selected to provide both ethnic and geographic diversity. Demographic data are presented in Table 1 (Capitalworkforce, 2008; Market Analysis, 2008; U.S. Census Bureau, 2005-2007). The study used indoor locations having ambient temperature between 65- 90^{0}F as measured by a certified thermometer (Hicks, & Thompson, 2006).

Table 1. *Location, Adult Percent of Population, and Ethnicity*

City*	**Population**	**Adults, %**	**White, %****	**Hispanic, %**	**Black, %**	**Asian, %**	**Other, %**
Portland	2,133,931	71.9	84	5	5	5	1
Hartford	1,185,150	72.4	16	41	39	0	4
Minneapolis	3,172,801	70.6	89	3	4	4	0
Albuquerque	819,576	70.3	60	35	2	2	1

*Includes greater metropolitan area; **White non-Hispanic.

A wide variety of study locations were used and were chosen to recruit the full 21-100 age range. Sites included community centers, offices, schools, churches, retirement communities, colleges, senior health fairs, and private homes. A list of study locations by city is presented in Table 2.

Table 2. *Study Sites*

Portland	**Hartford**	**Minneapolis**	**Albuquerque**
Mt. Tabor Community Center Portland State University On The Move Community Jackson Middle School Private Homes	Middlewood Retirement Communites, Farmington, Newington United Church of Christ University of Connecticut Manchester Community College Manchester High School University of Hartford Magnet School Revera Living Office Regional School Nurses	Grace Lutheran Church Normandale Community College Metro State University Private Homes	University of New Mexico:University Chorus, Department of Internal Medicine. Senior Health Fair Albuquerque Theater Guild Private Homes

Sample Size

A non randomized non probability sample of 1000 community dwelling adults comprised the study population, 250 recruited from each site. The original Wunderlich data resulted from axillary temperatures taken from twenty-five thousand patients and included over 1,000,000 measurements (Wunderlich, Woodward, 1871). Although that quantity could not be duplicated in this study, 1000 participants allowed 2000 measurements (1000 oral and 1000 tympanic temperatures) from a large diverse population. This is a much larger sample size than the 1992 Mackowiak study that reported data from 700 oral temperatures taken from 148 participants over 2 1/2 days.

A power analysis and sample size estimation indicated that a minimum of 865 measurements per thermometer type would be necessary to have 90% power to detect a difference of $.4^0$F at an alpha error level of $p <.05$. The effect size estimate was based on a mean of 98.2^0F and standard deviation of .9 using data published by Mackowiak (1992). In this study, 1000 measurements were selected in case any data needed to be excluded from statistical analysis and, as previously mentioned, to fully capture the range of temperatures in a large population.

Study Population

Inclusions. Community dwelling adults ages 21-100, who described themselves as “well today,” able to give consent, not on steroids or antibiotics, not organ recipients, not being treated for cancer or HIV/AIDS, not pregnant or nursing, who had not eaten within the 30 minutes prior to temperature taking (participants who reported only sips of room-temperature water and nothing by mouth for 15 minutes were allowed to participate), and who had not taken antipyretics in the last 24 hours (with the exception of 81 mg ASA), who were willing to sit for five minutes, complete a brief questionnaire, and have their temperatures taken were eligible for participation. Participants who wore bilateral hearing aids removed them for five minutes prior to the temperature taking. All participants understood spoken and written English.

Exclusions. Those ineligible to participate were those younger than 21 years of age or older than 100, unable to give consent, unable to understand and read English, pregnant or nursing, currently taking antibiotics and/or steroids (except inhaled steroids), ASA or antipyretic use in the last 24 hours, organ transplant recipient, receiving treatment for cancer, HIV/AIDS, wearing bilateral hearing aids and unwilling to remove them for the study, had eaten within the last 30 minutes, and those unable or unwilling to sit for five minutes prior to having their temperature taken.

Study Variables

The primary dependent variable of interest was body temperature. Correlates and predictors, as suggested by the available data for well adults included gender, age, smoking status, ethnicity, time of day temperature was taken, menstrual status, diabetes, 81mg aspirin use, statin use, and body mass index (Adam, 1989; Bogart, Hughes, & Mahaffy, 1969; Egan, et al., 2005; Gomolin, Aung, Wolf-Klein, & Auerbach, 2005; Prinz, Moe, Vitiello, Marks, & Larsen, 1992; Smith, 2003). Additional information elicited in the questionnaire included a question about full-time night work and exercise. Both oral and tympanic temperatures were measured.

At the time of study design, it was hoped to include patient medication use (if any) in the analysis. However, once data collection had begun, it became clear that most participants did not know the names of medications they were taking and rarely knew the doses even if they could name the medication. A great deal of researcher time in the early part of the study was spent trying to assist participants with this aspect of the questionnaire. After approximately 100 participants were enrolled in this study, this question was dropped. The information was deemed too inaccurate and haphazard to be included in any meaningful analysis.

Data Collection and Analysis

All data were collected by the primary investigator. She received assistance in various locations from volunteers who helped with setting out clipboards, arranging chairs, and coordinating location administrative details with study site contacts. All data forms were handled by the PI and remained in her secure custody.

Instruments

Identical models of thermometers were used at each location. Each study location was equipped with two Welch Allyn Braun Thermoscan Infrared Tympanic Thermometers, IRT400P, and two Welch Allyn Sure Temp Plus Contact Electronic Thermometers. These thermometers have an acceptable ambient temperature range from 60-95^{0}F and operational ranges from 80.3 – 109.9^{0}F (Hicks & Thompson, 2006). Thermometers were certified for accuracy prior to use in accordance with the International Temperature Scale of 1990 by the manufacturer (Simpson, Machin, McEvoy, & Rusby, 2006). Temperature probe covers specific to each thermometer type were used for each individual participant.

According to manufacturer's published standards, further quality checks were not necessary during the data collection period unless a thermometer was dropped or otherwise damaged (Hicks & Thompson, 2006). This did not happen. These instruments or an earlier version of them have been used in other studies primarily focused on comparisons between temperature sites (Crawford, Hicks, & Thompson, 2006; Daanen, 2006; Devrim, et al, 2007; Heusch, Suresh, & McCarthy, 2006; Smith, 2003a; Smith

2003b). Ambient air temperature was measured using an Edwards Scientific Digital Pocket Stem Thermometer with an ambient temperature range of -4^{0}F to +300^{0}F.

Data Collection

Upon arriving at a site at which permission had been granted to gather data, the ambient temperature was checked and verified to be within the acceptable thermometer operating range, 60-95^{0}F. A sign asking for volunteers was posted in the immediate area (See Appendix B). A table with clipboards, consent forms and questionnaires, pens, and the thermometers was placed in the most visible area possible that did not impede traffic and 4-6 chairs were placed near the table. A large poster describing the study was hung in the area. The PI and any volunteers present wore large buttons that said “May I Take Your Temperature?”

Potential participants were asked if they would be willing to participate in a study that would involve completing a short questionnaire and having their temperature taken with an ear thermometer and an oral thermometer. They were told that no personal identifying data was to be collected. Those who answered affirmatively were asked several screening questions to determine suitability for participation: Do you speak and read English? Do you regard yourself as well today? Have you taken any Tylenol, aspirin – except for a baby aspirin, naproxen, or ibuprofen in the last 24 hours? Have you had anything to eat or drink in the last 30 minutes?

Participants who spoke English, had not taken antipyretics, who had not recently eaten, and who regarded themselves as well were asked to sit down, read the “informed consent” document, ask any questions they might have, and sign the informed consent. While they were sitting, they completed a gender specific questionnaire (Appendix C).

The questionnaire was then reviewed by the PI for completeness and for other exclusions (HIV/AIDS, cancer, organ transplant, pregnant or nursing). If exclusions were noted, potential participants were thanked for volunteering and told that unfortunately they could not be included in the study. If omissions were noticed, the participant was asked to complete the missing information prior to temperature taking.

At the end of the five minute period, both oral and tympanic temperatures were taken. The oral thermometer was placed in the participant's mouth under the tongue on the right per the manufacturer's recommendations. After the thermometer registered the temperature, the temperature was recorded on the questionnaire. The tympanic thermometer was placed in the right ear canal and the result recorded on the questionnaire. If the left ear was used, it was noted. (Although there are some data that report that when temperature is taken in both ears, the second temperature is slightly higher, and that right or left handedness may influence ear temperature, the differences were trivial (Heusch, Suresh, & McCarthy, 2006; McCarthy, 2006)).

All temperatures were recorded in degrees F., the scale most preferred by patients and providers in the U.S. (Mackowiak, 1995). Participants were thanked for their participation and informed of their temperatures. No treatment or advice was given to any participant. No participant had a temperature of 100.4^0F or greater (the current standard for "fever"). The consent forms and the questionnaires were then separated and maintained in separate secure files. After a second review of the questionnaire to verify completeness and that the participant had no exclusions that might have been overlooked, the questionnaire was assigned a unique, site specific number: Albuquerque 1-250, Hartford 251-500, Minneapolis-St Paul 501-750, Portland 751-1000.

Data Management

Using a password protected computer, data were entered into a password protected Access data base. The data were screened for obvious errors (out of range data) and then entered into SPSS Version 17.0 for Windows, and SAS 9.2. Completed questionnaires and consent forms remain in the secure custody of the researcher with plans for their destruction after 5 years following institutional guidelines for the destruction of research documents.

Data Analysis

Screening. Data were checked for normality by visual inspection and were screened for outliers defined as temperatures $>100.4^0$F, defined as fever, and $<92.0^0$F (there are not any reports of temperatures of $<92.0^0$F in healthy adults).

Descriptive statistics. In order to fully describe the study population, descriptive statistics were calculated to provide an overall picture of the 1000 participants. Included are both aggregate and city-specific information regarding participants and the covariates: gender, age, smoking status, ethnicity, time of day temperature was taken, menstrual status, diabetes, 81mg aspirin use, statin use, and body mass index. Oral and tympanic temperature measurements means for each variable are reported. The descriptive statistics include measures of central tendency: means, medians, modes and standard deviations.

Correlation. Pearson correlation tests were conducted to identify any statistical association between the potential continuous covariates of age and body mass index (BMI) and oral and tympanic temperature. An additional Pearson r test was conducted to determine the correlation between the oral and tympanic temperature measurements.

