International Journal of Nursing Studies 46 (2009) 1415–1422

Contents lists available at ScienceDirect

International Journal of Nursing Studies

journal homepage: www.elsevier.com/ijns

The effects of measurement site and ambient temperature on body temperature values in healthy older adults: A cross-sectional comparative study

Shu-Hua Lu [a,b], Yu-Tzu Dai [a,c,*], Chung-Jen Yen [d]

[a] *Department of Nursing, College of Medicine, National Taiwan University, Taiwan*
[b] *Department of Nursing, Mackay Medicine, Nursing and Management College, Taiwan*
[c] *Department of Nursing, National Taiwan University Hospital, Taiwan*
[d] *Department of Internal Medicine, National Taiwan University Hospital, Taiwan*

ARTICLE INFO

Article history:
Received 9 January 2009
Received in revised form 10 April 2009
Accepted 5 May 2009

Keywords:
Ambient temperature
Body temperature
Body temperature measurement
Elderly
Oral temperature
Tympanic membrane temperature

ABSTRACT

Background: Accurate baseline body temperature measurement is essential for assessment. Tympanic membrane temperature (TMT) measurement is popular, but there is no consensus on whether it is as accurate as oral temperature (OT) for use with the elderly at varying ambient temperature levels.
Objectives: To test agreement between TMT and OT measurement of body temperature among an elderly population; and to explore whether agreement between the two sites depends on ambient temperature.
Design: A cross-sectional comparison study.
Methods: Two samples of older community-dwelling adults were recruited from 17 community senior citizen centers in Taipei, Taiwan in winter ($n = 262$) and summer ($n = 257$) of 2007. TMT and OT were simultaneously measured by electronic infrared ear thermometer and electronic digital thermometer. Ambient temperatures measured by digital thermo-hygrometer of the data collection setting were recorded when body temperature was taken.
Results: In winter mean TMT was 36.64 °C (S.D. 0.37), and mean OT was 36.74 °C (S.D. 0.18). In summer, the mean TMT was 37.05 °C (S.D. 0.30) and mean OT was 36.85 °C (S.D. 0.22). The relationship between TMT and OT were $r = 0.42$ ($p < 0.001$) in winter and $r = 0.57$ ($p < 0.001$) in summer. The values of OT were used as standard to assess the accuracy of the measurement. The bias between TMT and OT was −0.10 °C (S.D. 0.34) and 95% limits of agreement were 0.57 and −0.77 °C in winter; and bias was 0.20 °C (S.D. 0.25) and 95% limits of agreement were 0.69 and −0.29 °C in summer. The findings of this study demonstrate that the TMT has high variability that may under or over estimate body temperatures.
Conclusions: There is a lack of agreement in body temperatures values between TMT and OT in community-dwelling elderly in both winter and summer. OT was more stable than TMT regardless of ambient temperature influences. Therefore, the oral cavity is preferable to the TM site for temperature measurement in alert elderly. The limitation of this study is that hospitalized patients who are most likely to need temperature measurement are not included in this study.

What is already known about the topic?

- Tympanic membrane temperature (TMT) readings in many situations such as cerumen, hair follicles in the

* Corresponding author at: No. 1, Sec 1, Jen-Ai Rd, Taipei 10051, Taiwan. Tel.: +886 2 2312 3456x88437/62178; fax: +886 2 2322 5187.
E-mail address: yutzu@ntu.edu.tw (Y.-T. Dai).

0020-7489/$ – see front matter © 2009 Elsevier Ltd. All rights reserved.
doi:10.1016/j.ijnurstu.2009.05.002

auditory canal, the natural curvature of the aural canal, or its size which result in inaccurate positioning of the thermometer probe tend to be inaccurate and show a falsely low body temperature.
- Ambient temperatures can influence blood flow to body surfaces, including those of the ear canal and tympanic membrane. Research has shown that body temperature readings may be influenced by ambient temperature.

