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Evaluation of the Applicability of Infrared and Thermistor-Thermometry in Thermophysiology Research

Jeong-Beom LEE[1], Mitsuo KOSAKA[1], Timothy OTHMAN[1], Takaaki MATSUMOTO[1], Eiko KANEDA[1], Masaki YAMAUCHI[1], Akihiro TAIMURA[1], Nobu OHWATARI[1], Katsuaki MOTOMURA[1], Mohamed SAAT[1], Yuzo NAKASE[2] and Shigeru MAKITA[3]

[1]*Department of Environmental Physiology, Institute of Tropical Medicine, Nagasaki University 1-12-4 Sakamoto, Nagasaki 852-8523 Japan.*
[2]*Technology and Science Department, Healthcare Company, OMRON Corporation, Kyoto 615-0084 Japan*
[3]*Healthcare Equipment Development Center, OMRON Institute of Life Science Co. Ltd, Kyoto 615-0084 Japan*

Abstract: The accuracy and reliability of temperature measuring devices in thermal physiology research and clinical practice has been subject of various investigations. Research data have been conflicting in some cases. Further investigations are therefore needed to elucidate the reliability and sensitivity of these devices under different temperature settings. The aim of this study was to evaluate the reliability and sensitivity of the tympanic thermistor (TT), infrared tympanic thermometer (ITT) and oral thermistor (OT) in the detection of body temperature changes in adults exposed to heat load. A single set of three simultaneous temperatures i.e. oral, left and right tympanic membrane were measured. At rest, core temperature (Tc) measured by TT was 0.45℃ and +0.10 ～ −0.12℃ (changed range) higher than that measured with OT and ITT respectively. At the end of 30min 43℃ water bath leg immersion, Tc measured by TT was 0.48℃ and 0.04℃ higher than that measured with OT and ITT. This showed that when subjects were exposed to heat load, there was no difference in Tc measured by TT and ITT, although both were significantly higher than that measured with OT. From these results, it might be thought that the sensitivity for Tc detection increased in the order tympanic thermistor > infrared thermometer > oral thermistor.

Further-more, in addition to the merits of infrared thermometer, the hazards and difficulties of tympanic temperature measurement were discussed from the view of development of the various kinds of thermometers.

Key words: core temperature, infrared thermometry, tympanic temperature, hyperthermia.

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is also exciting because it does not involve contact with the tympanic membrane which is a fragile structure. The aural based Tc measuring devices are therefore increasingly becoming popular (Childs *et al.*, 1999). And in general, aural based temperature measurements have been criticized because they are affected by changes in environmental temperature as well as by head or face cooling (McCaffrey *et al.*, 1975; Nishi *et al.*, 1990). And these shortcomings can be easily surmounted by insulating the sensors (Sato *et al.*, 1998).

Table 2. Analysis of distribution of temperature (mean ± SE) within the auditory canal as measured using the tympanic thermistor.

TYMPANITIC	0 mm	-2 mm	-4 mm	-6 mm	-8 mm	-10 mm
Sub. NO 1	36.74	36.64	36.54	36.38	36.17	35.91
Sub. NO 2	36.71	36.61	36.51	36.34	36.15	36.01
Sub. NO 3	36.72	36.62	36.43	36.28	36.08	35.79
Sub. NO 4	36.79	36.65	36.41	36.28	36.08	35.9
Sub. NO 5	37.25	37.05	36.96	36.78	36.51	36.29
Sub. NO 14	36.92	36.75	36.52	36.32	36.16	35.93
Sub. NO 15	37.19	37.01	36.86	36.71	36.43	36.01
Sub. NO 16	36.85	36.71	36.54	36.28	36.14	35.91
N	8	8	8	8	8	8
Mean	36.90	36.76	36.60	36.42	36.22	35.97
SD	0.20	0.16	0.19	0.19	0.15	0.14
SE	0.07	0.06	0.07	0.07	0.05	0.05
paired t-test	**0.0047** *** p<0.01**	**0.6653** **N. S**	**0.0029** *** p<0.01**	**0.0000** **** p<0.001**	**0.0000** **** p<0.001**	**0.0000** **** p<0.001**

