

## TEMPERATURE TELEMETER

**Background of the Invention****1. Field of the Invention**

5       The present invention relates generally to the measurement of body temperature. More particularly, the present invention relates to a system and method for measuring temperature from a body cavity and wirelessly transmitting the temperature reading to a receiver for monitoring.

**2. Description of the Related Art**

10       The measuring and monitoring of a person's core temperature ( $T_c$ ), also known as deep body temperature, is important for a variety of health and safety reasons. This is because a person's  $T_c$  must be maintained within a very narrow range for the body to function normally. Any excursion outside of this prescribed range can result in a number of temperature-related disorders and other physiological problems.

15       At elevated core temperatures, a person can develop disorders such as heat stroke and other symptoms such as exhaustion, cramps, rashes, and fatigue that may develop as a result of overheating. An abnormally high  $T_c$  may even result in death. Persons engaged in activities involving high ambient temperatures, radiant heat sources, high humidity, direct physical contact with hot objects, or strenuous physical activities are  
20       highly susceptible to heat disorders. Such risks are inherent in many industries and professions, including fire fighting, athletics, active military combat positions, and construction work. This is particularly true for workers that are required to wear semi-permeable or impermeable protective clothing.

25       At the other end of the spectrum, if  $T_c$  is too low, hypothermia may occur. A person may develop hypothermia when  $T_c$  falls below 35°C. In addition, hypothermia is frequently fatal when  $T_c$  falls below 32°C. Infants, neonates and elderly persons are generally susceptible to hypothermia. Elderly persons usually have a more limited ability to detect cold while infants and neonates are prone to becoming hypothermic because of

their lack of subcutaneous fat. In addition, mountain climbers, skiers, and other travelers to areas having chilly climates are also susceptible to hypothermia.

5 In many instances, temperature related disorders might be easily prevented by early detection of temperature excursions out of the acceptable range and administration of the appropriate preventive measures and treatments. After detection, prompt treatment will usually lead to a rapid and complete recovery. Therefore, it is best if persons at risk of developing temperature-related disorders, such as those involved in strenuous physical activity, have their core temperatures monitored.

10 For example, temperature monitoring is common in hospitals. During surgery, a patient's  $T_c$  is monitored and maintained at around  $36^\circ\text{C}$  to prevent the onset of mild hypothermia (except in cases of induced hypothermia). Another example of the use of temperature monitoring in hospitals is in an Intensive Care Unit (ICU). Because patients warded in an ICU are usually in serious condition, therefore in most cases, they must have their core temperatures monitored.

15 Because of the extensive applicability of core temperature measurements, a number of core temperature measuring devices have been developed. In hospitals, a patient's core temperature is usually monitored via a temperature probe inserted into a body cavity of the patient, such as the mouth, the axilla or the rectum. The temperature probe can also be inserted through the patient's nose, down to the esophagus. 20 Unfortunately, the insertion of a temperature probe into a patient's rectum or esophagus usually causes significant discomfort to the patient. Hence, a less invasive core temperature measuring device is highly preferred.

An example of a core temperature measuring device is an ingestible transmitter disclosed in U.S. Patent No. 4,844,076 issued to Lesho et al. The ingestible transmitter is 25 encapsulated in a pill and swallowed by a subject or patient. To ensure that the transmitter is in the proper location when  $T_c$  readings are taken, the subject must swallow the transmitter at least an hour before the temperature is measured.

To avoid interference between multiple transmitters, only one transmitter can be ingested at any one time. Therefore, the subject has to wait for the egression of the first

transmitter before swallowing a second. This limits the flexibility of the use of such core temperature measuring devices because there is a time lag before the core temperature measurements can be taken and utilized. Secondly, temperature measurements cannot be monitored for lengthy periods of time because the transmitter will not always be in the right position and will eventually be egressed. As such, the use of such core temperature measuring devices must be planned beforehand and timed accordingly.

Additionally, the temperature of foods and liquids consumed by the subject as well as fluids generated by the body may influence the core temperature measurements obtained through the use of such transmitters. Hence, the accuracy and consistency of the readings taken may vary. A further drawback of the Lesho transmitter is that it cannot be reused due to hygienic considerations. Therefore, the use of such ingestible transmitters can be rather costly since each transmitter is only operable for a limited period of time.

Other prior art devices which transmit temperature information from internal body locations are described in the following patent documents.

European Patent Application EP 476,730 describes a system for ovulation detection and prediction using an embedded temperature sensor which emits temperature information.

United States Patent US 4,515,167 and United Kingdom Patent Application GB 2,285,134 describe intra-vaginal temperature sensing and transmitting devices.

United States Patent US 4,676,254 describes an intrauterine device for monitoring ovulation by taken and storing a succession of temperature readings which are subsequently downloaded to an external device.

United States Patent US 5,033,864 describes a baby pacifier which is used intra-orally to detect temperature and transmit a signal to an external device if the detected temperature is outside a predetermined range.