What this paper adds

- There is lack of agreement in body temperatures values between TMT and oral temperature (OT) in community-dwelling elderly in both winter and summer.
- Agreement between the TMT and OT depends on ambient temperature and TMT has heavier dependency on ambient temperature.
- The TMT has high variability that may under or over estimate body temperatures.
- For the alert elderly the oral cavity is the preferred, more stable and reliable temperature measurement site over the tympanic membrane.

1. Introduction

Accurate measurement of body temperature is widely considered a necessity in detecting infection, monitoring inflammatory processes or evaluating the progress of disease or treatment (Fulbrook, 1993a; Smith, 2003). Development of the hand-held tympanic membrane thermometer led to its widespread use in clinical settings, due to its non-invasiveness and convenience. The use of disposable probes helps reduce the chance of cross-infection and the device is highly acceptable to both patients and health care providers (Klein et al., 1993; Lattavo et al., 1995). Despite its popularity, there remains considerable controversy about how well tympanic membrane temperature (TMT) measurement represents the core body temperature. Moderating conditions for some patients, particularly the elderly may affect the accuracy of TMT measurement. Rectal temperature, long considered "core temperature" has fallen into disfavor because of its invasiveness and the risk of bowel perforation. Whether a specific measurement site is limited by age-induced physiological changes in blood flow, by cerumen in the ear canal, or by environmental factors, finding a site that is safe, easily accessible and reflects core temperature change accurately is essential (Erickson and Yount, 1991; Smith, 2003). Ideally, measurement of a site that is supplied with the same blood supply as the hypothalamus is more likely to reflect core body temperature. The blood supply to the tympanic membrane arises from the same branch of the carotid arteries as the hypothalamus, the control center for body temperature (Boulant, 1998). The oral cavity is another popular site for temperature measurement, because the thermometer probe is placed in a sublingual pocket near deep tongue arteries that are also supplied by the carotid artery. However, it may be difficult for a cognitively impaired elder to be cooperative to hold an oral thermometer in place and keep air-tight (Fulbrook, 1993a; Smith, 2003).

Because ambient temperatures can influence blood flow to body surfaces, including those of the ear canal and tympanic membrane (Doyle et al., 1992; Zehner and Terndrup, 1991), it is of clinical significance to determine if OT and TMT readings differ and if either are influenced by fluctuations in ambient temperature. Several factors may result in an inaccurate measurement when using a TMT because the infrared beam requires a clear passage to reflect on the tympanic membrane. If the infrared beam is blocked by cerumen, or improper positioning of the thermometer probe, temperature readings will be inaccurate. Lack of sufficient training in the tympanic membrane thermometer placement technique in operators also results in error reading. TMT readings in these situations tend to be inaccurate and show a falsely low body temperature (Doezema et al., 1995; Hasel and Erickson, 1995; Holtzclaw, 2002).

Therefore, the purpose of this study was (1) to test agreement between TMT and OT measurement of body temperature among an elderly population; and (2) to explore whether agreement between the two sites depends on ambient temperature.

2. Background and significance

As one might expect, different measurement sites consistently have different temperatures depending on their proximity to large vascular beds and insulation by surrounding tissue. For example, rectal temperature is generally considered to be consistently about 0.5 °C higher than OT. Differences between OT and TMT have not been consistent, although one study found that TMT was 0.5 °C lower than OT in 20.73% (85 out of 410) of subjects when OT and TMT were measured simultaneously (Abolnik et al., 1999).

Many studies reported situations and environment conditions exist at the time of measurement that could influence temperature of skin and mucous membranes. For example hot and cold beverages, smoking of cigarettes and chewing gum should be avoided for a minimum of 30 min before temperature measurement (Quatrara et al., 2007; Sugarek, 1986) to avoid false high or low readings. In older people, dentures may impair the accuracy of readings due to the difficulty keeping the probe in place and the lips sealed (Marion et al., 1991). Also, persons with dementia or experiencing confusion may have inaccurate readings due to the inability of the individual to keep the temperature probe in the sublingual pocket and the lips sealed (Albertson, 2007; Edwards, 1997; Fulbrook, 1993a). Research has shown that body temperature readings may be influenced by ambient temperature (Doyle et al., 1992; Zehner and Terndrup, 1991). Whether those low body temperatures in Abolnik et al.'s study were associated with an ambient temperature effect was not reported.