Analysis of variance. Analysis of variance was conducted to detect any statistically significant interaction between the covariates of gender, smoking status, ethnicity, time of day temperature was taken, menstrual status, diabetes, 81mg aspirin use, statin use, and oral and tympanic temperature.

Multiple regression. Stepwise model selection techniques were employed to find the best fitting regression model to predict temperature. Multiple regression analysis were fit using stepwise variable selection. Separate models were fit for both tympanic and oral temperature measurement methods as the response variable.

Student's *t* test. A one sample two-tailed t-test was conducted to compare the aggregate oral and tympanic temperatures in the study population. A one sample t-test was performed to compare the mean temperatures between each thermometer type and the accepted normal temperatures of 98.6^0F as reported by Wunderlich and the 98.2^0F as reported by Mackowiak. Finally, to answer the research question "What is normal body temperature in well adults?" a one sample t-test was performed to determine if the aggregate mean of the 2000 temperatures was statistically different from the accepted normal temperatures of 98.6^0F as reported by Wunderlich and the 98.2^0F as reported by Mackowiak.

CHAPTER 4

RESULTS

This chapter reports the data preparation steps and statistical analysis procedures. Data were analyzed using SPSS version 17.0 and SAS version 9.2.

Data Preparation for Analysis

Prior to analysis, data were screened for missing values and outliers. One questionnaire from Portland (the first study site) was unusable (potential participant was an organ recipient) and was excluded prior to being assigned a study number. As a result, an additional participant from Minneapolis was then included so that the study population totaled 1000 participants. One participant did not enter height and weight information and was excluded from the body mass index (BMI) analysis. Temperatures ranged from a low of 92.5^{0}F (n=1) to a high of 100.1^{0}F (n=1). These would usually be considered outliers; however, since the intent of this study was to capture the full range of temperatures and to fully reflect the study population, no temperature data were excluded. Normality was evaluated by visual inspection and analysis of skewness and kurtosis. Both tympanic and oral temperatures patterns were found to be normally distributed and thus no data transformations were performed.

Results of the Analysis

Key Findings

Comparison with previously known mean temperatures. The aggregate oral and tympanic temperatures of participants were independently compared to the widely accepted norms of 98.2^0F, as stated by Mackowiak and 98.6^0F as stated by Wunderlich. The results of the two-tailed t-test demonstrated that there is a statistical difference between both widely accepted values, both in the case of oral *($p < .000$)* and tympanic temperature *($p < .000$)*. This information is shown below in Table 3.

Table 3. *Two-Tailed t-Test of Average Body Temperatures*

	df	98.2^0F (Mackowiak)		98.6^0F (Wunderlich)	
		t	Sig.	t	Sig.
Oral Temperature	999	5.479	.000	-17.375	.001
Tympanic Temperature	998	-9.929	.000	-25.340	.001

Composite mean temperature. The mean of the aggregate total temperatures, 98.1^0F (n = 2000, 100%), were compared with the widely accepted norm of 98.6^0F as stated by Wunderlich. The result, showing statistical significance, is shown in Table 4.

Table 4. *98.6^0F vs. Measured Overall Temperatures*

N	Mean	SD	SE	Minimum	Maximum	95% CI Mean		DF	*T* value	Pr < |t|
2000	98.1	0.7	0.016	92.5	100.1	98.0	98.1	1999	-29.82	<.001

Descriptive Statistics

City summary information. Participants consisted of 250 adults in Albuquerque, NM, 250 adults in Hartford, CT, 249 adults in Portland, OR, and 251 adults in Minneapolis-St Paul, MN, as shown in Table 5.

Table 5. *Study Location and Number*

City	N	%
Albuquerque	250	25.0
Hartford	250	25.0
Minneapolis/St Paul	251	25.1
Portland	249	24.9
	1000	100

Site-specific data are presented in Table 6. Some statistically significant differences across study sites were observed for gender, age group, ethnicity, menstrual status, statin use, exercise within one hour, and eating within 30 minutes (p < .001).

Gender. This was a convenience sample and there was no plan to balance gender. Although every effort was made to recruit men, women were more likely to volunteer at every site

***Age group*.** Minnesota has an unemployment/educational support policy that pays tuition and a stipend to unemployed adults who attend college. Recruitment in the Twin Cities was centered on two large community colleges. This accounted for the unexpectedly large population of persons under 40 (n=149, 59.4%). Hartford was the last research site and a special effort was made to include older adults in the study population to improve representation in the 71 and older group (n=47, 18.8%).

Table 6. *Covariates by Location: Categorical Variables*

	Albuquerque		Hartford		Minneapolis		Portland		Total		P-value*
	n	%	n	%	n	%	n	%	n	%	
Gender											
F	181	72.4	186	74.4	152	60.6	164	65.9	683	68.3	0.003
M	69	27.6	64	25.6	99	39.4	85	34.1	317	31.7	
Age group											
21 - 30	38	15.2	46	18.4	93	37.1	39	15.7	216	21.6	<0.001
31 - 40	32	12.8	39	15.6	56	22.3	44	17.7	171	17.1	
41 - 50	26	10.4	43	17.2	41	16.3	67	26.9	177	17.7	
51 - 60	44	17.6	46	18.4	26	10.4	43	17.3	159	15.9	
61 - 70	64	25.6	29	11.6	21	8.4	38	15.3	152	15.2	
71 - 80	32	12.8	8	3.2	8	3.2	15	6.0	63	6.3	
81 - 90	12	4.8	21	8.4	6	2.4	3	1.2	42	4.2	
91 - 100	2	0.8	18	7.2	0	0	0	0	20	2.0	
Smoke (Y/N)											
No	225	90.0	232	92.8	217	86.5	226	90.8	900	90.0	0.119
Yes	25	10.0	18	7.2	34	13.5	23	9.2	100	10.0	
Ethnicity											
African American	4	1.6	35	14.0	49	19.5	13	5.2	101	10.1	<0.001
White	187	74.8	187	74.8	158	62.9	206	82.7	738	73.8	
Asian	2	0.8	5	2.0	19	7.6	11	4.4	37	3.7	
Hispanic	50	20.0	12	4.8	3	1.2	7	2.8	72	7.2	
Native Am	3	1.2	1	0.4	7	2.8	0	0	11	1.1	
Other	4	1.6	10	4.0	15	6.0	12	4.8	41	4.1	
Works at night											
No	245	98.0	238	95.2	235	93.6	241	96.8	959	95.9	0.074

	Albuquerque		Hartford		Minneapolis		Portland		Total		P-value*
	n	%	n	%	n	%	n	%	n	%	
Yes	5	2.0	12	4.8	16	6.4	8	3.2	41	4.1	
Eat in last 30 minutes											
No	247	98.8	242	96.8	245	97.6	244	97.2	978	97.9	<0.001
Yes * sips of room temp water	3	1.2	8	3.2	6	2.4	7	2.8	24	2.4	
Exercised in the last 1 hour											<0.001
No	249	99.6	248	99.2	244	97.2	232	93.2	973	97.3	
Yes	1	0.4	2	0.8	7	2.8	17	6.8	27	2.7	
Menstrual Cycle Phase											
Follicular	22	8.8	41	16.4	59	23.5	36	14.5	158	15.8	
Luteal	40	16.0	36	14.4	41	16.3	35	14.1	152	15.2	<0.001
N/A-Male	69	27.6	64	25.6	99	39.4	85	34.1	317	31.7	
N/A-No Ovaries	1	0.4	2	0.8	1	0.4	15	6.0	19	1.9	
No response	0	0	0	0	0	0	12	4.8	12	1.2	
Peri menopausal	14	5.6	16	6.4	12	4.8	8	3.2	50	5.0	
Post menopausal	104	41.6	91	36.4	39	15.5	58	23.3	292	29.2	
Diabetes (Y/N)											
No	235	94.0	234	93.6	241	96.0	242	97.2	952	95.2	0.194
Yes	15	6.0	16	6.4	10	4.0	7	2.8	48	4.8	
81 mg Aspirin											0.057
No	192	76.8	204	81.6	215	85.7	209	83.9	820	82.0	

	Albuquerque		Hartford		Minneapolis		Portland		Total		P-value*
	n	%	n	%	n	%	n	%	n	%	
Yes	58	23.2	46	18.4	36	14.3	40	16.1	180	18.0	
Currently taking statins											0.005
No	197	78.8	210	84.0	225	89.6	217	87.1	849	84.9	
Yes	53	21.2	40	16.0	26	10.4	32	12.9	151	15.1	
BMI range											0.127
Weight not reported	0	0	0	0	0	0	1	0.4	1	0.1	
<16.5	0	0	0	0	2	0.8	1	0.4	3	0.3	
16.5 - <18.5	2	0.8	5	2.0	4	1.6	4	1.6	15	1.5	
18.5 - <25.0	103	41.2	116	46.4	96	38.2	120	48.2	435	43.5	
25.0 - <30.1	88	35.2	77	30.8	94	37.5	77	30.9	336	33.6	
30.1 - <35.0	29	11.6	30	12.0	33	13.1	25	10.0	117	11.7	
35.0 - 40.0	17	6.8	10	4.0	16	6.4	17	6.8	60	6.0	
>40.0	11	4.4	12	4.8	6	2.4	4	1.6	33	3.3	
Total	250	100.0	250	100.0	251	100.0	249	100.0	1000	100.0	N/A

P-values obtained from Score chi-square statistics after performing logistic regression with the explanatory variable of interest as the dependent variable, and location as the independent variable. If $p < 0.05$, it can be concluded that the dependent vaiable varied between location.

Ethnicity. As expected, ethnicity was varied and reflected the demographics presented in Chapter 3. Most participants identifying themselves as Hispanic were from the Albuquerque setting (n=50, 20%). African-Americans were represented primarily in the Hartford and Minneapolis settings (n=84, 33.5%).

Participants identifying themselves as “Other” primarily came from Middle Eastern countries and from the Caribbean.

Statin and menstrual status. It was expected that statin use would vary with age, with older adults more likely to take statins. Since statins are not generally prescribed for pre menopausal women, sites with a higher proportion of younger women reported less statin use.