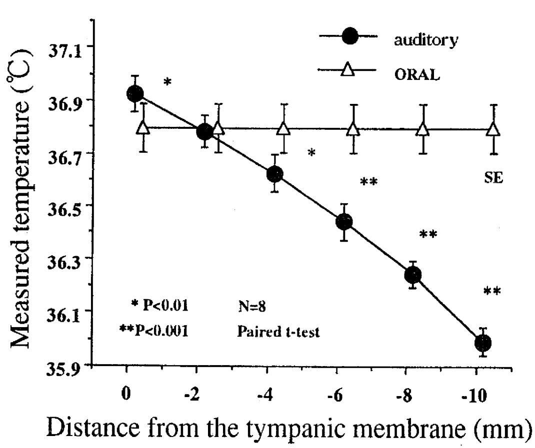

Fig 3. The distribution of temperature within the auditory canal as measured using the tympnic thermistor.

Table 1. Summary of the physical characteristics of the experimental subjects used showing the age distribution.

SUB. NO	Age	Height	Weight	BSA
N=1	16	164	54	1.579
N=2	40	170	60	1.695
N=3	34	175	65	1.791
N=4	34	170	72	1.832
N=5	22	180	76	1.953
N=6	21	174	73	1.874
N=7	25	173	66	1.788
N=8	30	180	82	2.017
N=9	20	164	56	1.604
N=10	32	170	69	1.799
N=11	22	172	70	1.825
N=12	65	165	44	1.454
N=13	52	167	63	1.708
N=14	62	165	66	1.727
N=15	74	162	61	1.648
N=16	19	172	69	1.814
N	16	16	16	16
Mean	35.50	170.19	65.38	1.76
SD	17.63	5.32	8.90	0.14
SE	4.41	1.33	2.23	0.03

Temperature measurements

All experiments were carried out in a climatic chamber (24±0.5℃, relative humidity 40±3% and less than 1 m·sec^{-1} air velocity) at 2–5 PM, between March and June 1999 in Nagasaki, Japan. On arrival into the climatic chamber, the subject wore light indoor clothing and sat on a chair for 60 min to get conditioned before the experiment commenced. After the 60 min rest, tympanic temperature (Tty) was measured using the ITT (Gentle TempTM, MC–505, OMRON Health Care Inc, 1996), in the right ear, TT (K923, TAKARA instrument Co. Ltd.), connected to a personal computer (PC–9801, NEC) in the left ear and oral temperature (To) using the OT (thermistor) were measured for 5 min. Heat load was then applied to each subject by immersing the lower legs in a hot water bath (43℃) for the next 30 min when the Tty and To measurements continued uninterrupted. After cessation of the 30 min heat load, the subject removed the legs from the water bath and continued to sit quietly on the chair when temperature measurements continued during the recovery for a further 30 min. Tty using the TT, To using the OT and Tty using the ITT were recorded every 30 sec.

To measure the Tty using the ITT, the device was inserted into the external auditory canal, as close as possible to, but not making physical contact with the tympanic membrane (Details are available from OMRON Health Care Inc operating manual, 1996). To measure

Tty using TT, the device was inserted into the external auditory canal to make a physical contact with the tympanic membrane. When the TT touched the tympanic membrane, slight discomfort was felt and a scratching noise could be heard. The inner pinna was then filled with small cotton balls to anchor the TT probe in a fixed position. To was taken using OT by placing the device in the sublingual position. In a second set of experiments, distribution of temperature within the auditory canal was measured using TT. To do this, the device was inserted into the auditory canal to make physical contact with the tympanic membrane, and Tty was recorded. The probe was then gradually pulled outwards along the wall of the canal. The temperature of the auditory canal wall was recorded at each 2 mm distance. The temperature taken in the auditory canal using this method was compared with To taken at the sublingual position using the OT, and mean body temperature (mTb) calculated by Tty and mean skin temperature (mTs) as follows; mTb = $(0.9 \times \text{Tty} + 0.1 \times \text{mTs})$ mTs was calculated according to Ramanathan's Formula (1964) as well as to Sugenoya and Ogawa (1985).