These prior art devices are not ingested and are not used invasively in the usual medical sense of surgical invasion, i.e. involving puncture or incision of the skin. However, the positioning of these or other measurement devices to measure vaginal,

uterine, rectal or oral temperatures is intrusive, i.e. is invasive of the subject's privacy; and/or causes a degree of discomfort during insertion, use and/or retrieval; and/or is obstructive of the subject's normal functions and movements.

Core temperature measuring devices, such as ear temperature monitor 10 illustrated in Figure 1, are also commonly employed. Ear temperature monitor 10 comprises a monitor 12 coupled to an earpiece 14 via a flexible wire 16. Earpiece 14 further comprises a thermistor 18 encased in a foam earplug 20, and a speaker 22. Foam earplug 20 is first inserted into the ear canal of a subject. Thermistor 18 then measures the temperature within the ear canal. The measured temperature reading is sent through flexible wire 16 to monitor 12, where the temperature reading is stored and displayed on a screen 24. When a pre-set temperature threshold is reached, speaker 22 may be configured to sound a warning signal.

One limitation of this core temperature measuring device is that only the subject of ear temperature monitor 10 may conveniently monitor his own  $T_c$ . In the event of an emergency, for instance an acute case of hypothermia, devices such as ear temperature monitor 10 are unable to warn others of the subject's predicament. Even in less urgent circumstances, ear temperature monitor 10 is not well suited to provide the  $T_c$  of the subject to another monitoring entity.

Another problem with conventional core temperature measuring devices, such as ear temperature monitor 10, is that they are wired systems using thermistors or thermocouples. It is inconvenient and cumbersome to have a wire hanging out of a subject's ear, which is further connected to a monitor of considerable size. The wires may interfere with or hamper the mobility of the subject, while the monitor is an undesirable burden. This is particularly true when it is desirable to monitor the temperature of an active subject, such as a soldier or a construction worker. In such cases, the wires would become an occupational hazard.

In view of the foregoing, it is desirable to have a system and method to measure core temperature that is non-invasive and non-intrusive. It is also desirable to have an inexpensive system that can be used continually to generate consistent and accurate

readings, and that can be reused. Additionally, it is desirable to have a system, which allows monitoring of the core temperatures of a number of persons from a main terminal.

## **Summary of the Invention**

The present invention fills these needs by providing a temperature telemeter and a method and system to measure a body temperature. It should be appreciated that the present invention can be implemented in numerous ways, including as a process, an apparatus, a system, a device or a method. Several inventive embodiments of the present invention are described below.

In a first embodiment of the present invention, a temperature telemeter is provided. The temperature telemeter includes a sensor to measure a temperature of a body cavity, preferably an ear canal, of a subject. A transmitter coupled to the sensor receives the temperature from the sensor and generates a signal to transmit the temperature. A monitor receives the signal wirelessly from the transmitter and uses a conversion algorithm to convert the temperature to an estimated core temperature. The temperature telemeter preferably includes a housing to support the sensor and the transmitter.

Preferably, the housing secures the temperature telemeter to the ear canal. The housing is also preferably shaped to fit in the ear canal. Additionally, the temperature telemeter preferably includes a modulator, coupled between the sensor and the transmitter, to amplify the signal. Preferably, the temperature telemeter includes a battery housing for supporting a battery to provide power for the sensor and the transmitter.

In a preferred embodiment, the temperature telemeter includes an ambient temperature sensor to measure an ambient temperature. The temperature telemeter preferably includes a compensation algorithm which uses the ambient temperature to compensate the estimated core temperature for changes in the ambient temperature. The estimated core temperature may be displayed on the monitor.

In a second embodiment of the invention, a method for providing an estimated core temperature of a subject is provided. The method begins by measuring a temperature from a body cavity of the subject to generate a temperature measurement, which is transmitted wirelessly to a monitor. The temperature is converted to an

estimated core temperature using a conversion algorithm. Preferably, an alert is provided when the temperature exceeds or falls below a predetermined temperature range.

In a third embodiment of the invention, a temperature telemetric system is provided. The temperature telemetric system includes a plurality of temperature  
5 telemeters. Each of the plurality of temperature telemeters includes a sensor to measure a temperature of a body cavity of a subject and a transmitter coupled to the sensor to receive the temperature from the sensor. The transmitter generates a signal to transmit the temperature. A central monitor receives the signal wirelessly from the transmitter of each of the plurality of temperature telemeters and uses a conversion algorithm to convert  
10 the temperature to an estimated core temperature.

In a fourth embodiment of the invention, a temperature telemeter is provided. The temperature telemeter comprises a sensor to measure a temperature of a body cavity of a subject and a transmitter coupled to the sensor. The transmitter receives the temperature from the sensor and generates a signal to transmit the temperature. A monitor receives  
15 the signal from the transmitter wirelessly. The temperature telemeter includes an ambient temperature sensor to measure an ambient temperature.

Preferably, the temperature telemeter includes a compensation algorithm which uses the ambient temperature to compensate the temperature of the body cavity for changes in the ambient temperature. The monitor may display the temperature of the  
20 body cavity.