Exercise and eating. Exercise within one hour showed statistical significance, but the number was extremely small and reflects recruitment at a community center that has a gym for senior citizens. Based on observation at the site, it was felt that the participants’ definitions of exercise did not meet a subjective criterion of exercise vigorous enough to exclude them. However they were identified as having exercised in case this needed to be analyzed separately. Eating within 30 minutes also showed slight statistical significance. A few participants at each site reported that they had had sips of room temperature water at least 20 minutes prior to temperature taking and were allowed to participate. The numbers were very small and were not regarded as significant

Summary. Although these variations by city of data collection were statistically significant, there were reasonable explanations for the differences observed and they were viewed as a reflection of the population as a whole. They were not viewed as having significant potential to bias temperature results, and they were not felt to be clinically significant. Variability between cities was not determined to be of further relevance and was not further investigated.

Characteristics of Study Population

Study participants were predominantly female (n = 683, 68.3%), white (n = 738, 73.8%), non smoking (n =900, 90%), without diabetes (n = 952, 95%), and did not take an aspirin (n = 820, 82%) or statin (n = 820, 84.9%).

Measures of Central Tendency

Measures of Central Tendency are shown in Table 7. It should be noted that based on the mean, median and mode, a majority of the participants are classified as overweight by their BMI. ABQ (n =145, 58%) and MSP (n = 149, 59.4%), had more slightly more overweight participants than did HCT (n = 129, 51.8%), or PDX (n = 123, 49.3%). Tables 8, 9, and 10 show the mean, median, and mode of temperature; the range of oral temperatures; and the range of tympanic temperatures, respectively.

Table 7. *Summary of Measures of Central Tendency*

		Age	**HT**	**WT**	**BMI**
N	Valid	1000	1000	999	999
	Missing	0	0	1	1*
Mean		48.39	5’5”	171.9	26.7
Median		47.50	5’5”	160.3	25.6
Mode		21.00	5’5”	150.31	25.9
Std. Deviation		18.69	.10	19.07	5.79
Minimum		21.00	4’0”	85.1	14.0
Maximum		100.00	6’8”	400.8	57.5

*One participant would not disclose her weight.

Table 8. *Mean, Median, and Mode of Temperatures*

	Oral	**Tympanic**
Mean	**98.3**	**97.9**
Median	**98.3**	**98.0**
Mode	**97.9**	**98.3**
Std. Deviation	.55	.82
Variance	.31	.67

Table 9. *Range of Oral Temperatures*

Range Oral			
Lowest Value	**Case Number**	**Highest Value**	**Case Number**
94.3	116	99.7	294
95.9	547	99.7	621
96.4	951	99.8	357
96.7	945	99.8	599
96.7	748	**100.1**	98

Table 10. *Range of Tympanic Temperatures*

Range Tympanic			
Lowest Value	**Case Number**	**Highest Value**	**Case Number**
92.5	913	99.5	97
94.2	751	99.5	349
94.3	549	99.5	463
94.4	561	99.5	967
94.5	235	**99.6**	867

Temperatures by Method and Covariates

There was variability in temperature measurements between the tympanic and oral thermometers. Tympanic temperatures were consistently lower than oral temperatures. Figures 1 and 2 present each covariate and the oral and tympanic temperature measurements. Table 11 presents the data in summary form.

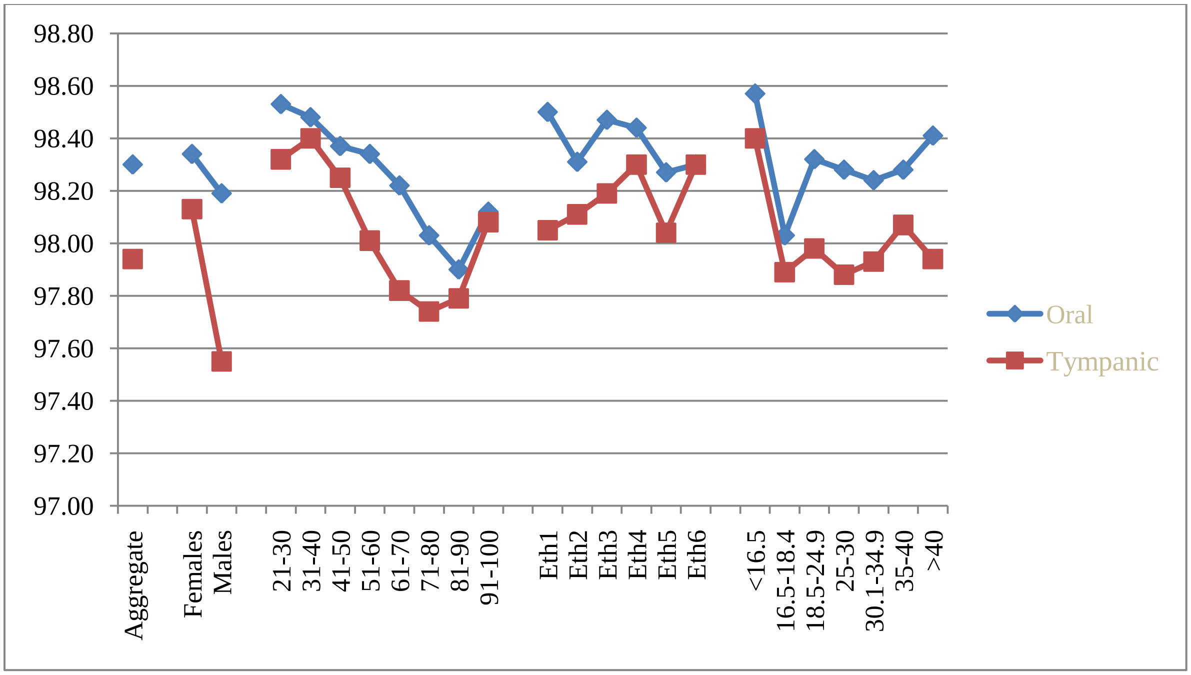

Figure 1. Average body temperature (in degrees Fahrenheit) of the study population (ethnicities: 1 African American, 2 White, 3 Asian, 4 Hispanic, 5 Native American, 6 other).

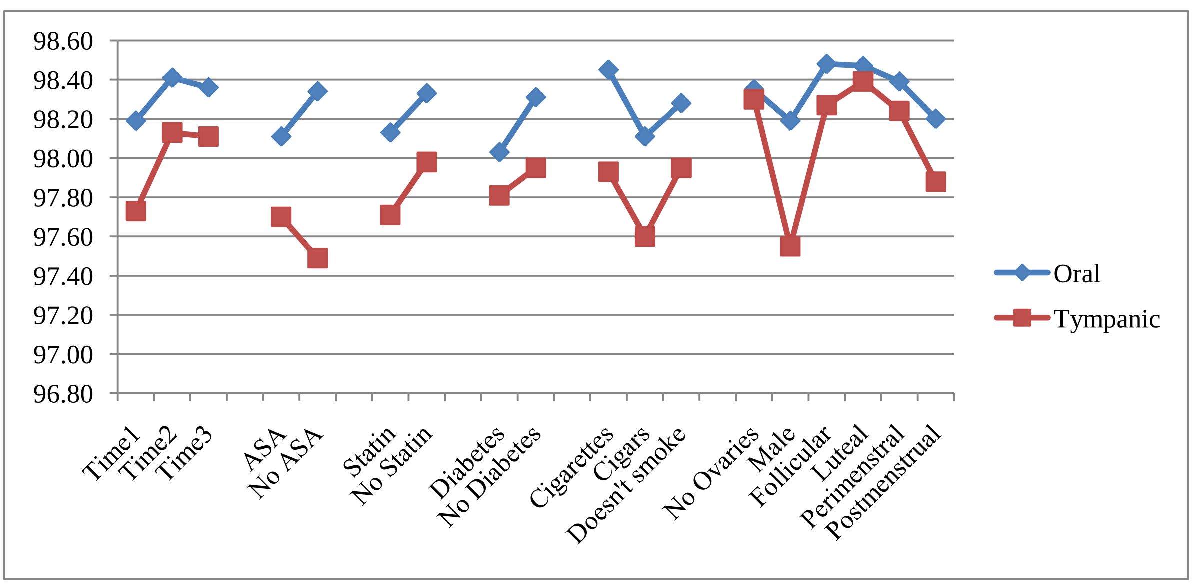

Figure 2. Average body temperature (in degrees Fahrenheit) of the study population (Time 1: 8 AM-11:59; Time 2: 12 Noon-3:59 PM; Time 3: 4 PM-8 PM).

Table 11. *Oral and Tympanic Temperatures by Variable*

	Oral Temperature (ºF)			Tympanic Temperature (ºF)		
	n	**Mean**	**St. Dev.**	**n**	**Mean**	**St. Dev.**
Location						
Albuquerque, NM	250	98.2	0.6	250	98.0	0.8
Hartford, CT	250	98.3	0.5	250	97.9	0.8
Minneapolis, MN	251	98.4	0.6	251	97.9	0.8
Portland, OR	249	98.3	0.5	249	97.9	0.9
Gender						
F	683	98.3	0.5	683	98.1	0.7
M	317	98.2	0.6	317	97.5	0.9
Age Group						
21 - 30	216	98.5	0.5	216	98.0	0.8
31 - 40	171	98.4	0.5	171	98.1	0.9
41 - 50	177	98.3	0.5	177	98.1	0.7
51 - 60	159	98.3	0.6	159	97.9	0.9
61 - 70	152	98.1	0.6	152	97.7	0.8
71 - 80	63	98.0	0.5	63	97.6	0.8
81 - 90	42	97.8	0.5	42	97.7	0.7
91 - 100	20	98.1	0.5	20	97.9	0.7
Smoke (Y/N)						
No	900	98.3	0.6	900	97.9	0.8
Yes	100	98.4	0.6	100	97.9	0.9
Ethnicity						
African American	101	98.4	0.6	101	97.9	0.8
White	738	98.3	0.6	738	97.9	0.8
Asian	37	98.5	0.5	37	98.0	1.1