In addition to the consideration of measurement site and the influencing factor of temperature measurement, the accuracy of temperature measurement need to be explored further. The term of "accuracy" is equal to "validity" in physiologic measurement. Accuracy means the ability of the instrument to measure true value (Ganz and Pugh, 2004). Furthermore, accuracy of a thermometer "*refers to the confidence that a particular measurement reflects the true existing temperature*" (Holtzclaw, 1993, p. 47). It is an essential characteristic of the ideal thermometers. Some measurements can be validated by an objective criterion, we call this criterion validity (Polit and Beck, 2004). Previous studies estimated the accuracy of measurement methods (sites or devices) by comparing the correlation coefficient between a highly reliable gold standard and the new method (Fulbrook, 1993b; Henker and Coyne, 1995; Klein et al., 1993). However, it is ignored that different site of body have different blood flows and muscular activity (Holtzclaw, 2002). Also strong correlation do not confirm agreement (Hanneman, 2008). For body temperature measurements there may be no objective criterion. When using non-invasive methods, body temperature can be measured only indirectly. As Bland and Altman (2002, p. 606) stated "*our criterion becomes agreement with another indirect measurement*". For this reason this study use bland and Altman plot to examine the agreement between TMT and OT which is used as a standard.

Review of relevant literature revealed several investigations that compared the accuracy of temperature measurement of different sites, mostly in critical care units where subjects were younger adults (Farnell et al., 2005; Giuliano et al., 1999; Lawson et al., 2007). Methods typically used to measure temperatures in younger adult populations may not be appropriately adapted for the older population. Few studies focused on elderly subjects and conclusions were not consistent (Castle et al., 1992; Smitz et al., 2000; Varney et al., 2002). There is a major gap in the literature regarding the influence of ambient temperature on temperature measurement from different sites. Further investigation on these relationships could clarify the effects of ambient temperature on body temperature values and help to determine the most appropriate temperature measurement site and method for the elderly.

3. Methods

3.1. Design, setting, and subjects

A cross-sectional comparison study of two samples was conducted with community-dwelling participants ($n = 519$), age 65 and over. Data were collected in 17 community centers for senior citizens in Taipei, Taiwan with two samples: one in winter ($n = 262$) (from November 2006 to March 2007) and one in summer ($n = 257$) (from April 2007 to July 2007).

The inclusion criteria were: persons ≥65 years old living in the community no exacerbation of chronic disease, no acute illness, and capable of independent activities of daily living. The exclusion criteria included: persons manifesting acute febrile illness or body temperature over 38 °C at any measurement site; those who had drunk hot or cold liquid, smoked, chewed gum or betel nut within 30 min before temperature measurement; those for whom OT or TMT measurement was contraindicated (e.g., mouth mucosa or ear cavity ulcer); and those who had been prescribed antipyretics, anti-inflammation medication, or had been inoculated with influenza or other vaccine within 1 week.

3.2. Variables and instruments

The study instruments were: (1) a demographic data collection sheet, (2) TMT was measured by a Genius 3000A electronic infrared ear thermometer in the oral equivalent adjusted mode (Winning Medical Inc. TW), with accuracy estimated at ±0.1 °C, over the range 35–39 °C; and (3) A Welch Allyn Sure Temp 679 electronic digital thermometer with a thermistor probe (Amesdata Technology Co., TW) for measuring OT, the temperature value displayed digitally in 4–6 s during temperature taking, with accuracy of ±0.1 °C, over the range 26.7–43.3 °C. The thermometers were calibrated for accuracy, according to manufacturer's standard, before and periodically throughout the study was performed. In addition the instruments were only research use. Ambient temperatures were measured by a digital thermo-hygrometer (Yeong-Shin Co., TW) with accuracy ±0.1 °C, over the range −20 to 70 °C.