Sweating rate measurements

During the heat loading, local sweating rate on the forearm, thigh, abdomen and chest were continuously recorded by the capacitance hygrometer–ventilated capsule method (Fan, 1987; Matsumoto *et al.*, 1993). In brief, dry nitrogen gas flowed into a capsule (6.026 cm^2 in area) attached to the skin at the point to be measured at a constant flow rate of 1/min–1, and the humidity of effluent gas was detected by a hygrometer (H211, Technol Seven, Yokohama, Japan). The sweating rate was recorded with PC (PC-9801, NEC, Japan) every 30 sec, and expressed in $mg \cdot cm^{-2} \cdot min^{-1}$.

Statistical analysis

All data are expressed as means $\pm$ SE. Analysis of variance for repeated measurements was used for comparison of the temperatures between oral and auditory canal tested by Student's paired t–test. For all statistical manipulations significance was set at $P<0.05$.

Results

Results showing the comparative sensitivity of the tympanic thermistor (TT), the infrared thermometer (ITT) and oral thermistor (OT) are shown in Figs 1 and 2. In Fig 1, the simultaneous changes of core temperature ($n=8$) measured by the three devices as well as the sweat rate, before, during and after heat load are illustrated. At rest, core temperature (Tc) measured using TT was 0.45℃ and 0.10℃ or −0.12℃ (change range) higher than that measured with OT and ITT respectively. At the end of 30 min 43℃ water bath leg immersion, Tc measured using TT was 0.48℃ and 0.04℃ higher than that measured with OT and ITT. This showed that when subjects were exposed to heat load, there was no difference in Tc measured by TT and ITT, although both were significantly higher than that measured with OT. During heat loading there was an initial gradual decrease in Tc followed by a sharp increase that started 12 min after heat exposure. This increase in Tc roughly coincided with an initiation of sweating (Fig 1). Maximum sweating rate across the different parts of the body ranged between 0.2–0.4mg·cm^{-2}·min^{-1}. This mode of sweating has earlier been reported in this laboratory (Matsumoto *et al.*, 1993; Kosaka *et al.*, 1994).

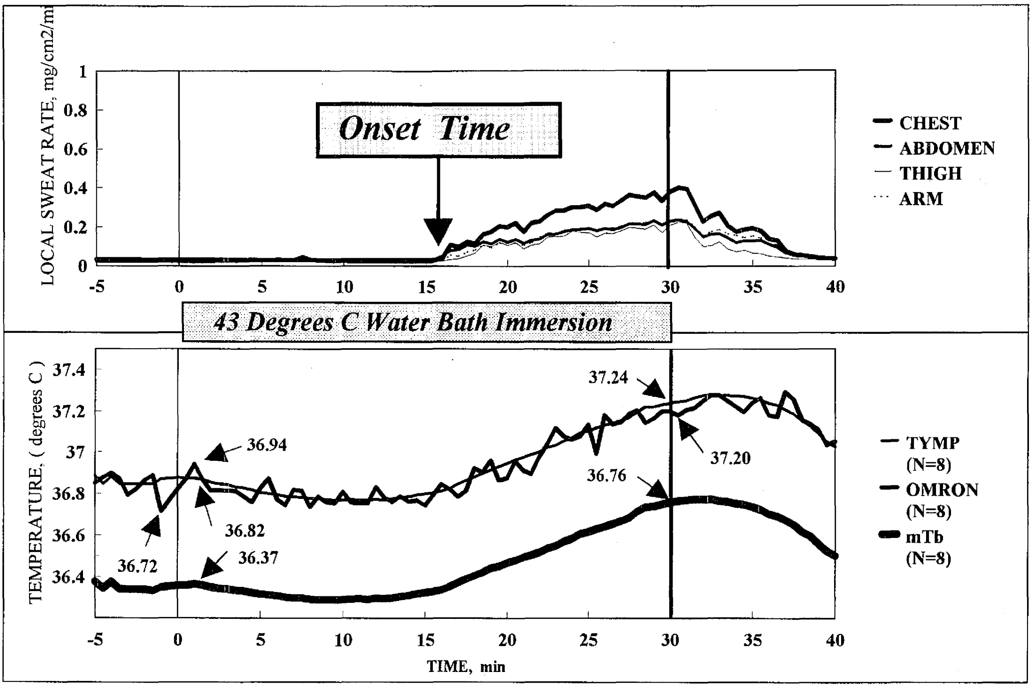

Fig 1. Simultaneous changes of core temperature (n = 8) measured by the three divices; the infrared tympanic thermometer, tympanic thermistor and the oral thermistor as well as the sweat rate, before during and after heat load.