	Oral Temperature (ºF)			Tympanic Temperature (ºF)		
	n	**Mean**	**St. Dev.**	**n**	**Mean**	**St. Dev.**
Hispanic	72	98.4	0.4	72	98.2	0.7
Native Am	11	98.3	0.6	11	98.0	0.8
Other	41	98.3	0.5	41	97.9	1.0
Time of Day						
1 8 AM – 11:59 AM	465	98.2	0.5	465	97.7	0.9
2 12 N – 3:59 PM	267	98.4	0.6	267	98.1	0.7
3 4 PM – 8 PM	268	98.4	0.6	268	98.1	0.8
Works at night						
No	959	98.3	0.6	959	97.9	0.8
Yes	41	98.4	0.5	41	97.9	0.9
Eat in the last 30 minutes						
No	913	98.3	0.6	913	97.9	0.8
Yes	87	98.3	0.6	87	97.9	1.0
Exercised in the last 1 hour						
No	973	98.3	0.6	973	98.0	0.8
Yes	27	98.2	0.6	27	97.6	1.5
Menstrual Cycle Phase						
Follicular	158	98.5	0.5	158	98.3	0.6
Luteal	152	98.5	0.5	152	98.4	0.6
N/A-Male	317	98.2	0.6	317	97.5	0.9
N/A-No Ovaries	19	98.4	0.5	19	98.3	0.8
No response	12	98.2	0.6	12	98.3	0.9
Peri menopausal	50	98.4	0.5	50	98.2	0.8
Post menopausal	292	98.2	0.6	292	97.9	0.8
Diabetes (Y/N)						
No	952	98.3	0.5	952	97.9	0.8

	Oral Temperature (ºF)			Tympanic Temperature (ºF)		
	n	Mean	St. Dev.	n	Mean	St. Dev.
Yes	48	98.0	0.6	48	97.8	0.7
81 mg Aspirin						
No	820	98.3	0.6	820	98.0	0.8
Yes	180	98.1	0.5	180	97.7	0.7
Currently taking statins						
No	849	98.3	0.5	849	98.0	0.8
Yes	151	98.1	0.6	151	97.7	0.8
BMI range						
Weight not reported	1	99.0	0	1	97.6	0
<16.5	3	98.6	0.3	3	98.4	0.8
16.5 - <18.5	15	98.0	0.5	15	97.9	0.8
18.5 - <25.0	435	98.3	0.5	435	98.0	0.8
25.0 - <30.1	336	98.3	0.6	336	97.9	0.8
30.1 - <35.0	117	98.3	0.5	117	98.0	0.8
35.0 - 40.0	60	98.3	0.6	60	98.1	0.6
>40.0	33	98.4	0.6	33	97.9	0.8
Total	1000	98.3	0.6	1000	97.9	0.8

Gender

Males had lower temperatures than women regardless of thermometer type. This has not been previously reported in such a large population. It is particularly striking that men had mean tympanic temperatures, 97.5^{0}F (SD.9), more than a full degree lower than 98.6^{0}F.

Age

Younger participants had higher temperatures with both thermometer types. Temperature decreased as age increased until the last decade when it rose slightly. Although the numbers are small, the rise in temperature of the very elderly is congruent with the original Wunderlich data.

Gender and Age

Men consistently had lower temperatures regardless of thermometer type and this difference was constant across the age spectrum. This is presented in Table 12.

Table 12. *Temperature by Gender and Age*

		N	**Oral**	**Tympanic**
Females				
	21 – 30	144	98.5	98.3
	31 – 40	116	98.4	98.4
	41 – 50	118	98.3	98.2
	51 – 60	111	98.3	98.0
	61 – 70	104	98.2	97.8
	71 – 80	46	98.0	97.7
	81 – 90	27	97.9	97.7
	91 – 100	18	98.1	98.0
Males				
	21 – 30	72	98.3	97.5
	31 – 40	55	98.3	97.4
	41 – 50	59	98.2	97.8
	51 – 60	48	98.2	97.5
	61 – 70	48	97.9	97.4
	71 – 80	17	97.9	97.4
	81 – 90	15	97.7	97.5
	91 - 100	2	97.7	97.2

Smoking Status

Although smoking cigars was included in the participant questionnaire, this category was collapsed into the cigarettes category: only 1 woman and 5 men reported smoking cigars. Only 5 women over 61 smoked. No men over 61 smoked cigarettes. No person over 81 smoked (Table 13).

Table 13. *Smoking by Age and Gender*

		Smoking	**N**	**Oral**	**Tympanic**
Females					
	21-30	Cigarettes	14	98.6	98.4
		Doesn't Smoke	128	98.5	98.3
	31-40	Cigarettes	13	98.5	98.2
		Doesn't Smoke	103	98.4	98.4
	41-50	Cigarettes	17	98.3	98.0
		Doesn't Smoke	101	98.3	98.2
	51-60	Cigarettes	10	98.5	97.9
		Doesn't Smoke	101	98.3	98.0
	61-70	Cigarettes	3	97.9	97.5
		Doesn't Smoke	101	98.2	97.8
	71-80	Cigarettes	2	97.9	97.5
		Doesn't Smoke	44	98.0	97.7
	81-90	Cigarettes	0	--	--
		Doesn't Smoke	27	97.9	97.7

	91-100	Cigarettes	0	--	--
		Doesn't Smoke	17	98.1	98.0
Males					
	21-30	Cigarettes	17	98.4	97.6
		Doesn't Smoke	54	98.3	97.4
	31-40	Cigarettes	10	98.4	97.7
		Doesn't Smoke	45	98.3	97.4
	41-50	Cigarettes	5	98.3	97.3
		Doesn't Smoke	54	98.2	97.8
	51-60	Cigarettes	6	98.3	97.4
		Doesn't Smoke	42	98.1	97.6
	61-70	Cigarettes	2	98.1	98.0
		Doesn't Smoke	46	97.9	97.3
	71-80	Cigarettes	0	--	--
		Doesn't Smoke	17	97.9	97.4
		*Cigars	1	97.5	97.5
		Doesn't Smoke	14	97.7	97.5
	91-100	Cigarettes	0	--	--
		Doesn't Smoke	2	97.7	97.2

Ethnicity

Temperature varied only 0.3^0F between ethnic groups. However, Asian and Native Americans comprised less that 5% of the study population, and Hispanics only 7%.

Time of Day

As expected, temperatures in the morning were lower regardless of thermometer type. It is interesting that even in the aggregate 12 PM -8PM group, mean temperature did not reach 98.6^0F (Table 14).

Table 14. *Temperature by Gender and Time of Day*

Time of Day	465	98.2	97.7
1 8 AM – 11:59 AM			
Female	311		
Male	71		
2 12 N – 3:59 PM	267	98.4	98.1
Female	196		
Male	71		
3 4 PM – 8 PM	268	98.4	98.1
Female	176		
Male	92		

Works at Night

There was essentially no difference between the temperatures of those who reported that they worked full time at night and those who did not. It was expected that circadian rhythm changes might have “reset” body clocks and that night shift workers would have higher morning temperatures. It should be noted that only 41 participants (4.1%) worked at night.

Eat in the Last 30 Minutes

There was no difference between the temperatures of those who reported that they had not eaten and those who had sips of room temperature water.

Exercise in the Last Hour

Those reporting that they had exercised had lower temperatures regardless of thermometer type. It should be remembered that it is likely that the “exercise” was not strenuous.

Menstrual Cycle Status

Menstruating and peri menopausal women had higher temperatures than post menopausal women who had the lowest temperatures. There was essentially no difference between the follicular and luteal menstrual phase with essentially the same number of women in each group (follicular n=158, luteal n=152). However, many women were uncertain about the time of their last period making the assignment to the follicular or luteal phase problematic and somewhat subjective. Many women did not include this information when they initially completed the questionnaire but would disclose it when asked directly by the researcher. Some women reported that they had an IUD and had erratic periods or were on the “mini” pill and had infrequent periods. They were categorized as follicular if the first day of their last period was within the last14 days, luteal if it was 15 days or later (Williams, 1997).

Diabetes

Although the number of participants with diabetes was small (n = 48, 4.8%), they had lower temperatures than the non diabetic population. This was unexpected and has not been previously reported (Table 15).

Table 15. *Gender, Diabetes, and Temperature*

		Diabetes	N	Oral Temp.	Tympanic
Females					
	21-30	Yes	1	98.3	97.5
		No	143	98.5	98.3
	31-40	Yes	1	99.3	99.0
		No	115	98.4	98.3
	41-50	Yes	3	98.2	98.1
		No	115	98.3	98.2
	51-60	Yes	3	98.2	97.4
		No	108	98.3	98.0
	61-70	Yes	14	98.2	97.9
		No	90	98.2	97.8
	71-80	Yes	4	97.7	97.8
		No	42	98.0	97.7
	81-90	Yes	1	97.6	98.2

		No	26	97.9	97.7
	91-100	Yes	2	97.6	97.7
		No	16	98.1	98.1
Males					
	21-30	Yes	0	--	--
		No	72	98.3	97.5
	31-40	Yes	0	--	--
		No	55	98.3	97.4
	41-50	Yes	3	97.7	97.9
		No	56	98.2	97.8
	51-60	Yes	4	98.1	97.8
		No	44	98.2	97.5
	61-70	Yes	3	97.5	97.7
		No	45	97.9	97.3
	71-80	Yes	3	98.2	97.3
		No	14	97.8	97.4
	81-90	Yes	4	97.6	97.7
		No	11	97.7	97.4
	91-100	Yes	0	--	--
		No	2	97.7	97.2

Aspirin Use

In some age groups by gender, users of 81 mg of aspirin had lower temperatures than non aspirin users. The trend was particularly noteworthy in oral temperatures of women over 51. As with aspirin, older adults are more likely to have lower temperatures independent of aspirin use (Table 16).