3.3. Data collection procedure

This study was approved by the Research Ethics Committee of National Taiwan University Hospital and written informed consent was obtained from each subject. All temperature measurements were made between 8 and 10 a.m. Subjects were instructed not to eat, drink, or smoke for 30 min, and to rest for at least 15 min prior to temperature measurement. For preventing false temperature readings as suggested by Heusch and McCarthy (2005) TMT measurements were made from both the left and right ear and the higher readings was recorded at the same time that OT were measured. The oral temperature was also measured two times and the higher oral temperature was used for analysis. Ambient temperature was recorded at the time of measurement.

Because insufficiently skilled operators may cause inconsistencies in TMT measurement, all temperatures in this study were measured by one nurse research assistant who was formally trained in use of the device including choosing the correct measurement site (e.g., sublingual pocket) and practicing infrared ear thermometer probe placement (e.g., ear tug technique). The research nurse received individualized training and supervised practice with older adults in the use of the instrument and the ear tug method (straightens the external auditory canal by pulling in an upward and backward direction) from one of the investigators (Shu-Hua, Lu) to ensure uniform application of the correct technique. Throughout the study the investigator made both scheduled and unannounced visits to the research sites to audit application of correct technique.

3.4. Data analysis

The statistical package SPSS version 12.0 was used for data analysis. First, descriptive statistics were computed.

Table 1
Demographic data and health status of subjects.

	Winter, $n = 262$			Summer, $n = 257$		
	n	%	Mean ± S.D. (range)	n	%	Mean ± S.D. (range)
Sex						
Male	140	52.4		131	51.0	
Female	122	46.4		126	49.0	
Age						
65–74	139	53.1	75.5 ± 6.3 (65–93)	107	41.6	76.6 ± 7.5 (65–95)
75–84	105	40.1		107	41.6	
>85	18	6.9		43	16.7	
Number of chronic diseases						
0	52	19.8	1.6 ± 1.3 (0–6)	36	14.0	2.0 ± 1.4 (0–6)
1–3	185	73.3		178	69.5	
4–6	18	6.9		43	16.8	
Number of routinely taken medications						
0	83	31.7	1.2 ± 1.2 (0–10)	60	23.3	2.1 ± 1.2 (0–10)
1–5	177	67.9		193	75.1	
6–9	1	0.4		4	1.6	

Second, the Pearson-product moment correlation was used to examine the relationships among ambient temperature, TMT and OT. Finally, in order to determine agreement between TMT and OT measurement, the Bland and Altman method was used (Bland and Altman, 1999; Hanneman, 2008), with the OT taken as the reference site.

The accuracy and precision were used to assess the agreement between two methods of measurement. The accuracy of measurement is indicated by the mean of difference (also called bias) between the TMT and OT (difference score were calculated by subtracting TMT from the OT that is taken from "reference site"). When the bias is close to zero, on average, the TMT site agree well with OT site (Bland and Altman, 1999; Fisk and Arcona, 2001; Washington and Matney, 2008). According to manufacturer's standard the accuracy of TMT (infrared ear thermometer; Winning Medical Inc. TW) and OT (electronic digital thermometer; Amesdata Technology Co., TW) were at ±0.1 °C. As suggested by Hanneman (2008) investigator could set the criteria of bias at 0.1 °C or higher. For this study the criteria of bias was set at ±0.2 °C.

The precision is equal to the term "reliability" in physiologic measurement and is indicated by the 95% limits of agreement. To extend the concept of bias, the variation of mean difference is estimated by the standard deviation (S.D.) of the differences. If the differences are normally distributed, we would expect 95% of the differences to lie between the bias ±1.96 S.D. that we call 95% of limits of agreement (Bland and Altman, 1999). Therefore, the 95% of limit of agreement represent "*the range of values in which agreement between methods will lie of approximately 95% of the sample*" (Hanneman, 2008, p. 226).

