PHYSICAL PROPERTIES OF SEVERAL INFRARED TYMPANIC THERMOMETERS

John Frim and Michel B. Ducharme
Defence and Civil Institute of Environmental Medicine, North York, Ontario, Canada M3M 3B9

INTRODUCTION

Deep body temperature measurement is a fundamental requirement in most research on thermal stress in humans. This need arises either as an objective of the study whereby one is in pursuit of the elusive "core" temperature, or as a safety criterion for the prevention of thermal injury as dictated by an ethics committee. Numerous techniques and body sites are available for performing such measurements, each having advantages and disadvantages in terms of accuracy, relevance to the measurement objective, ease of use, and discomfort to the subject. While most sites yield usable information, there can be differences in absolute values, temperature response trends, and sensitivity of the site temperature to external influences.

There seems to be a never-ending quest to find a better method or device for measuring deep body temperature. Ease of use for the operator and diminution of discomfort to the patient, probably followed by reproducibility and then accuracy, are perhaps the most important criteria in a clinical setting where there exists a business opportunity for mass production and marketing. Thus, it is no surprise that a number of infrared tympanic thermometers (ITTs) have made their appearance in recent years. ITTs are inherently safe, easy to use, fast responding, and relatively unobtrusive to the patient, making them well suited to a hospital setting. There is, however, a trend emerging to use ITTs more frequently in thermal research as well. While the medical community may disagree somewhat, absolute accuracy, reproducibility, and sensitivity criteria can be more demanding in research, and there is a concern over the suitability of ITTs in such applications. Several recent studies have, in fact, reported on comparisons of measurements between ITTs and more traditional methods of measuring deep body temperature. The purpose of this study was to compare the physical and operational performance characteristics of three ITTs as a background to an in-depth companion study that examined the influence of instrument, operator, and ear canal anatomy on accuracy and reproducibility of ITT readings (see following paper in these Proceedings).

MATERIALS AND METHODS

Three ITTs were used in this study: Genius First-Temp model 3000A (Intelligent Medical Systems Inc., Carlsbad, CA); Thermoscan IR-1 (Thermoscan Inc., San Diego, CA); and Diatek model 9000 (Diatek Inc., San Diego, CA). All three instruments have "mode" settings whereby mathematical algorithms convert the actual surface temperature read by the sensor into a value that might be obtained using conventional thermometry at a different deep body temperature site such as the mouth ("oral" mode), pulmonary artery or esophagus ("core" mode), or the rectum ("rectal" mode). The algorithms are generally based on statistical relationships between data obtained in clinical settings, and they can have restrictions (e.g., the Thermoscan instrument's "rectal" algorithm was developed from a population of children under 3 y of age). All instruments use protective sheaths over the tip, a feature designed to prevent the spread of disease between patients in a clinical setting. Safety interlocks make it very cumbersome to use a sheath more than once.

One major objective of this study was to compare the correction algorithms of the ITTs. The experiments were conducted in the laboratory at a room temperature of 23–24°C. The "tympanum" or target being measured was a 50 mm diameter temperature controlled disk (a black body calibration standard for a thermography system) heated to several temperatures between ambient (i.e., no heating) and 37°C. The three ITTs were set to their various modes and brought to within 3 mm of the target to obtain a reading.

A second major objective was to determine how a non-uniform temperature distribution within the angle of view of the ITT affects the temperature reading, since during use the sensor will "see" not only the tympanic membrane but also a portion of the auditory canal. Since the ear canal might not have the same temperature as the tympanic membrane, there is a strong possibility that the reading can become "contaminated". For this evaluation the temperature controlled disk target (at a temperature of 30.6°C) was mounted on a support 8.5 cm in front of a cold background which consisted of a thin vertical metal tank 1 m wide × 1 m high × 30 mm deep filled with water at room temperature (21°C). The temperature across the surface of the disk was found to be uniform to within ±0.05°C as determined with an infrared camera (AGEMA Thermovision 750). The temperature distribution of the cold background indicated a very slight gradient from top to bottom of about 0.4°C related to temperature stratification of the water (evaporation from the surface of the water caused a slight cooling near the top of the container). All three ITTs were set to surface mode and temperature readings were obtained as a function of distance between the sensor tip and the disc over the range of 0–500 mm. The entire series of measurements was repeated twice and the data were averaged over the two readings.