Table 16. *Gender, ASA, and Temperature*

		ASA Use	N	Oral	Tympanic
Females					
	21-30	Yes	1	98.6	98.6
		No	143	98.5	98.3
	31-40	Yes	2	97.7	98.0
		No	114	98.4	98.4
	41-50	Yes	8	98.6	98.1
		No	110	98.3	98.2
	51-60	Yes	15	98.1	97.7
		No	96	98.3	98.0
	61-70	Yes	44	98.1	97.8
		No	60	98.2	97.8
	71-80	Yes	25	97.9	97.7
		No	21	98.1	97.7
	81-90	Yes	9	97.7	97.3
		No	18	97.9	97.9

	91-100	Yes	6	98.0	97.8
		No	12	98.1	98.1
Males					
	21-30	Yes	0	--	--
		No	72	98.3	97.5
	31-40	Yes	2	98.3	97.9
		No	53	98.3	97.4
	41-50	Yes	12	98.0	97.8
		No	47	98.3	97.8
	51-60	Yes	15	98.4	97.8
		No	33	98.0	97.4
	61-70	Yes	22	97.9	97.2
		No	26	97.9	97.5
	71-80	Yes	9	98.0	97.4
		No	8	97.7	97.3
	81-90	Yes	9	97.8	97.6
		No	6	97.5	97.4
	91-100	Yes	1	98.0	97.1
		No	1	97.4	97.3

Statin Use

Most statin users had slightly lower temperatures than non users. Older adults were also more likely to have lower temperatures independent of statin use (Table 17).

Table 17. *Gender, Statin, and Temperature*

		Statin Use	N	Oral Temp.	Aural Temp.
Females					
	21-30	Yes	0	--	--
		No	144	98.5	98.3
	31-40	Yes	1	99.3	99.0
		No	115	98.4	98.3
	41-50	Yes	7	98.2	98.0
		No	111	98.3	98.2
	51-60	Yes	15	98.1	97.5
		No	96	98.3	98.0
	61-70	Yes	35	98.3	97.7
		No	69	98.1	97.8
	71-80	Yes	20	97.9	97.8
		No	26	98.1	97.7
	81-90	Yes	8	97.6	97.7
		No	19	97.9	97.8
	91-100	Yes	5	97.9	97.9
		No	13	98.1	98.1

Males					
	21-30	Yes	1	97.9	97.2
		No	71	98.3	97.5
	31-40	Yes	1	98.0	97.9
		No	54	98.3	97.4
	41-50	Yes	4	98.1	98.4
		No	55	98.2	97.8
	51-60	Yes	13	98.3	97.6
		No	35	98.1	97.5
	61-70	Yes	20	98.0	97.6
		No	28	97.9	97.2
	71-80	Yes	12	98.0	97.4
		No	5	97.6	97.3
	81-90	Yes	8	97.7	97.6
		No	7	97.6	97.4
	91-100	Yes	2	97.7	97.2
		No	0	--	--

Body Mass Index

The thinnest participants, BMI <16.5 (severely underweight), had the highest temperatures for both thermometer types 98.6^{0}F (oral) and 98.4^{0}F (tympanic). However the N =3. With the exception of this group, there was little difference between participant BMI and temperature.

Correlation Analysis

A Pearson correlation analysis was performed in order to test for statistically significant associations between the continuous covariates of age and BMI and the associated mean oral and tympanic temperatures. The results of the analysis are shown below in Table 18. For both thermometer types, older persons had lower temperatures. There was not a significant association between thermometer type and BMI.

Table 18. *Results of Correlation Analysis*

	Oral Temperature		**Tympanic Temperature**	
	Correlation	**Sig.**	**Correlation**	**Sig.**
By Age	-.295	**.001**	-.152	**.001**
By BMI	-.006	.862	-.001	.977

A correlation analysis was also performed to test for statistical relationship between thermometer types. The correlation coefficient was 0.35 (p 0.001). Although this may be regarded as a moderate correlation (Lipsey, 1990), it is lower than would be expected based on data from other studies that show a higher level of correlation between the measurements of oral and tympanic thermometers.

Analysis of Variance

An analysis of variance (ANOVA) was performed to determine whether any covariates accounted for statistically significant relationships between oral or tympanic temperature. Based on the information shown in Table 19, there are statistically significant relationships for either or both the oral and tympanic temperatures of the participants for all covariates but one.

Oral and tympanic temperatures independently demonstrated statistical significance for age, gender, time of day, 81 mg aspirin use, statin use, and menstrual status. Additionally, oral temperatures were statistically significant for ethnicity, smoking status, and diabetes. Based on the ANOVA findings there is no evidence to suggest that there was a relationship between temperature and BMI (oral: f =1.37, *p* .22, tympanic: f =.90, *p* .49).

Table 19. *ANOVA Between Mean Body Temperatures of Participants (Aggregate*)

	Oral Temperature		Tympanic Temperature	
	f	Sig.	f	Sig.
By age	14.731	**.000**	6.790	**.000**
By gender	16.987	**.000**	120.742	**.000**
By ethnicity	3.590	**.003**	1.463	.199
By BMI	1.372	.223	.902	.492
By Time of Day	15.971	**.000**	29.700	**.000**
By ASA Use	26.469	**.000**	18.875	**.000**
By Statin Use	17.471	**.000**	13.925	**.000**
By Smoking Status	4.126	**.016**	.631	.532
By Diabetes Status	12.214	**.000**	1.271	.260
By Menstrual Status	11.595	**.000**	36.447	**.000**

Multiple Regression

Model selection techniques were employed to determine which explanatory variables significantly contribute to the outcome of temperature. Based on the previous ANOVA and chi-square analysis, significant variables were included in the full model and then stepwise selection was used to find the best-fitting regression model. Two separate models were fit, one to model the response of oral temperature, and the other to model the response of tympanic temperature. Although menstrual cycle status was found to be significant in the ANOVA analysis, it was left out of the models due to multicollinearity with the gender variable. Both best-fitting models have the same explanatory variables: age, time of day at which temperature was measured, and gender. Neither model accounted for more that 18% of the variance suggesting that individual differences and unrecognized factors accounted for most of the variance. For oral temperature, the parameter estimates are given in Table 20. Table 21 presents the tympanic regression model.

From this model, the parameter estimates can be interpreted as the following: for every increase in one year of age, oral temperature decreases by 0.008° F. If subjects are females, their oral temperatures will, on average, be 0.17° F higher than males. Oral temperatures measured in the middle part of the day will be, on average 0.14° F higher than if measured in the morning. Oral temperatures measured in the late afternoon/early evening will, on average, be 0.25° F higher than if measured in the morning.

From this model, the parameter estimates can be interpreted as the following: for every increase in one year of age, tympanic temperature decreases by 0.006° F. If subjects are females, their tympanic temperatures will, on average, be 0.58° F higher than males. Tympanic temperatures measured in the middle part of the day will be, on average 0.31° F higher than if measured in the morning. Tympanic temperatures measured in the late afternoon/early evening will, on average, be 0.66° F higher than if measured in the morning.

Table 20. *Oral Multiple Regression Model*

Parameter	Estimate	Standard Error	t Value	r > |t|
Intercept	98.521	0.056	1739.65	.001
Age	-0.008	0.001	-9.39	.001
Gender F	0.165	0.035	4.68	.001
Gender M	0.000	.	.	.
time 3	0.106	0.040	2.63	.086
time 2	0.144	0.040	3.56	.004
time 1	0.000	.	.	.

$F=35.12$ $p<0.001$ $r^2=0.12$

Table 21. *Tympanic Multiple Regression Model*

Parameter	**Estimate**	**Standard Error**	**t Value**	**r > |t|**
Intercept	97.658	0.081	1201.61	.001
Age	-0.005	0.001	-4.66	.001
Gender F	0.582	0.050	11.46	.001
Gender M	0.000			
Time 3	0.346	0.057	5.99	.001
Time 2	0.314	0.058	5.40	.001
Time 1	0.000		.	

$F=53.70$ $p<0.001$ $r^2=.18$

Comparison of Means

Oral and Tympanic Thermometers

A *t* test was done to compare the means between the two thermometer types. The means were statistically different (*p* 0.001). Table 22 summarizes the analysis.

Table 22. *Comparison Between Oral and Tympanic Temperatures*

	Mean	**95% CI**	**t-value**	**p-value**
Oral	98.3	(98.26-98.33)	-13.64	<0.001
Tympanic	97.9	(97.89-97.99)	-13.64	<0.001

Comparison With Previously Known Mean Temperatures

The aggregate oral and tympanic temperatures of participants were independently compared to the widely accepted norms of 98.2^0F, as stated by Mackowiak and 98.6^0F as stated by Wunderlich. The results of the two-tailed t-test demonstrated that there is a statistical difference between both widely accepted values, both in the case of oral $(p < .000)$ and tympanic temperature $(p < .000)$. This information is shown below in- 23.

Table 23*. Two-Tailed t-Test of Average Body Temperatures*

	df	**98.2^0F(Mackowiak)**		**98.6^0F (Wunderlich)**	
		t	**Sig.**	**t**	**Sig.**
Oral Temperature	999	5.479	.001	-17.375	.001
Tympanic Temperature	998	-9.929	.001	-25.340	.001

Summary

The purpose of this research was to determine the normal body temperature of 1000 community-dwelling adults between the ages of 21 and 100 who described their current state of health as well. Univariate and multivariate analysis were conducted to examine the relationship between potential predictor variables and body temperature, both oral and tympanic. In addition, the correlation between oral and tympanic temperature for this sample was determined.

In the study population, men had lower temperatures than women for both temperature measurement methods; temperature decreased as age increased; temperature was statistically correlated with age, gender, time of day, aspirin use, and menstrual status. In the multiple regression models only gender, age, and time of day were predictive of temperature and accounted for less than 18% of the variance.

Thermometer agreement was moderate (r^2 = .35) with tympanic measurements consistently lower than oral measurements. The mean oral and tympanic temperatures for men and women were as follows: men/oral 98.2^0F, men/tympanic 97.5^0F: women/oral 98.3^0F, tympanic 98.1^0F. It is striking that the mean tympanic temperature for men (97.5^0F) was a full degree lower than the Wunderlich mean of 98.6^0F (p = .001). The combined means of the oral and tympanic temperatures of the study population was 98.1^0F and was statistically significantly different from the Mackowiak mean of 98.2^0F ($p < 0.001$) and the Wunderlich mean ($p < 0.001$).

Based on this multi-site study of 1000 well persons of ages 21-100, using two thermometer types commonly used in clinical practice, it is concluded that 98.1^0F is the mean temperature of the total population. The null hypothesis is rejected and the alternate hypothesis accepted.

CHAPTER 5

DISCUSSION

This section will discuss the research question, findings regarding the covariates, clinical implications, strengths and weaknesses of the study, and recommendations for future research.