In addition, the scatter plots were constructed to provide visual examination of how well the methods agree. In general, a large S.D. and wide limits of agreement reveal a problem of agreement (Bland and Altman, 1999). For this study the criteria of the 95% limits of agreement was set at the bias ±0.5 °C.

4. Results

4.1. Demographic description of the sample

Table 1 shows the demographic and health profile of subjects. During the time body temperatures were taken, the ambient temperature ranged from 19.0 to 27.4 °C in the winter season and 22.0 to 34.6 °C in the summer season.

4.2. Bland and Altman method for assessing agreement

In winter, mean TMT was 36.64 °C (S.D. 0.37), and mean OT was 36.74 °C (S.D. 0.18). In summer, mean TMT was 37.05 °C (S.D. 0.30) and mean OT was 36.85 °C (S.D. 0.22). The box plots in Fig. 1 demonstrate the variability of OT and TMT. In both winter and summer, OT has less

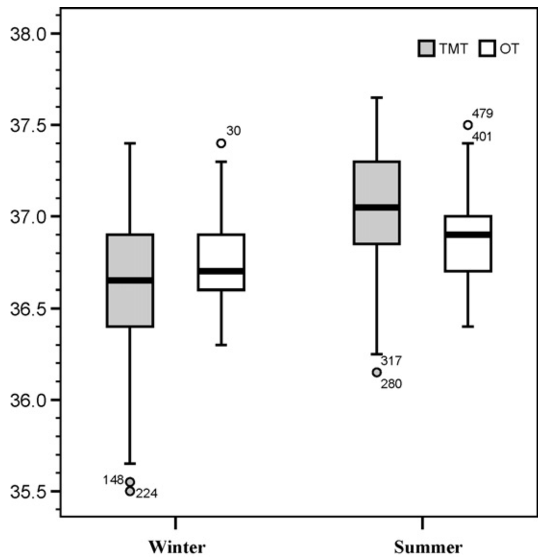

Fig. 1. Box plots represent variability of TMT and OT during the two different seasons (°C). *Note*: small circles mean outliers; TMT, tympanic membrane temperature; OT, oral temperature.

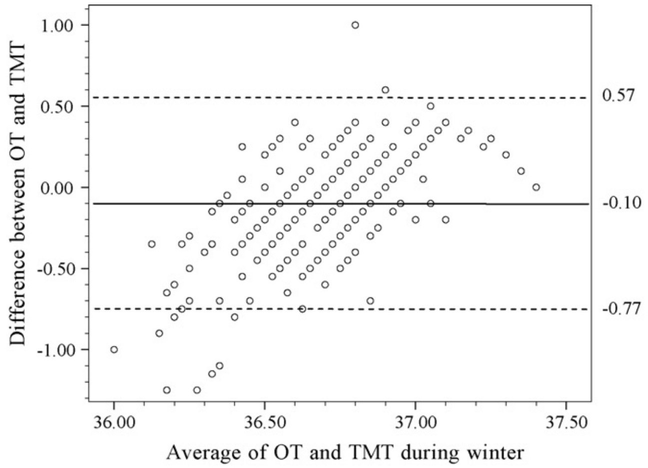

Fig. 2. Bland–Altman analysis of TMT vs. OT during winter. *Note*: TMT, tympanic membrane temperature; OT, oral temperature.

variability then TMT. The correlation between TMT and OT were $r = 0.42$ ($p < 0.001$) in winter and $r = 0.57$ ($p < 0.001$) in summer.

Bland and Altman plots are shown in Figs. 2 and 3. The bias between TMT and OT was −0.10 °C (S.D. 0.34), more dots were distributed over the negative side of the *Y*-axis. The upper limit of agreement was 0.57 °C ($-0.10 + 1.96 \times 0.34$) and lower limit of agreement was −0.77 °C ($-0.10 - 1.96 \times 0.34$) in winter. In summer, the bias between TMT and OT was 0.20 °C (S.D. 0.25), more dots were distributed over the positive side of *Y*-axis. The upper limit of agreement was 0.69 °C ($0.20 + 1.96 \times 0.25$) and lower limit of agreement was −0.29 °C ($0.20 - 1.96 \times 0.25$) (Table 2).