In a fifth embodiment of the invention, a method for measuring a body temperature of a subject is provided. The method begins by measuring a temperature from a body cavity of the subject to generate a temperature measurement, which is wirelessly transmitting to a monitor. An ambient temperature is measured and used with  
25 the ambient temperature in a compensation algorithm to compensate the temperature measurement for changes in the ambient temperature and thereby generate a compensated temperature value. The compensated temperature value may be displayed.

Other aspects and advantages of the invention will become apparent from the following detailed description, taken in conjunction with the accompanying drawings, illustrating by way of example the principles of the invention.

### **Brief Description of the Drawings**

The present invention will be readily understood by the following detailed description in conjunction with the accompanying drawings. To facilitate this description, like reference numerals designate like structural elements.

5        Figure 1 illustrates a conventional ear temperature monitor.

Figure 2 illustrates a schematic of a temperature telemeter in accordance with one embodiment of the present invention.

Figure 3 illustrates a perspective view of a temperature telemeter in accordance with one embodiment of the present invention.

10       Figure 4 illustrates an anatomical view of an ear canal with a probe inserted therein in accordance with one embodiment of the present invention.

Figure 5a illustrates a scatter diagram of  $T_{ec}$  as a function of  $T_{re}$  based on data obtained from a trial conducted on one embodiment of the present invention.

15       Figure 5b illustrates a scatter diagram of  $T_{ec}$  as a function of  $T_{gi}$  based on data obtained from a trial conducted on one embodiment of the present invention.

Figure 5c illustrates a scatter diagram of  $T_{ec}$  as a function of  $T_{alt}$  based on data obtained from a trial conducted on one embodiment of the present invention.

Figure 6 illustrates a perspective view of a subject wearing a temperature telemeter in accordance with one embodiment of the present invention.

20       Figure 7 illustrates an anatomical view of an ear canal with a probe inserted therein in accordance with one embodiment of the present invention.

Figure 8 illustrates a schematic of a temperature telemeter in accordance with another embodiment of the present invention.

Figure 9 illustrates an anatomical view of an ear canal with a probe inserted therein in accordance with another embodiment of the present invention.

Figure 10 illustrates a schematic of temperature telemetric system in accordance with a further embodiment of the present invention.

## **Detailed Description of the Preferred Embodiments**

A temperature telemeter and a method to measure a body temperature are provided. In the following description, numerous specific details are set forth in order to provide a thorough understanding of the present invention. It will be understood, however, to one skilled in the art, that the present invention may be practiced without some or all of these specific details. In other instances, well known process operations have not been described in detail in order not to unnecessarily obscure the present invention.

Figure 2 illustrates a schematic of a temperature telemeter 50 in accordance with one embodiment of the present invention. Temperature telemeter 50 comprises a sensor 52 enclosed in a probe 54 coupled to a housing 56, which supports a modulator 58, a transmitter 60 and a battery casing 62. A battery supported by battery casing 62 may be used to power sensor 52, modulator 58, and transmitter 60. Temperature telemeter 50 further comprises a monitor 64, which receives temperature signals wirelessly from transmitter 60.

Probe 54 is inserted into a body cavity, such as an ear canal, under an armpit, in a mouth, etc., so that sensor 52 can measure the temperature in the body cavity ( $T_{bc}$ ) and generate a temperature signal. Sensor 52 is positioned near the surface of probe 54 so that sensor 52 will be in close proximity to the surface of the body cavity. This facilitates the attainment of a more accurate temperature measurement. The temperature signal generated by sensor 52 is relayed to modulator 58. Modulator 58 varies the amplitude, frequency, and/or phase of the temperature signal to an appropriate waveform for transmission by transmitter 60.

Monitor 64 receives the temperature signal wirelessly from transmitter 60 and displays  $T_{bc}$  in real-time. Additionally, the temperature signals received by monitor 64 may be stored and collated so that  $T_{bc}$  can be displayed in a graphical form when prompted by a subject. The option to display  $T_{bc}$  graphically allows the subject to keep track of the changes in  $T_{bc}$  more easily. To facilitate mobility, monitor 64 may be

implemented as a watch to be worn on a wrist or as a pager, which could be attached to a belt or kept in the subject's pocket.

5 An alarm 66 in monitor 64 alerts the subject when  $T_{bc}$  exceeds or falls below a predetermined temperature range. The warning given by alarm 66 can be auditory, such as a beep, a string of notes, etc., or vibratory. Alarm 66 can also be programmed to emit different types of signals depending on the severity of the incursion outside the predetermined temperature range. If information regarding an individual subject's physical conditions and abilities is available, alarm 66 can be tailored to suit a specific subject's requirements.

10 A battery to provide electrical energy to operate sensor 52, modulator 58 and transmitter 60 is inserted into battery casing 62. Battery casing 62 is designed such that the battery can be easily removed and replaced once the battery is flat so that temperature telemeter 50 can be reused. Many types of batteries may be implemented to provide power for the present invention. For example, two 1.55 Volt silver oxide batteries have  
15 been successfully implemented.