Findings

Research Question

Since the publication of *Verhalten der Eigenwarme in Krankenheiten* in 1868, 98.6^0F has been used as the referent to establish normality in human body temperature. This norm has been so widely accepted that almost anyone when asked "what is normal body temperature" replies 98.6^0F.

Despite conclusions of other researchers that "normal" body temperature was likely lower, as discussed in Chapter 2, there has not been widespread acceptance of these findings and none of them clearly established an alternate or new "normal." To date, this is the largest reported study of temperature in community-dwelling well adults. This study asked the question "What is normal body temperature in well adults" and, based on 2000 measurements from 1000 persons in four cities, concluded that 98.1^0F better represented "normal" temperature in well persons.

Although the overall mean of 98.1^0F (which combines the lower tympanic mean 97.9 ^{0}F and the oral mean 98.2^0F) is statistically significantly different from the 1992 Mackowiak mean from 150 adults of 98.2^0F (p <.001), the overall *oral* mean is the same, 98.2^{0}F. This provides further support for the establishment of a “new” normal temperature when a measurement is taken with an oral thermometer.

Tympanic mean temperature is harder to compare in that there are fewer comparisons of tympanic measurements in well persons. In this study population, the mean tympanic temperature was 97.9^{0}F, well below both 98.6^{0}F and 98.2^{0}F, suggesting that a tympanic measurement of 98.6^{0}F could never be “normal.” Regardless of measurement type, this study provides strong support for the establishment of lower mean temperature that more accurately represents “normal” body temperature when measured by an oral or tympanic thermometer.

Covariates

Covariates of interest were gender, age, smoking status, ethnicity, time of day temperature was taken, menstrual status, diabetes, 81mg aspirin use, statin use, and body mass index. Two covariates, exercise within the last hour and eating within 30 minutes were used primarily for screening and are not included in this discussion. The covariate of working at night is also excluded from discussion. There was no statistical difference in temperature between those who worked nights and those who did not and conclusions regarding circadian variability cannot be drawn from the very small number who worked nights.

The covariates of gender, age and time of day were most predictive of body temperature; however all covariates except BMI were statistically significantly associated with either oral or tympanic thermometer measurements, or both, and are discussed in the following section.

Gender. Gender was highly correlated with both thermometer measurements (*p* <.001) and in the multiple regression model was predictive of body temperature for both thermometer types (*p* <.001). Regardless of thermometer type, men had lower temperatures in every age group. Although the aggregate mean oral temperatures for men and women were similar (98.2^{0}F and 98.3^{0}F), the aggregate mean tympanic temperatures were strikingly dissimilar (97.5^{0}F and 98.1^{0}F).

Women had lower temperatures as they aged, but these temperatures were consistently higher than men's temperatures in every age group. It is worth noting that regardless of thermometer type, the highest mean temperature for all men over 61 (n = 48) was 97.9^{0}F, and in the 81-100 group, the tympanic mean was only 97.3^{0}F (n = 17). These numbers are relatively small but they provide a foundation for other studies that might include a larger population of well elderly men.

The gender difference noted in this data is at variance with other recent studies that found no statistical difference between the temperatures of elderly men and women (Gomolin, Aung, Wolf-Klein & Auerbach, 2005; Gunes & Zaybak, 2008). The magnitude of the difference between older men and women has not been previously described in any current literature. Men were underrepresented in every age group in this study population and further research is needed to determine if this finding can be further substantiated. If lower temperatures are characteristic of men, temperature norms would have to be further reconsidered. This will be discussed further under clinical considerations.

Age. Generally, temperature steadily decreased as age increased, dropping more than one half degree over the adult life-time. Age was statistically significant in predicting temperature (p <.001) and was highly correlated with temperature (p <.001). Both the oral and tympanic temperature means steadily decreased with each decade for both men and women, with the lowest means for women ages 81-90 (n = 18), and the oldest men 91-100 (n = 2).

Younger men and women had higher oral and tympanic temperatures. Women between the ages of 21-30 had oral temperature means closest to 98.6^0F (98.4^0F). This was the highest mean temperature for any age group regardless of thermometer type. However, the tympanic mean in this group was lower (98.3^0F).

Based on this study population, it is very unlikely that well adults over 61 would present with a temperature 98.6^0F, regardless of type thermometer type. Using mean oral and tympanic temperatures for all men and women ages 61 and older (97.9^0F) a measured temperature of 98.6^0F could represent an equivalent temperature of 99.4^0F. If only the tympanic mean (97.5^0F) is used, the equivalent 98.6^0F temperature could be 99.7^0F.

It has been assumed that older persons do not mount a fever in response to illness because they rarely have temperatures above “normal.” Dinarello and Gelfand, in Harrison (2001), state “…elderly individuals can exhibit a reduced ability to develop fever, with only a modest fever even in severe infections” (p. 91). *UpToDate*, an authoritative on line reference for Providers states, “…it is well-established that the ability to develop fever in the elderly is impaired…” (May 2010).

If 98.6^0F is used as a referent, the results of this study suggest that if persons older than 71 had tympanic temperatures of 98.6^0F, they could have the equivalent temperature of 99.6^{0}F for women, and 100.0^{0}F for men. The current definition of fever (100.4^{0}F) could possibly represent a real temperature as high as 101.3^{0}F in elderly men, and 100.9^{0}F in elderly females. It may be that elderly persons with a "modest" temperature have indeed mounted a response to infection, but that it has gone unrecognized. This finding deserves further study, and if this point is substantiated, it has important ramifications as the population of the U.S. ages.

Time of day. Circadian variability has been well established, with temperatures reported to be lowest in the morning and highest in the evening. As expected, in this sample, temperatures by both methods were lowest in the period 8 AM – 11:59 AM: oral 98.2^{0}F, tympanic 97.7^{0}F. However, they were identical for the 12 PM – 3:59 PM period, and the 4 PM to 8 PM period: oral 98.4^{0}F, tympanic 98.1^{0}F.

The afternoon/evening group represented over one half of the total sample (n = 535) and in this population, temperatures did not rise as expected from afternoon to evening. Significantly, no one in any age group reached an afternoon temperature of 99.9^{0}F, reported to be the "maximum normal oral temperature" from 4 PM to 6 PM (p. 90) in Harrison's *Principles of Internal Medicine* (2001). Based on study data there is little reason to dismiss an afternoon or evening oral or tympanic temperature of greater than 99.0^{0}F as "normal."

Smoking. Previous studies (Winn, 2001) have reported that smokers had higher oral temperatures than non smokers. In this sample, 10% (n = 100) smoked, and there was a statistically significant correlation between higher oral temperatures and smoking (*p* .016*).* Approximately the same number of men (n = 46) and women (n = 54) smoked. Most male (n = 27) and female (n = 27) smokers were younger than 40. It should be noted that these were the age groups that also had the highest mean oral temperatures regardless of smoking status, and smoking was not predictive of temperature in the multivariate model. Tympanic temperature was not statistically different between smokers and non smokers suggesting that if smokers have oral higher temperatures, it is likely due to some factor associated with cigarette smoking.

Ethnicity. Ethnicity was self reported and it was correlated with oral temperature (*p* .003). However, the samples of Native Americans (n = 11, 1.1%), Asians (n = 37, 3.7%), and Hispanics (n = 72, 7.2%) were too small to draw any meaningful conclusions about possible ethnic differences. Ethnicity becomes increasingly difficult to determine as racial blending becomes increasingly common, and categories for self identification expand.

At several community college sites participants talked among themselves about how to respond, unsure whether they should respond “other” because they regarded their heritage as African or Caribbean, or “African American” because they were black. Many of the “other” respondents indicated that they were from Middle Eastern countries. Any further investigation of this covariate should more clearly define ethnic categories and should include much larger representative populations.

Menstrual status. Menstrual status, self reported, was highly correlated with both thermometer measurements, (*p* <.001) but was not predictive in the multivariate analysis. Many women did not voluntarily respond to this question but disclosed the date of their last period when discretely asked. Many gave approximate dates making the distinction between the follicular and luteal phase of the menstrual cycle difficult to identify with precision. Based on dates women gave, there was no difference in temperatures between the luteal (n = 152) or follicular (n = 158) phase. This is at variance with many published studies that report slight temperature elevations in the luteal phase of the menstrual cycle; however, based on the uncertainty of menstrual cycle dates in this study, no meaningful conclusion can be drawn from this data. Post menopausal women (n = 292) had mean oral temperatures of 98.0^0F, tympanic mean temperatures of 97.8^0F.

Diabetes. The number of participants identifying themselves as having diabetes (no differentiation was made between insulin and non insulin dependent diabetics) was small (n = 48, 4.8%) and only oral temperature showed a statistically significant correlation (p <.001) with temperature. It is interesting to note that those with diabetes had lower oral temperatures than those without diabetes. No data was captured about average blood glucose levels, medications, or diabetes trajectory. It was anticipated that diabetics would have higher temperatures because diabetes is associated with a pro inflammatory state. This finding is an area for further inquiry. If diabetics truly have lower temperatures as a consequence of their disease, medications, or other factors, temperature elevations may not be recognized as such in this population.

Aspirin use. Low dose aspirin use (81 mg) was correlated with oral and tympanic temperatures (*p* <.001 for both). Although it was not predictive of temperature in the multivariate model, women 61 and older taking 81 mg ASA averaged lower temperatures than the non ASA users (97.7^0F compared with 97.9^0F). There was no difference in temperature between men 61 and older who took 81 mg of ASA and those who did not.

Statin use. Statin use was considered as a covariate because of its reported pleiotropic effect in reducing inflammation (Liao & Laufs, 2004), possibly resulting in lower temperatures among statin users. Although statin use was statistically significantly correlated with both oral and tympanic temperatures (*p* <.001), it was not predictive in the multivariate model. Since the study did not collect information on statin type or dose, or other variables such as length of time on statin, no conclusions can be drawn from this data in this study.