Fig 2 shows a typical recording which compared tympanic temperature directly measured by the TT and To measured with OT as well as mean body temperature (mTb) calculated from the modified Ramanathan's formula (Ramanathan, 1964; Sugenoya and Ogawa, 1985). Tc measured with the TT was higher, followed by that measured by the OT with the calculated value being lower. In this experiment, increases in tympanic and oral temperatures occurred 13 min after heat load, and sweat secretion occurred 17 min after heat load.

Fig 3 demonstrates the distribution of temperature within the auditory canal as measured using TT. As the TT was gradually pulled outwards along the wall of the canal, the temperature of the auditory canal wall decreased accordingly. When the changes in the temperature of the auditory canal wall was compared with To taken at the sublingual position using the OT, there was a significant difference at all time positions except at −2 mm. The Tty value when the TT probe was in contact with tympanic membrane (0 mm) was higher than the To.

Table 1 summarizes the physical characteristics of the subjects (n=16) showing the age distribution and Table 2 shows a summary of the mean ± SE distribution of temperature within the auditory canal (n=16) as measured using TT. No difference was detected between

Tc taken at 0 mm and –2 mm. There was significant difference when Tty was taken at 0 mm as compared with those taken at –4 mm ($P<0.01$) to –10 mm ($P<0.001$) (Paired t–test).

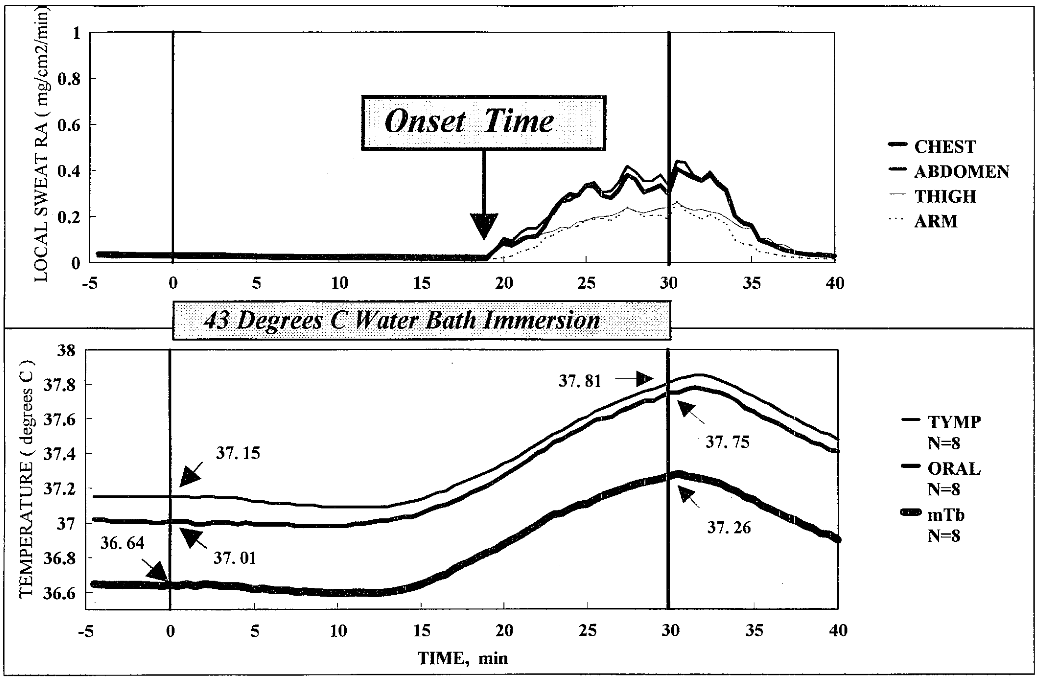

Fig 2. A typical recording showing the comparison of tympanic temperature directly measured by the tympanic thermistor and oral temperature measured with the oral thermistor, as well as mean body temperature (n=8) calculated from the modified Ramanathan′s formula.