Figure 3 illustrates a temperature telemeter 100 in accordance with one embodiment of the present invention. Temperature telemeter 100 comprises a probe 102 coupled to a housing 104 by a flexible wire 106. Further, temperature telemeter 100 includes a monitor 108, which receives temperature signals wirelessly from a transmitter  
20 supported in housing 104.

A sensor 110, enclosed in probe 102, is inserted into an ear canal 150 as illustrated in Figure 4 to measure the temperature ( $T_{ec}$ ) in ear canal 150. Sensor 110 is located close to the surface of probe 102 so that sensor 110 will be in close proximity of the surface of ear canal 150. This facilitates the attainment of a more accurate  
25 temperature measurement.

Probe 102 may be molded according to the ear impression of a subject to obtain a better fit. As an alternative, sensor 110 may be embedded in a piece of foam or any other malleable material. With a better fit, probe 102 will be more securely positioned in ear

canal 150 and will not be easily dislodged. The subject is then able to carry out vigorous activities without fears of dislodging probe 102.

In the process of measuring  $T_{ec}$ , a temperature signal is generated by sensor 110. Referring back to Figure 3, a modulator, supported in housing 104, receives the temperature signal from sensor 110 and adjusts the amplitude, frequency, and/or phase of the temperature signal to an appropriate waveform before transmission by the transmitter to monitor 108.

The temperature signal, transmitted wirelessly by the transmitter, is received in monitor 108 and may be converted into a digital form.  $T_{ec}$  is then displayed digitally on a display 112 such as a liquid crystal display (LCD). As described in the previous illustration, the option of displaying  $T_{ec}$  graphically is also available. Having a graphical display is advantageous to track the history of changes in the  $T_{ec}$  of a subject.

Monitor 108 preferably includes a processor to execute a compensation algorithm to perform calculations to compensate for changes in ambient temperature ( $T_{amb}$ ). A  $T_{amb}$  sensor may be coupled to monitor 108 to measure  $T_{amb}$ . With  $T_{amb}$  as an input, the compensation algorithm is able to perform the appropriate calculations to generate a good estimate of  $T_{ec}$ . As an alternative, the  $T_{amb}$  sensor can also be located outside the ear canal, for example, in or behind the external ear, at housing 104.

Additionally, the present invention may include sensors to measure a variety of environmental conditions, such as dry bulb temperature, relative humidity, globe temperature, wet bulb temperature, and solar radiation. Additionally, the present invention may be integrated with other sensors to measure physiological conditions, such as heart rate, blood pressure, blood oxygen saturation, and electrocardiogram (ECG). In addition, the present invention may include a microphone to aid the subject's hearing.

At present, rectal ( $T_{re}$ ) and esophageal ( $T_{es}$ ) temperatures are the most commonly used indicators of  $T_c$ . Comparatively,  $T_{ec}$  is a less frequently used indicator of  $T_c$ . However, the present invention provides for a method of measuring  $T_{ec}$  to estimate  $T_c$  in occupational settings (or where the subject is active). In such environments, where temperature related disorders pose health and safety risks,  $T_{ec}$  is much more convenient

and less intrusive to measure than  $T_{re}$  and  $T_{es}$ , or temperatures at other body orifices or cavities, such as the vagina or mouth, because it is less invasive and cumbersome and allows the subject to continue with minimal if any impediment to normal movements and functions. Although the use of a temperature telemeter in an ear canal may cause some  
 5 impairment of normal binaural hearing, that impairment will be limited to one ear, and will not affect hearing in the other ear. A temperature telemetric device according to the current invention can be readily mounted in an ear canal with little or no invasion of the privacy of the subject, and with a reduced risk of infection when compared to the insertion and location of such devices in other body orifices which secrete greater  
 10 quantities of mucus.

$T_{ec}$  is seldomly used by thermal physiologists in research due to the difficulty in obtaining accurate measurements. Ideally, a temperature measurement should be measured as close as possible to the tympanic membrane. However, this poses a health and safety risk as there is a danger that the tympanic membrane may be pierced by  
 15 accident, rendering a person deaf or partially deaf as a result. As such, the temperature  $T_{ec}$  is usually measured along the ear canal instead.

Applicants' conducted a study to evaluate the validity of  $T_{ec}$  as a surrogate measure of  $T_c$  and to establish the relationship between  $T_{re}$  and  $T_{ec}$ .  $T_{re}$  was measured by a rectal probe (YSI, USA) inserted 10 centimeters (cm) into the rectum. Gastrointestinal  
 20 temperature ( $T_{gi}$ ) was measured through a temperature sensor pill (CorTemp, USA). A probe in accordance with one embodiment of the present invention was inserted by about 1.5 cm into one ear to monitor  $T_{ec}$ , whilst a conventional  $T_{ec}$  measurement device (Quest Technologies, USA) was inserted into the other ear to monitor the temperature in the other ear ( $T_{alt}$ ).