4.3. Associations between ambient temperatures and measurement method

The correlations between ambient temperatures and TMT were $r = 0.30$ ($p < 0.001$), between ambient temperatures and OT were $r = -0.09$ ($p = 0.134$) in winter. Correlations between ambient temperatures and TMT were $r = 0.34$ ($p < 0.001$), between ambient temperatures and OT were $r = 0.35$ ($p < 0.001$) in summer. When winter and summer temperatures were combined the correlations between ambient temperatures and TMT were $r = 0.56$ ($p < 0.001$), between ambient temperatures and OT were $r = 0.30$ ($p < 0.001$).

5. Discussion

The purpose of this study was to investigate whether temperature measurement method and ambient temperatures influence body temperature values in the elderly when operator-influenced variation is controlled. The study goal was to find whether using the TMT or OT measurement is a more reliable measure in community-dwelling elders irrespective of ambient temperature.

The findings in the relationship between body temperature and ambient temperature are congruent with those of Doyle et al. (1992) and Zehner and Terndrup (1991) in that the TM method was influenced by ambient

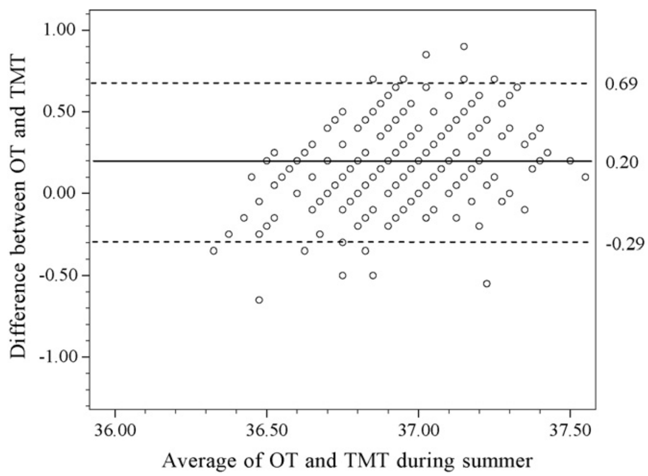

Fig. 3. Bland–Altman analysis of TMT vs. OT during summer. *Note*: TMT, tympanic membrane temperature; OT, oral temperature.

Table 2
Comparison between TM and OT during different seasons.

Season	Sites compared	*n*	Temperature (°C)			95% Limits of agreement	
			Mean ± S.D.	Range	Bias (S.D.)	Upper LOA	Lower LOA
Winter	OT (reference site)	262	36.74 ± 0.18	36.30–37.40			
	TMT (test site)	262	36.64 ± 0.37	35.50–37.40			
	TMT–OT	262			−0.10 (0.34)	0.57	−0.77
Summer	OT (reference site)	257	36.85 ± 0.22	36.40–37.50			
	TMT (test site)	257	37.05 ± 0.30	36.15–37.65			
	TMT–OT	257			0.20 (0.25)	0.69	−0.29

Note: TMT, tympanic membrane temperature; OT, oral temperature, Bias, mean difference between TMT and OT, LOA, limits of agreement.

temperature resulting in falsely elevated readings in warm ambient temperature situations. However, unlike Doyle et al. and Zehner et al. the ambient temperature did not appear to influence the OT. One possible reason for the inconsistent finding may be that Doyle et al. and Zehner et al. exposed their subjects more to extreme environmental temperatures; warmer (35 and 43.5 °C) in summer and cooler (18.3 and −5 °C) in winter compared to the moderate (winter: 19.0–27.4 °C, summer: 22.0–34.6 °C) ambient temperature variation in the current study. These conclusions are consistent with those of Abolnik et al. (1999) and those of Giuliano et al. (1999), who also compared OT and TMT with pulmonary artery temperature.