Body mass index. There is considerable concern regarding the increasing number of overweight persons, and average BMI has steadily increased over the last several decades. Information regarding the height and weight of each participant was requested and all but one person complied. However, many participants “guessed” their weight (although almost all knew their exact height). The very highest temperatures by both methods were found in the small sample (n = 3) of the severely underweight, BMI <16.5: oral temperature 98.6^0F, tympanic 98.4^0F. BMI was not correlated with temperature whether run as a continuous or categorical variable and was not included in the multivariate model. If BMI is to be accurately evaluated, participants would have to be weighed and measured at the time of temperature taking.

Clinical Implications

Recognition of illness. What is the purpose of temperature evaluation? As discussed in Chapter 1, assessment of temperature, whether subjectively or objectively, has been a component of determining health status since the earliest known times (Mackowiak, 1998b). Until the widespread use of the clinical thermometer, temperature elevation above the perception of normal or expected was a subjective value and was usually correlated with an observable illness. When *Verhalten der Eigenwarme in Krankenheiten* was published in 1868 and subsequently translated into English for the English in 1873 (Woodward), and into English for Americans (Seguin) also in 1873, the quantification of temperature became a gold standard in determining not only illness, but also degrees of illness.

Although there were studies published prior to *Verhalten der Eigenwarme in Krankenheiten* that proposed other (lower) temperatures, hardly any of them were translated into English. As a result of the widespread dissemination of the Woodward and Seguin translations, 98.6^0F quickly became the accepted normal temperature and endured with only tepid challenges until the 1992 Mackowiak publication.

Despite findings from the Mackowiak (1992) study (n = 150) that mean oral temperatures were lower (98.2^0F), and general statements in medical and nursing textbooks that temperatures vary from person to person, vary by measurement type, vary by time of day, no new mean has been convincingly established to supplant 98.6^0F. This continues to be the referent to determine whether or not a person is “febrile.” Even authoritative sites such as Mayoclinic.com (“…average body temperature of 98.6^0F …”), and senior-health-medicare (…”normal oral body temperature of 98.6^0F …), and many other sites providing general health information continue to disseminate 98.6^0F as "normal" temperature.

Many participants in this study thought their temperatures would be lower. There were many comments about "my temperature is usually 97"…"it's going to be 96"…"it's always low, you probably don't want me." At all sites participants complained that when their temperatures were 98.6^0F, they were "really sick" and that if they sought medical attention, their illness was not taken seriously. There were several recountings about friends or relatives who had serious illnesses that were not diagnosed in a timely fashion because of temperatures that were 98.6^0F and were regarded as normal.

The findings of this study have important implications for temperature evaluation in adults, but they are of particular importance in older adults. Based on this data, temperature is likely to be elevated in all adults when it reaches 98.6^0F: a temperature of 98.6^0F represents a significant elevation in adults over 61, and it is very significantly elevated in the oldest adults.

Recognition of fever, however it is defined and quantified, is a cornerstone of patient evaluation and is a "vital" sign. Regardless of decisions about the treatment of fever which is beyond the scope of this study, identification of fever is as essential part of diagnosis and patient care, and has important public health implication. Evaluation for fever has been instituted on a global scale when pandemics have threatened, most recently during the H1N1 flu outbreak. Mass screenings for fever in airports, such as were done in the H1N1 epidemic, and also in the SARS and Bird Flu outbreak, have been done with infrared thermal imaging.

New international standards have been accepted to standardize screening (Ring, McEvoy, Jung, Zuber, & Machin, 2010). However, most mass screenings devices are programmed to recognize temperatures of 99.0^{0}F to 99.2^{0}F well into the fever range for most adults (reference). Recognition and acceptance of a lower referent for fever may literally be lifesaving for large populations if fever, as a marker in potential pandemics, is accurately identified.

Strengths and Limitations

Strengths. Strengths of this study included standardization of technique and thermometers, data were gathered from four geographically separated cities, the large sample (n = 1000) included the entire adult age range, and the period of data collection included temperatures taken during morning, afternoon, and evening hours.

Only two thermometers of each type were used in the study. All temperature measurement was conducted by the researcher using technique specified by the manufacturer and was consistent for all participants at all sites. This is particularly important in that some prior comparisons showing wide variability between oral and tympanic measurements has been attributed to variability in user technique or to anomalous ear anatomy. Given the consistently lower tympanic readings, all taken by the same researcher, it does not seem likely that the discordance can reasonably be attributed to these factors, unless one assumes a very large number of participants had ear anatomy not suited to tympanic measurement. It seems more likely that the differences between the thermometer types are real.

Temperature measurements were gathered from four geographically separated cities enhancing confidence in the generalizability of the data. Unlike the other studies that also identified lower temperatures in specific populations of adults, the entire spectrum of adult ages was represented in this large sample allowing the determination of a true mean.

The temperature-taking time period covered 12 hours, from 8 AM to 8 PM. As previously discussed, findings from the study population did not reflect the magnitude of temperature rise expected from circadian literature. Many studies of circadian variation use rectal thermometers that were left *in situ* during the period of investigation. It is difficult to make comparisons between measurement types especially when considering the variability in this study between oral and tympanic measurements, but in this multi site population, temperature did not rise even to “normal” in the afternoon and evening, further discrediting the continued use of 98.6^0F. If this finding should be replicated in sufficiently large population to be convincing, using both measurement methods, there are also important implications for assessment of afternoon and evening temperatures.

Limitations. There are significant limitations to this study. The study population was not a random sample. Volunteers were recruited from a variety of sites and were entirely self-selected. More women than men volunteered in every setting. The number of older adults is small. Neither the sites nor the volunteers from the sites may have been representative of the population at large.

All data collected except for the temperature measurements was self reported. Ethnicity, as previously discussed, was confusing; height and weight were not measured; menstrual status was particularly uncertain; participants may not have been entirely well. Temperatures were taken during the flu season, and in fact data collection was postponed during the time of H1N1 outbreak so as to avoid participants who might have early flu.

Differences Between Oral and Tympanic Thermometers

One of the most surprising results was the striking difference between oral and tympanic temperatures in many participants. The data were not analyzed until data collection was completed, and during the temperature taking period, while it was clear that there were differences, the magnitude of the difference was not apparent. Some participants had as much as 2^0F difference between oral and tympanic measurements: differences of over 1^0F were common, but no direction, whether the oral or tympanic was higher, was apparent. The thermometers used in this were both manufactured by Braun-Welch Allyn. Both oral and tympanic models used in this study were more recent updates of thermometers used in other studies. These findings lead to questions regarding the interchangeability of the two measurement methods.

There have been many studies comparing the accuracy of oral and tympanic measurements from the time of the introduction of the tympanic thermometer to the present. A great number of them come from the pediatric literature and the findings are inconsistent (Paes, Vermeulen, Broheet, van der Ploeg, & Winter, 2010). Adult studies have also been inconclusive. In a 2000 person single site hospital study in Pakistan, tympanic measurements were found to be reliable in persons under age 60, but not for those older (Rabbani, Malik, Nufti, Bun Pervev, & Ilfekhar, 2010). Hasper, Nee, Schefold, Krueger, and Storm (2009) had similar findings, also in a single site hospital population. Conversely, Lu, Dai, and Yen (2009) reach the opposite conclusion in a multi site study of 500 elderly community-dwelling adults in Taiwan, as did Onur, Guneysel, Akoglu, Aydin, and Denizbasi (2008) in a single site Australian population. They conclude, "Tympanic thermometers seem to be optimal for use with the elderly population," (p. 34) and "…there is no statistically significant variation between younger and older adults [as regards measurement methods]" (p. 337).

It is difficult to reconcile these differences. In this 1000 person four city study, rigorously controlled for thermometer type and user technique, thermometer agreement was r^2 .35, indicating only moderate agreement (Lipsey, 2000). It seems likely that there may be even greater variability between methods when there are multiple temperature takers such as the patient taking her own temperature, family members, medical assistants, nurses, and other professional and non professional people. The findings from this study, in accord with others, suggest that the two temperature measurement methods are not interchangeable, and that it is important that the method of measurement be taken into account in temperature evaluation.

A new method of temperature evaluation, the temporal artery thermometer, is increasingly used for both adults and children. Studies sponsored by the manufacturer initially established its accuracy. Despite a number of studies questioning its correlation with either tympanic or oral measurements, it continues to be used in many settings presumably because of convenience. It was considered for inclusion in this study, however, at the time of study design it was concluded that there was insufficient data to support its reliability (Hooper & Andrews, 2006; Ronneberg, Roberts, McBean, & Center, 2008). A recent comparison of several brands of oral, tympanic, and temporal thermometers in a pediatric population concluded that the temporal thermometers preformed less well than oral and tympanic thermometers and commented on, "…the inaccuracies of infrared skin thermometers in this study" (Paes, Vermeulen, Brohet, van der Ploeg, & de Winter, 2010, p. 4). It is worrisome that the accuracy of this temperature measurement device continues to be questioned, yet it remains in use.

Fahrenheit and Centigrade

Since the time of the introduction of the Fahrenheit and Centigrade scales they have both been in common usage. One was never regarded as more “scientific” than the other. It is puzzling why centigrade came to be used in “scientific” nomenclature and Fahrenheit in community and common-place language. Perhaps it is a measure of convenience; since fever is currently defined as of as a single reading 38.5^0C (101.0^0F) or a reading of 38^0C (100.4^0F) over one hour, most practitioners simply regard temperatures of less than 38^0C as representing an “afebrile” state regardless of the measurement method.

Unlike medical professionals almost no patients in the US report their temperatures in centigrade and they are not familiar with the scale except in a very general way. The Fahrenheit scale is ubiquitous in the US. It is used to report weather temperature, recommended cooking temperatures, room temperatures, etc., and the centigrade scale is unused except in the “scientific” setting. Since it is unlikely that the centigrade scale will come into widespread use (consider the failure of the concerted campaign to use kilometers instead of miles), medical personnel should communicate using the scale that patients best understand and should reframe their thinking to regard temperatures greater than 36^0C as likely temperature elevations.

Recommendations for Future Research

1. The gender difference in temperatures was striking and has potential clinical significance and should be studied further. There is burgeoning interest in

women's health and important differences between men and women continue to be identified.