25 A trial was conducted in a climatic chamber programmed at 35°C ambient temperature, 70% relative humidity and 800 Watts per square meter ( $W.m^{-2}$ ) of simulated solar simulation, and the trial subjects were clothed in military uniforms made of 50% cotton and 50% polyester. During the trial, the trial subjects were asked to walk on a treadmill at a pace that corresponded with 70% to 80% of their heart rate reserve (HRR)  
 30 and were allowed to consume water freely.  $T_{ec}$ ,  $T_{re}$ ,  $T_{gi}$  and  $T_{alt}$  of each test subject were

recorded at intervals of 15 seconds, 1 minute, 15 seconds, and 10 seconds, respectively. The trial ceased after a trial subject's  $T_{re}$  reached 39.5°C and remained at or above this temperature for at least 1 minute. The data collected was then analyzed. A statistical significance (p-value) of less than 0.05 was deemed an acceptable level of error.

5 The relationships between  $T_{ec}$ ,  $T_{re}$ ,  $T_{gi}$  and  $T_{alt}$  were analyzed with the Pearson Product Moment Correlation ( $r$ ), which reflects the linear relationship between a pair of variables. Pearson's correlation ( $r$ ) ranges from +1 to -1, with a value of +1 indicating a perfect positive linear relationship between the pair of variables. Similarly, high positive  $r$ -values indicate a strong positive linear relationship between the pair of variables. The  
10 data obtained from the trial was used to plot scatter diagrams of  $T_{ec}$  as a function of  $T_{re}$ ,  $T_{gi}$  and  $T_{alt}$ . The scatter diagrams are useful for evaluating the nature and degree of relationship between the variables.

Figure 5a illustrates a scatter diagram of  $T_{ec}$  as a function of  $T_{re}$ . The scatter diagram in Figure 5a indicates that there is a positive linear correlation between  $T_{ec}$  and  
15  $T_{re}$ . Figure 5b illustrates a scatter diagram of  $T_{ec}$  as a function of  $T_{gi}$ . The scatter diagram in Figure 5b indicates that there is a positive linear correlation between  $T_{ec}$  and  $T_{gi}$ . Figure 5c illustrates a scatter diagram of  $T_{ec}$  as a function of  $T_{alt}$ . The scatter diagram in Figure 5c indicates that there is a positive linear correlation between  $T_{ec}$  and  $T_{al}$ .

Pearson's correlation ( $r$ ) between the different types of temperature measurements  
20 was then computed with the following formula:

$$r = \frac{\sum XY - \frac{\sum X \sum Y}{N}}{\sqrt{\left(\sum X^2 - \frac{(\sum X)^2}{N}\right) \left(\sum Y^2 - \frac{(\sum Y)^2}{N}\right)}} \quad (1)$$

where

|     |   |                                       |
|-----|---|---------------------------------------|
| $X$ | = | $T_{ec}$ (°C)                         |
| $Y$ | = | $T_{re}$ , $T_{gi}$ or $T_{alt}$ (°C) |
| $N$ | = | Number of data points                 |

25

A summary of the computed r-values is displayed in Table 1.

**Table 1** Pearson's correlation (r) between  $T_{ec}$ , and  $T_{re}$ ,  $T_{gi}$  and  $T_{alt}$

|           | $T_{re}$ | $T_{gi}$ | $T_{alt}$ | $T_{ec}$ |
|-----------|----------|----------|-----------|----------|
| $T_{re}$  |          | 0.91     | 0.82      | 0.87     |
| $T_{gi}$  |          |          | 0.84      | 0.85     |
| $T_{alt}$ |          |          |           | 0.95     |

As observed in Table 1, the r-values between  $T_{ec}$ , and  $T_{re}$ ,  $T_{gi}$  and  $T_{alt}$  are high.  
 5 This implies that even though the absolute temperature readings were not the same, the changes in  $T_{re}$ ,  $T_{gi}$  and  $T_{alt}$  are in tandem with changes in  $T_{ec}$ .

However, because Pearson's correlation measures the strength of a relation between a pair of variables, but not the agreement between the pair of variables, further calculations were conducted to verify the agreement between the pair of variables.  
 10 Perfect agreement is only attained if a data point lies on the line of equality, that is, the line of best fit drawn through all the data points on a scatter diagram. The agreement between the variables can be measured by computing the coefficient of determination ( $r^2$ ), which indicates the percentage of data points, which lie on the line of equality. A summary of the  $r^2$ -values calculated from the r-values in Table 1 is displayed in Table 2.