Discussion

Accurate measurement of body temperature is essential in Thermal Physiology Research in order to obtain valid research data (Burke and Hawley, 1997; Hargreaves and Febbraio, 1998). During the early years of the development of the thermometer, body temperature measurements were restricted to the diagnosis of febrile conditions. Over the last 50 years, a series of developments have resulted in better instruments for Tc measurement. The early thermometers were mainly used to detect temperatures via the sublingual pocket, axilla or rectal orifice. However, in man, it was recognized early as 1959 (Benzinger, 1959) that the tympanic membrane and the hypothalamus are both supplied by the internal carotid artery. In addition, the hypothalamus is richly endowed with warm sensors. Tympanic temperature is therefore assumed to best reflect Tc. This has resulted in the development of aural based thermistors and infrared thermometry (Torndrup, 1992), thus, modifying our current practices, and minimizing mercury hazards. The hazards and difficulties associated with tympanic temperature measurement has been highlighted by Benzinger 1959 and Cooper *et al.*, 1964, such as puncture of tympanic membrane and the feeling of uncomfort sensation. In particular, infrared thermometers are quick, easy and non–invasive and therefore offer great appeals. It

Introduction

Accurate measurement of body temperature is essential in Thermal Physiology Research in order to acquire valid research data (Burke and Hawley, 1997 Hargreaves and Febbraio, 1998). The development of new measuring techniques, and awareness of mercury associated hazards are leading to the modification of our current practices. In particular, devices that are quick, easy and non-invasive offer great appeals. Coming on the heels of the traditional mercury-in-glass thermometer are newer devices which include thermocouples, thermistors and infrared thermometers. The aural based Tc measuring devices are particularly becoming popular (Childs *et al.*, 1999), as the aural temperature is very close to the hypothalamic temperature as possible (Benzinger, 1959). The recently developed infrared thermometry (Torndrup, 1992) offers a less risky, less stressful, less threatening, non-invasive technique (Shinozaki *et al.*, 1988; Montoya-Cabrera *et al.*, 1998; Lanham *et al.*, 1999). However, its accuracy in clinical practice has been questioned, based on the fact that researchers believe it does not detect febrile Tcs accurately in children (Childs *et al.*, 1999; Lanham *et al.*, 1999), or is unreliable and inaccurate (Matsumoto *et al.*, 1996; Matsukawa *et al.*, 1997; Robinson *et al.*, 1998; Abolnik *et al.*, 1999). Others however find its use satisfactory (Androkites *et al.*, 1998), even accurate (Stavem *et al.*, 1997). Matsumoto *et al.*, 1996 particularly found the ITT unsatisfactory in 5% of the population. The reasons given were that these individuals had a hairy ear canal or that the ear canal is too narrow. The TT has also been criticized for causing subject discomfort, pain, risk of injury and infection (Benzinger and Taylor, 1963; Shinozaki *et al.*, 1988), although its use was judged to be satisfactory (Leick-Rude and Bloom, 1998; Montoya-Cabrera, 1998). Considering that each device has merits and demerits, it is vital to compare their sensitivities for Tc detection in order to determine if the demerits can be traded off for the merits. The aim of this study therefore was to evaluate and rank the sensitivity of the TT, ITT, and OT for detection of Tc during exposure of adults to heat load. Although it is still a hypothesis, the sensitivity for Tc detection seems to be increased in the order tympanic thermistor>infrared thermometer>oral thermistor.

Materials and Methods

Experimental subjects

Sixteen healthy untrained male subjects of mean age 35.5±17.6 (range 16−74) years, body weight 65.4±8.8 kg, height 170.2±5.3 cm and body surface area 1.8±0.1 m^2 were used in this study. The wide age range was deliberately chosen to test the sensitivities across wide age range. All the subjects were informed of the aims, risks, and benefits of this investigation both verbally and in writing prior to signing an informed consent document. We paid great attention to the subjects in accordance with the Helsinki Declaration of 1975.