RESULTS

Algorithm Check: In surface mode, regardless of the temperature of the target, all three ITTs read the temperature correctly to within 0.1°C (i.e., the resolution of the display on the instruments). However, the temperatures displayed at the other mode settings varied considerably between instruments as a function of both target temperature and mode setting. The Genius instrument applied a fairly constant offset to the surface reading dependent only on the mode setting. This response was designated "flat". The Thermoscan instrument revealed a "curvilinear" algorithm as a function of mode and target temperature. When the target was at room temperature, all three modes gave readings that were within 0.1°C of the target temperature; however, as the target temperature was increased, the displayed values began to separate. The response of the Diatek instrument was designated "sloped" in that the offset increased as target temperature increased, but the differences in displayed temperatures between the various modes were fairly constant. The data for a target temperature of 23 and 37°C are presented below. What is not known from this test is whether the offsets are determined by ambient temperature or target temperature in an absolute sense, or by the difference in temperature between the target and the ambient environment in which the instrument is used.

Instrument	Response	Target (°C)	Temperature Offset (Mean ± SEM; °C) in Mode: Surface	Oral	Core	Rectal
Genius	Flat	23	0.00±0.05	0.80±0.05	1.30±0.05	1.10±0.03
		37	0.10±0.05	0.90±0.03	1.30±0.04	1.10±0.05
Thermoscan	Curvilinear	23	0.10±0.03	0.05±0.03	0.10±0.03	0.10±0.03
		37	0.10±0.10	0.30±0.03	0.70±0.03	1.00±0.03
Diatek	Sloped	23	0.10±0.02	0.10±0.03	0.20±0.02	0.30±0.03
		37	0.10±0.02	0.90±0.03	1.10±0.03	1.30±0.04

Angle of View Test: All ITTs again gave good readings of the target temperature (within 0.1°C) for sensor-to-target distances ≤20 mm, after which point the indicated readings decreased curvilinearly. This clearly indicates contamination of the temperature reading by the colder surface of the backdrop as it becomes part of the field of view. The ITT response curves matched closely the shape of a theoretical curve based on a 50° angle of view with an area-weighted average temperature as a function of distance from the 30.6°C target and cool background. This suggests that the instruments do in fact measure the average temperature of a fairly wide angle field of view (one instrument is specified to have a 90° angle of view).

DISCUSSION

All three instruments measure temperature correctly when set to surface mode and exposed to a target that completely fills the field of view with a uniform temperature. It is highly unlikely that the tympanum will satisfy this requirement (see following paper in these Proceedings). The experiments with the small warm target in front of a cooler background clearly indicate that the instruments read an area-weighted temperature of whatever is in the field of view. Thus, the ear canal, if "seen" by the instrument and cooler than the tympanum, will lower the temperature reading by some unknown amount. In addition, the correction algorithms, if used, differ between instruments and can raise the indicated temperature by as much as 1.3°C above the temperature actually read by the sensor. Thus, the displayed temperature is not likely, under any circumstances, an accurate measure of tympanic temperature, nor any other deep body temperature. One must also question the validity of applying a fixed mathematical expression to the highly variable and dynamic relationships between the various deep body temperature sites encountered when outside of a hospital environment. The instruments are probably very good for following changes in temperature, but one should not rely on the absolute reading.

CONCLUSIONS

ITTs provide an easy way of obtaining an indication of a deep body temperature. The method is very unobtrusive and is more readily acceptable than several other means of obtaining such temperature information. When presented with an ideal target and set to surface mode, the instruments have an absolute accuracy of 0.1°C. The ear canal and tympanum provide a target that can be far from the ideal, and this, coupled with the built-in temperature correction algorithms, can cause the instruments to display a temperature that is quite different from that of the tympanum. The instruments may provide a simple technique for following changes in temperature, but they should not be relied upon for an absolute measure of deep body temperature.