15 **Table 2** Coefficient of determination ( $r^2$ ) between  $T_{ec}$ , and  $T_{re}$ ,  $T_{gi}$  and  $T_{alt}$

|           | $T_{re}$ | $T_{gi}$ | $T_{alt}$ | $T_{ec}$ |
|-----------|----------|----------|-----------|----------|
| $T_{re}$  |          | 0.83     | 0.67      | 0.76     |
| $T_{gi}$  |          |          | 0.71      | 0.73     |
| $T_{alt}$ |          |          |           | 0.91     |

The results in Table 2 indicate that 76%, 73% and 91% of the data points in Figures 5a, 5b and 5c, respectively, are in agreement. The significantly high  $r$  and  $r^2$  values reported in the current study demonstrate that  $T_{ec}$  is indeed a valid indication of  $T_c$ , that is, that  $T_{ec}$  can be used as an indirect measure of  $T_c$ .

In a preferred embodiment of the present invention, a conversion algorithm having a regression equation is used to estimate  $T_c$ ,  $T_{re}$ , or  $T_{gi}$  from  $T_{ec}$  measured by a sensor. The regression equation can be obtained by performing linear regression on the data points plotted in a scatter diagram. For example, a linear regression performed on the data plotted in Figures 5a and 5b gave rise to the following prediction models:

$$T_{re} = 0.795 (T_{ec}) + 8.507 \quad \text{--- (2)}$$

$$T_{gi} = 0.808 (T_{ec}) + 8.095 \quad \text{--- (3)}$$

Monitor 108 with equation (2) programmed therein would display a  $T_{re}$  of 38.7°C when sensor 110 measures a  $T_{ec}$  of 38°C. Likewise, monitor 108 with equation (3) programmed therein would display a  $T_{gi}$  of 38.8°C when sensor 110 measures a  $T_{ec}$  of 38°C.

Alternatively, the conversion algorithm may be used to convert  $T_{ec}$  to  $T_{re}$  by adding the mean of the error (MOE) between  $T_{ec}$  and  $T_{re}$  to  $T_{ec}$  measured by sensor 110 to obtain  $T_{re}$ . To obtain  $T_{gi}$ , the MOE between  $T_{ec}$  and  $T_{gi}$  is added to  $T_{ec}$  measured by sensor 110. Using the value of the MOE between  $T_{re}$  and  $T_{ec}$  in Figure 5a, that is, 0.81°C, a  $T_{ec}$  of 38°C would correspond to a  $T_{re}$  of 38.81°C. The conversion algorithm can also be programmed to perform both types of conversion, that is, from  $T_{ec}$  to both  $T_{re}$  and  $T_{gi}$ . The methodology described above may be applied to obtain a conversion algorithm in respect of any body cavity, such as the armpit or the mouth.

With reference to Figure 3, housing 104 also supports a battery casing 114, in which a battery, such as a pair of 1.55 Volts silver oxide batteries, may be inserted. The battery is coupled to and provides power for sensor 110, the modulator, and the transmitter. Battery casing 114 includes a battery casing door 116 with a tab 118, which assists in the opening and closing of battery casing door 116.

Figure 6 illustrates a perspective view of a subject 160 wearing temperature telemeter 100, shown in Figure 3, in accordance with one embodiment of the present invention. Housing 104, which is placed behind an earlobe 154, is coupled to flexible wire 106, which extends around the top of earlobe 154. This arrangement of housing 104 and flexible wire 106 secures housing 104 to subject 160 and allows temperature telemeter 100 to access the ear canal of subject 160.

Figure 7 illustrates an anatomical view of an ear canal 200 with a probe 202 inserted therein in accordance with one embodiment of the present invention. Probe 202 is coupled to a housing 204 located in earlobe 206. Housing 204 preferably supports a modulator, a transmitter and a battery casing having a battery casing door 210. A sensor enclosed in probe 202 measures  $T_{ec}$  in ear canal 200 and generates a temperature signal, which is relayed to the modulator in housing 204. The modulator varies the amplitude, frequency, and/or phase of the temperature signal to an appropriate waveform before transmission by the transmitter in housing 204. The temperature signal, which is transmitted wirelessly by the transmitter, is received by a receiver and preferably displayed on a monitor.

The sensor is located close to the surface of probe 202 so that the sensor will be as close as possible to the surface of ear canal 200. This facilitates the attainment of a more accurate temperature measurement. As discussed previously, the sensor is also placed as close as possible to a tympanic membrane 208. Probe 202 may be molded to an ear impression of a subject, or embedded in a piece of foam or any other malleable material to obtain a better fit.

Figure 8 illustrates a schematic of a temperature telemeter 250 in accordance with another embodiment of the present invention. Temperature telemeter 250 comprises a probe 252 in which a sensor 254, a modulator 256, a transmitter 258 and a battery casing 260 are enclosed. Temperature telemeter 250 further comprises a monitor 262, which receives temperature signals wirelessly from transmitter 258.

Probe 252 is inserted into a body cavity so that sensor 254 can measure  $T_{bc}$  and generate a temperature signal. Sensor 254 is positioned close to the surface of probe 252 so that sensor 254 will be in close proximity to the surface of the body cavity. This

facilitates the attainment of a more accurate temperature measurement. The temperature signal generated is relayed to modulator 256. Modulator 256 varies the amplitude, frequency, and phase of the temperature signal to an appropriate waveform for transmission by transmitter 258.