The aim of this study was to evaluate the reliability and sensitivity of the tympanic thermistor (TT), infrared tympanic thermometer (ITT) and oral thermistor (OT) in the detection of body temperature changes in adults exposed to heat load. The main findings in this study are as follows. 1) under heat load, detection of body temperature by TT and ITT are similar during both rest and under heat load. 2) both TT and ITT are more sensitive than OT for Tc detection at rest and under heat load. 3) It is important to ensure that when taking temperature with the TT, it is well secured make contact with the tympanic membrane as illustrated in Fig.3. 4) the close values of Tc measured by TT and ITT may indicate that Tc might be probably similar in both ears. Analysis of the data show that at rest, Tc measured by TT was 0.45℃ and +0.1 ～ −0.12℃ (changed range) higher than that measured with OT and ITT respectively. At the end of 30 min of 43℃ water bath leg immersion, Tc measured by TT was 0.48℃ and 0.04℃ higher than that measured with OT and ITT. This show that when subjects are exposed to heat load, there is no difference in Tc measured by TT and ITT, although both were significantly higher than that measured with OT. The close agreement between TT and ITT is significant, because ITT has received more criticizism for inaccuracy (Childs *et al.*, 1999; Lanham *et al.*, 1999; Matsukawa *et al.*, 1997; Robinson *et al.*, 1998; Abolnik *et al.*, 1999) compared to the TT (Leick–Rude and Bloom, 1998; Montoya–Cabrera, 1998), as well as its inability to detect febrile temperatures accurately (Childs *et al.*, 1999; Lanham *et al.*, 1999). On the other hand, TT has also been criticized for causing subject discomfort, pain risk of injury and infection (Shinozaki *et al.*, 1988), although its performance was judged to be satisfactory (Leick–Rude and Bloom, 1998; Montoya–Cabrera, 1998). Matsumoto *et al.*, (1996) believed that accurate Tc is not detectable using ITT in 5% of the population as a result of the presence of hair in the ear canal or due to narrowness of the auditory canal. Another possible source of error is the fact that the temperature of the auditory canal is taken rather than the specific surface of the tympanic membrane (Cooper *et al.*, 1964; see also Fig. 3). It is also recommended that the person using ITT to take temperature has to be well trained and highly skilled (Matsumoto *et al.*, 1996). This is because operator error can introduce as much as ±0.19℃, even though an error range of 0.1–0.2℃ was considered to be acceptable (Childs *et al.*, 1999).

However, in this study, there was a smaller difference between the TT and ITT during hyperthermia (0.04℃) than during rest (+0.10 ～ −0.12℃, although, change range). This implies that this brand of ITT (Gentle TempTM, MC–505, OMRON, Health Care Inc) could possibly detect febrile temperatures accurately. The criticism claimed against the ITT could be solved, because different brand names are used by different experimenters. Indeed when Matsukawa *et al.*, (1997) compared four different brands of ITT (Genius, Thermopit, Quick-thermo and Thermoscan) the accuracies differed significantly, with the Genius being most sensitive. Considering that the ITT is a less risky, less stressful, less threatening and non–invasive technique (Shinozaki *et al.*, 1988; Montoya–Cabrera, 1998; Lanham *et al.*, 1999), it can be recommended for the measurement of Tc.

With regard to the physical characteristics, we chose subjects with wide age range to determine if this effect will affect the outcome. This is because thermosensitivity of brain tissue varies with age. Table 2 shows a summary of the mean ± SE distribution of temperature within the auditory canal as measured using TT. No difference was detected between Tc taken at 0 mm and −2 mm. There was significant difference when Tc taken at 0 mm as compared with those taken at −4 mm ($P<0.01$) to −10 mm ($P<0.001$).

In conclusion, the ITT performed extremely well under the conditions studied, as it accurately measured Tty. Considering the fact that each temperature device has merits and demerits, it is important to compare the sensitivities for Tc detection and determine if the demerits can be traded off for the merits. From the present results, it may be thought that the sensitivity for Tc detection increased in the order tympanic thermistor>infrared thermometer>oral thermistor. Considering that the ITT is less risky, less thermometer>oral thermistor. Considering that the ITT is less risky, less stressful, less threatening and non-invasive, it is recommendable for the measurement of Tc changes in thermophysiology research.

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