The results of this study show a moderate relationship between TMT and OT. However, even high correlations do not confirm agreement (Hanneman, 2008). Thus in order to determine agreement between TMT and OT measurement, the Bland and Altman method (Bland and Altman, 1999; Hanneman, 2008) was used. In winter although the bias is −0.10 °C (S.D. 0.34), falls within the bias criteria of ±0.2 °C, the S.D. was large at 0.34. The wide limits of agreement were 0.57 and −0.77 (bias ± 1.96 S.D. = −0.10 ± 0.67) which exceeds the a priori criteria bias ±0.5 °C. The large S.D. and wide limits of agreement demonstrate that TMT has high variability in healthy elders during winter.

In summer the bias fell barely within the upper limit of the criteria at 0.20 °C. Therefore, TMT may tend to over estimate body temperatures during summer. Possibly were due to warmer auditory canal temperature. The S.D. was larger at 0.25, and wide limits of agreement were 0.69 and −0.29 °C (bias ± 1.96 S.D. = 0.20 ± 0.49) which is close to the a priori criterion bias ±0.5 °C. The large S.D. and wide limits of agreement demonstrate that the TMT has less acceptable variability. The TMT tends to be more stable in the healthy elder during summer than in winter.

In addition, TMT were more closely correlated with ambient temperatures when winter and summer temperatures were combined ($r = 0.56$, <0.001), whereas OT were only weakly correlated ($r = 0.30$, $p < 0.001$). In both winter and summer, OT was less variable than TMT. In summer, the mean difference between two methods was positive that means the TMT were slightly higher than the OT; however, the mean difference was negative in winter that indicated the TMT were lower than OT. These findings indicated that TMT are easier to fluctuate and influenced by the environment ambient temperature. Therefore, the findings of study conclude agreement between the TM and OT methods depends on ambient temperature and TMT has heavier dependency on ambient temperature.

6. Limitations

This study only included normally functioning ambulatory elderly; therefore, results may not be generalized to all elderly or to those who were most likely to need temperature measurement such as patients in condition of fever or acute illness.

Bland and Altman (1999) suggested the clinical accuracy of instrument should be tested to compare with an acknowledged gold standard. The thermometers in this study were calibrated and found to be accurate prior to the study. However, determining the clinical accuracy of either the OT or TMT site to estimate a patient's true temperature would necessitate a gold standard of body temperature which is generally acknowledged to be the temperature from an indwelling pulmonary artery catheter (Giuliano et al., 1999; Moran and Mendal, 2002). This study was conducted in a community setting where such invasive procedures are neither feasible nor acceptable, so a statistical alternative was used to measure agreement when no gold standard of actual body temperature exists (Bland and Altman, 1999; Hanneman, 2008).

In this study the tympanic temperature was displayed in the "oral equivalent adjusted mode" rather than the actual TMT. The mathematical algorithms used to calculate the oral equivalent are not consistent across brands TM of thermometer (Terndrup and Rajk, 1992). To overcome this limitation, future studies should use actual rather than adjusted TMT; however, findings of this study show the bias was small and fell within the a priori criterion acceptance range. The important finding, independent of offset algorithm, is that the TMT site demonstrates high variability.

Castle et al. (1992) assessed the extent of ear canal occlusion by cerumen and concluded that cerumen occlusion did not have a significant affect on TMT readings from THERMOSCAN® Instant Thermometer Professional Model (Pro 1). In the current study, we found that it was difficult to obtain TMT readings from patients with cerumen occlusion. Further study of the influence of cerumen occlusion in the elderly on readings from different TMT measurement instruments may be needed.

In addition to ambient temperature, future studies could consider additional variables that might influence body temperature measurements such as humidity, airflow, time in the measurement site environment prior to the temperature measurement, and protective headgear such as hat or scarves.

7. Conclusion

Findings of this study suggest that, for the alert elderly the oral cavity is the preferred and more stable and reliable temperature measurement site over the TMT site. But OT measurement is not appropriate for those who are unconscious, frail or confused as they may be unable to cooperate to open their mouths or properly hold a thermometer in their mouth.