5           Monitor 262 receives the temperature signal wirelessly from transmitter 258 and preferably displays the temperature in real-time. The temperature signals received are preferably converted into a digital form for display. Additionally, the temperature signals received by monitor 262 may be stored and collated so that  $T_{bc}$  can be displayed in a graphical form when prompted by a subject. The option to display  $T_{bc}$  graphically allows  
10 the subject to keep track of the changes in  $T_{bc}$  more readily. To facilitate mobility, monitor 262 may be implemented as a watch to be worn on a wrist or as a pager, which could be attached to a belt or kept in a subject's pocket.

          An alarm 264 in monitor 262 may be used to alert the subject when  $T_{bc}$  exceeds or falls below a predetermined temperature range. The warning given by alarm 264 can be  
15 auditory, such as a beep, a string of notes, etc., or vibratory. Alarm 264 can also be programmed to emit different types of signals to indicate different temperatures. If a database of an individual subject's physical condition and ability is available, alarm 264 can be tailored to suit a subject's requirements.

          A battery to provide electrical energy to operate sensor 254, modulator 256 and  
20 transmitter 258 may be inserted into battery casing 260. Battery casing 260 is designed such that the battery can be easily removed and replaced once the battery is flat so that temperature telemeter 250 can be reused. Probe 252 of temperature telemeter 250 can be inserted into an ear canal 300 as illustrated in Figure 9.

          Figure 9 illustrates an anatomical view of ear canal 300 with probe 252 inserted  
25 therein in accordance with another embodiment of the present invention. As described above, probe 252 comprises a sensor 254, a modulator, a transmitter and a battery casing. The sensor 254 is located close to the surface of probe 252 so that the sensor will be as close as possible to the surface of ear canal 300. This facilitates the attainment of a more accurate temperature measurement. As discussed previously, the sensor is also placed as  
30 close as possible to the tympanic membrane 302. Probe 252 further comprises a battery

casing door 266 and a door pull 268. By using door pull 268, battery casing door 266 can be opened to insert a battery or to remove a flat battery. Although door pull 268 is depicted in this embodiment as a string with a knob on one end, it will be appreciated that door pull 268 can also be any device that assists in removing probe 252 from ear canal  
5 300.

Figure 10 illustrates a schematic of temperature telemetric system 400 in accordance with a further embodiment of the present invention. Temperature telemetric system 400 comprises a central receiver or monitor 402, which receives temperature signals wirelessly from a plurality of temperature telemeters 404, which are used to  
10 monitor the temperature of multiple subjects. Temperature telemetric system 400 includes a plurality of warning devices 406. Each of the plurality of warning devices 406 is respectively coupled to each telemeter 404. Central monitor 402 is preferably used to display  $T_{bc}$  in real-time on a screen 408. Central monitor 402 is also preferably equipped with an alarm 410 to alert a supervisor when  $T_{bc}$  of any subject exceeds or falls below a  
15 predetermined temperature range.

Temperature telemetric system 400 can be implemented in situations where  $T_c$  of a number of persons need monitoring, for instance, an ICU in a hospital, where  $T_c$  of a number of patients must be monitored at any one time. Temperature telemetric system 400 is also applicable for military purposes as it would allow a commander to monitor the  
20 state of each soldier deployed.

Other embodiments of the invention will be apparent to those skilled in the art from consideration of the specification and practice of the invention. Furthermore, certain terminology has been used for the purposes of descriptive clarity, and not to limit the present invention. The embodiments and preferred features described above should  
25 be considered exemplary, with the invention being defined by the appended claims.

## CLAIMS

1. A temperature telemeter, comprising:  
a sensor to measure a temperature of a body cavity of a subject;  
5 a transmitter coupled to the sensor, wherein the transmitter is to receive the temperature from the sensor and wherein the transmitter is to generate a signal to transmit the temperature; and  
a monitor to wirelessly receive the signal from the transmitter, wherein the monitor uses a conversion algorithm to convert the temperature to an estimated core  
10 temperature.
2. The temperature telemeter as recited in claim 1, wherein the body cavity is an ear canal.
- 15 3. The temperature telemeter as recited in claim 2, further comprising a housing to support the sensor and the transmitter, wherein the housing is to secure the temperature telemeter to the ear canal.
- 20 4. The temperature telemeter as recited in any one of claims 1 to 3, further comprising a modulator coupled between the sensor and the transmitter, wherein the modulator is to amplify the signal.
- 25 5. The temperature telemeter as recited in any one of claims 1 to 4, further comprising a battery housing for supporting a battery, wherein the battery is to provide power for the sensor and the transmitter.
6. The temperature telemeter as recited in any one of claims 1 to 5, wherein the monitor displays the estimated core temperature.

7. The temperature telemeter as recited in any one of claims 3 to 6, wherein the housing is shaped to fit in the ear canal.

5 8. The temperature telemeter as recited in any one of claims 3 to 7, further comprising an ambient temperature sensor supported by the housing to measure an ambient temperature.