2. The consistently lower temperatures of older adults should be further explored with a larger number. As the US population ages and an increasing number of older adults make increased demands on the health care system, accurate and early diagnosis of potentially serious illness is essential. Accurate assessment of temperature is literally vital.
3. The temperature of children is generally assumed to be "normal" at 98.6^0F. Exploring temperature in a large population of well children of all ages would confirm 98.6^0F as a reasonable referent, or establish a new one more predictive of illness.
4. Replicating this study with large randomized samples for age and gender. Both men and older persons were underrepresented in this study, and other studies have not had large enough numbers to convincingly impact practice.
5. Further exploration of the possible relationships between statins and temperature and ASA and temperature. It is commonly assumed that these medications do not impact temperature. Dinarello and Gelfand, in Harrison (2001), state "Chronic high-dose therapy with antipyretics such as aspirin or the NSAIDs used in arthritis does not reduce normal core body temperature" (p. 94). Although ASA was not predictive or temperature in the regression model, both ASA and statin were highly correlated with temperature.

6. Similarly, the association between slightly lower temperatures in those participants reporting that they have diabetes is intriguing, and deserves further study.
7. Comparison between temperatures taken with professional grade thermometers and those used at home. In the same way that professional grade scales such as the ones used in clinical setting are often not concordant with home scale measurement, temperatures taken at home may not reflect the same measurements obtained with professional grade equipment. Since so many participants related that their home temperatures were lower that their temperatures obtained in this study, this may be an important undertaking.

Conclusion

Why has 98.6^0F endured since 1868 and why does it remained so entrenched? This researcher is convinced it is because no new convincing “normal” replaces it. Prior studies, essentially in agreement with the premise that body temperature is lower, have not taken a stand in proposing a new referent. It is insufficient to say that normal temperature is a range: that it varies from person to person: that it varies depending on time of day although all of these are true.

Almost 20 years ago, Mackowiak, in his sample of 148, found 98.2^0F to be the mean oral temperature in healthy adults, yet this convincing finding did not make its way into every day clinical practice and definitions of fever remain unadjusted. Authoritative information sources continue to present 98.6^0F as normal body temperature.

Based on findings in this study, and supported by the findings of Mackowiak, a new referent should replace 98.6^0F. It makes little real difference whether the population mean of 98.1^{0}F that combines oral and tympanic measurements or 98.2^{0}F, the oral mean is adopted and 98.2^{0}F is now confirmed as the mean oral temperature in two studies. Its widespread and immediate adoption is timely..

Wunderlich established 98.6^{0}F as normal body temperature based on the best information available to him in the mid 1800s using the best science of the time. But science has always had to accommodate new findings. What was “fact” has, in many instances, proven to be surprisingly mutable. We once thought the world was flat: then Magellan sailed. We once thought the sun revolved around the earth: then there was Copernicus. The world is not flat. The sun does not revolve around the earth. We have new information; 98.6^{0}F is not normal body temperature: it is 98.2^{0}F.

APPENDICES

Appendix A
Consent Form

The University of New Mexico Health Sciences Center
Consent to Participate in Research

An Exploration and Reconsideration of Human Body Temperature in Healthy Adults

Purpose and General Information
You are being asked to participate in a research study that is being done by Dr. Leah Albers, who is the Principal Investigator, and her associates. This research is being done to evaluate normal body temperature. You are being asked to participate because you are feeling well today. Approximately 1000 people will take part in this study from the University of New Mexico. Some 250 people will participate from Portland,OR, Minneapolis-St Paul, MN, Hartford, CT, and Albuquerque, NM.

This form will explain the study to you, including the possible risks as well as the possible benefits of participating. This is so you can make an informed choice about whether or not to participate in this study. Please read this Consent Form carefully. Ask the investigators or study staff to explain any words or information that you do not clearly understand.

What will happen if I participate?
If you agree to be in this study, you will be asked to read and sign this Consent Form. After you sign the Consent Form, the following things will happen: You will be asked to sit for five minutes, then have your temperature taken both orally (by mouth) and tympanically (with the ear thermometer). You will also be asked to fill out a short questionnaire while you are sitting.

Participation in this study will take a total of 5 minutes.

What are the possible risks or discomforts of being in this study?
Every effort will be made to protect the information you give us. However, there is a small risk of loss of confidentiality We will not collect any personally identifying information such as your name or address. We will ask some personal health information. Since you have had your temperature taken many times before in the past, other than the inconvenience of helping us today, we do not forsee any risk to you..

How will my information be kept confidential?
Your name and other identifying information will be maintained in locked files, available only to authorized members of the research team, for the duration of the study. The only document that will have your name is the consent document. The questionnaire will not identify you by name. Any personal identifying information and any record linking that information to study ID numbers will be destroyed when the study is completed. Information resulting from this study will be used for research purposes and may be published; however, you will not be identified by name in any publications.

Information from your participation in this study may be reviewed by the College of Nursing, federal and state regulatory agencies, and by the UNM Human Research Review Committee (HRRC) which provides regulatory and ethical oversight of human research.

What are the benefits to being in this study?
There may or may not be direct benefit to you from being in this study. However, your participation may help find out normal body temperature in well adults.

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The University of New Mexico Human Research Review Committee

What other choices do I have if I don't participate?
Taking part in this study is voluntary so you can choose not to participate.

Will I be paid for taking part in this study?
No.

Can I stop being in the study once I begin?
Yes. You can withdraw from this study at any time without affecting your participation if you let us know before you leave the study area. After you leave, we cannot discard your results because we won't know which ones are yours since we are not collecting any personal identifying data.

The investigators have the right to end your participation in this study if they determine that you no longer qualify to take part, if you do not follow study procedures, or if it is in your best interest or the study's best interest to stop your participation.

What if I have questions or complaints about this study?
If you have any questions, concerns or complaints at any time about the research study, Rebecca Mayo RN MA PhD(c), Nurse Practitioner, or her associates will be glad to answer them at 505-272-3843. If you would like to speak with someone other than the research team, you may call the Human Research Review Committee (HRRC) at (505) 272-1129. The HRRC is a group of people from UNM and the community who provide independent oversight of safety and ethical issues related to research involving human subjects.

What are my rights as a research subject?
If you have questions regarding your rights as a research subject, you may call the HRRC at (505) 272-1129 or visit the HRRC website at http://hsc.unm.edu/som/research/hrrc/.

Consent and Authorization
You are making a decision whether to participate in this study. Your signature below indicates that you read the information provided (or the information was read to you). By signing this Consent Form, you are not waiving any of your legal rights as a research subject.

I have had an opportunity to ask questions and all questions have been answered to my satisfaction. By signing this Consent Form, I agree to participate in this study and give permission for my health information to be used or disclosed as described in this Consent Form. A copy of this Consent Form will be provided to me.

__________________________ __________________________/_______
Name of Adult Participant (print) Signature of Adult Participant Date

I have explained the research to the subject and answered all of his/her questions. I believe that he/she understands the information in this consent form and freely consents to participate.

__________________________ __________________________/ __________
Name of Research Team Member Signature of Research Team Member/Date

Appendix B
Sign Asking for Volunteers

Nursing Research Project
Are you between 21 and 100?

Are you well today?

Could we take your temperature (ear and oral)?

No identifying data collected.

Only takes 5 minutes.

We’d really appreciate your help!

Appendix C
Gender-Specific Screening Questionnaires

Screening Questionnaire—Women

Please answer the following questions.

All of your responses will be confidential and your temperature and all other collected data will be reported only as part of group information.
Thank you very much for your participation.

Question	**Answer**
Do you consider yourself to be well today?	Yes No
Do you have any of the following conditions? Please circle if yes.	Arthritis Diabetes Cancer Lupus HIV/AIDS Organ transplant
Are you taking antibiotics?	Yes No
Do you take a "baby aspirin" – 81 mg?	Yes No
Have you taken Tylenol, Advil, Motrin, Ibuprofen, Naproxen, or any other fever reducing medication except a baby aspirin in the last 24 hours?	Yes No
Please list all the names of any medications you regularly take. If you do not know the name, please tell us what you take the medication for. For example, "a blood pressure pill."	
Do you take a "statin"? ie Lipitor, Pravastatin, Zocor	Yes No
What is your gender?	M F
What is your age today?	
What is your height?	
What is your weight?	
Do you smoke?	No Cigarettes A pipe Cigars
Do you consider your ethnicity to be:	African-American White Asian Hispanic/Latino Native American Other – please state
Do you work full time at night?	Yes No

Are you currently pregnant?	Yes No
Have you had anything to eat or drink in the last 30 minutes?	Yes No
Have you exercised vigorously in the last hour?	Yes No
When was your last menstrual period?	N/A
Do you consider yourself to be peri or post menopausal?	Yes - peri No Yes - post

STUDY LOCATION: AMBIENT TEMPERATURE:

ABQ MSP PDX HCT

Date: Oral temperature

Time: Aural temperature

Ear used: R L

Comments:

Study Number:

Appendix C (continued)
Gender-Specific Screening Questionnaires

Screening Questionnaire—Men

Please answer the following questions.

All of your responses will be confidential and your temperature and all other collected data will be reported only as part of group information.
Thank you very much for your participation.

Question	**Answer**
Do you consider yourself to be well today?	Yes No
Do you have any of the following conditions? Please circle if yes.	Arthritis Diabetes Cancer Lupus HIV/AIDS Organ transplant
Are you taking antibiotics?	Yes No
Do you take a "baby aspirin" – 81 mg?	Yes No
Have you taken Tylenol, Advil, Motrin, Ibuprofen, Naproxen, or any other fever reducing medication except a baby aspirin in the last 24 hours?	Yes No
Please list all the names of any medications you regularly take. If you do not know the name, please tell us what you take the medication for. For example, "a blood pressure pill."	
Do you take a "statin"? ie Lipitor, Pravastatin, Zocor	Yes No
What is your gender?	M F
What is your age today?	
What is your height?	
What is your weight?	
Do you smoke?	No Cigarettes A pipe Cigars
Do you consider your ethnicity to be:	African-American White Asian Hispanic/Latino Native American Other – please state
Do you work full time at night?	Yes No

Have you had anything to eat or drink in the last 30 minutes?	Yes	No
Have you exercised vigorously in the last hour?	Yes	No

STUDY LOCATION: AMBIENT TEMPERATURE:

ABQ MSP PDX HCT

Date: Oral temperature

Time: Aural temperature

Ear used: R L

Comments:

Study Number:

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