9. The temperature telemeter as recited in claim 8, further comprising a  
10 compensation algorithm which uses the ambient temperature to compensate the estimated core temperature for changes in the ambient temperature.

10. A method for providing an estimated core temperature of a subject, comprising:

15 measuring a temperature from a body cavity of the subject to generate a temperature measurement;

wirelessly transmitting the temperature measurement to a monitor; and

converting the temperature measurement to an estimated core temperature using a conversion algorithm.

20

11. The method for providing an estimated core temperature as recited in claim 10, wherein the body cavity is an ear canal.

12. The method for providing an estimated core temperature as recited in  
25 claim 10 or 11, further comprising providing an alert when the temperature exceeds or falls below a predetermined temperature range.

13. The method for providing an estimated core temperature as recited in any one of claims 10 to 12, further comprising displaying the estimated core temperature.

14. The method for providing an estimated core temperature as recited in any one of claims 10 to 13, further comprising measuring an ambient temperature, wherein the ambient temperature is to generate the estimated core temperature.

15. A temperature telemetric system comprising  
a plurality of temperature telemeters, wherein each of the plurality of temperature telemeters comprises:  
a sensor to measure a temperature of a body cavity of a subject; and  
a transmitter coupled to the sensor, wherein the transmitter is to receive the temperature from the sensor and wherein the transmitter is to generate a signal to transmit the temperature; and  
a central monitor to receive the signal wirelessly from the transmitter of each of the plurality of temperature telemeters, wherein the central monitor uses a conversion algorithm to convert the temperature to an estimated core temperature.

16. The temperature telemetric system as recited in claim 15, wherein the body cavity is an ear canal.

17. The temperature telemetric system as recited in claim 16, wherein each of the plurality of temperature telemeters further comprises a housing to support the sensor and the transmitter, wherein the housing is to secure the temperature telemeter to the ear canal.

18. The temperature telemetric system as recited in any one of claims 15 to 17, wherein each of the plurality of temperature telemeters further comprises a modulator

coupled between the sensor and the transmitter, wherein the modulator is to amplify the signal.

19. The temperature telemetric system as recited in any one of claims 15 to 18,  
5 wherein the central monitor displays the estimated core temperature.

20. The temperature telemetric system as recited in any one of claims 17 to 19,  
wherein the housing is shaped to fit in the ear canal.

10 21. A temperature telemeter, comprising:  
a sensor to measure a temperature of a body cavity of a subject;  
a transmitter coupled to the sensor, wherein the transmitter is to receive the  
temperature from the sensor and wherein the transmitter is to generate a signal to transmit  
the temperature;  
15 a monitor to wirelessly receive the signal from the transmitter; and  
an ambient temperature sensor to measure an ambient temperature.

22. The temperature telemeter as recited in claim 21, further comprising a  
compensation algorithm which uses the ambient temperature to compensate the  
20 temperature of the body cavity for changes in the ambient temperature.

23. The temperature telemeter as recited in claim 21 or 22, wherein the  
monitor displays the temperature of the body cavity.

25 24. The temperature telemeter as recited in any one of claims 21 to 23,  
wherein the monitor uses a conversion algorithm to convert the temperature of the body  
cavity to an estimated core temperature.

25. The temperature telemeter as recited in any one of claims 21 to 24, wherein the body cavity is an ear canal.

5        26. The temperature telemeter as recited in claim 25, further comprising a housing to support the sensor and the transmitter, wherein the housing is to secure the temperature telemeter to the ear canal.

10       27. The temperature telemeter as recited in any one of claims 21 to 26, further comprising a modulator coupled between the sensor and the transmitter, wherein the modulator is to amplify the signal.

15       28. The temperature telemeter as recited in any one of claims 21 to 27, further comprising a battery housing for supporting a battery, wherein the battery is to provide power for the sensor and the transmitter.

29. The temperature telemeter as recited in any one of claims 26 to 29, wherein the housing is shaped to fit in the ear canal.

20       30. A method for measuring a body temperature of a subject, comprising:  
measuring a temperature from a body cavity of the subject to generate a temperature measurement;  
wirelessly transmitting the temperature measurement to a monitor;  
measuring an ambient temperature; and  
25       using the temperature measurement and the ambient temperature in a compensation algorithm to compensate the temperature measurement for changes in the ambient temperature and thereby generate a compensated temperature value.

31. The method for measuring a body temperature of a subject as recited in claim 30, further comprising displaying the compensated temperature value.

5 32. The method for measuring a body temperature of a subject as recited in claim 30 or 31, further comprising converting the temperature measurement to an estimated core temperature using a conversion algorithm.

33. The method for measuring a body temperature of a subject as recited in  
10 any one of claims 30 to 32, wherein the body cavity is an ear canal.

34. The method for measuring a body temperature of a subject as recited in any one of claims 31 to 33, further comprising providing an alert when the compensated temperature value exceeds or falls below a predetermined temperature range.

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