None of the methods is perfect for measuring body temperature (Varney et al., 2002). TMT had higher tendency to fluctuate with ambient temperature. This study raises further questions about the validity of TMT as a clinical measure. Whether the dependency of TMT on ambient temperature is clinically significant and could result in misdiagnosis or delay in treatment need to be explored in the future.

Acknowledgements

The authors would like to thank the research subjects for their participation. The authors wish to acknowledge the mentorship and editorial assistance provided by Dr. Barbara J. Holtzclaw, Professor and Nurse Scientist at the University of Oklahoma Health Sciences Center, Oklahoma City, OK and Dr. Sharon Coon, Associate Professor, University of Oklahoma Health Sciences Center, Oklahoma City, OK and Director, Nursing Research OU Medical Center.

Conflict of interest

The authors declare that they have no conflict of interest.

Funding

This research was funded by grant No. 95-2314-B-002-189 from the National Science Council of Taiwan.

Ethical approval

This research was approved by the Research Ethics Committee of National Taiwan University Hospital, and the REC number is 200610023R.

References

Abolnik, I.Z., Kithas, P.A., McDonnald, J.J., Soller, J.B., Izrailevsky, Y.A., Granger, D.L., 1999. Comparison of oral and tympanic temperatures in a Veterans Administration outpatient clinic. American Journal of the Medical Sciences 317 (5), 301–303.

Albertson, B., 2007. Vital sign assessment. In: Craven, R.F., Hirnle, C.J. (Eds.), Fundamentals of Nursing: Human Health and Function. Lippincott Williams & Wilkins, Philadelphia, pp. 485–489.

Bland, J.M., Altman, D.G., 1999. Measuring agreement in method comparison studies. Statistical Methods in Medical Research 8 (2), 135–160.

Bland, J.M., Altman, D.G., 2002. Statistics notes: validating scales and indexes. BMJ 324 (7337), 606–607.

Boulant, J., 1998. Neural thermal reception and regulation of body temperature. In: Blatties, C. (Ed.), Physiology and Pathophysiology of Temperature Regulation. World Scientific Publishing, Singapore, pp. 94–155.

Castle, S.C., Toledo, S.D., Daskal, S.L., Norman, D.C., 1992. The equivalency of infrared tympanic membrane thermometry with standard thermometry in nursing home residents. Journal of the American Geriatrics Society 40 (12), 1212–1216.

Doezema, D., Lunt, M., Tandberg, D., Doezema, D., Lunt, M., Tandberg, D., 1995. Cerumen occlusion lowers infrared tympanic membrane temperature measurement. Academic Emergency Medicine 2 (1), 17–19.

Doyle, F., Zehner, W.J., Terndrup, T.E., 1992. The effect of ambient temperature extremes on tympanic and oral temperatures. American Journal of Emergency Medicine 10 (4), 285–289.

Edwards, S.L., 1997. Measuring temperature. Professional Nurse 13 (2) S5–S7, S14.

Erickson, R.S., Yount, S.T., 1991. Comparison of tympanic and oral temperatures in surgical patients. Nursing Research 40 (2), 90–93.

Farnell, S., Maxwell, L., Tan, S., Rhodes, A., Philips, B., 2005. Temperature measurement: comparison of non-invasive methods used in adult critical care. Journal of Clinical Nursing 14 (5), 632–639.

Fisk, J., Arcona, S., 2001. Comparing tympanic membrane and pulmonary artery catheter temperatures. Dimensions of Critical Care Nursing 20 (2), 44–49.

Fulbrook, P., 1993a. Core temperature measurement in adults: a literature review. Journal of Advanced Nursing 18 (9), 1451–1460.

Fulbrook, P., 1993b. Core temperature measurement: a comparison of rectal, axillary and pulmonary artery blood temperature. Intensive & Critical Care Nursing 9 (4), 217–225.

Ganz, F.D., Pugh, L.C., 2004. Physiologic measurement issue. In: Marilyn, F.S., Olsen, S.J. (Eds.), Instruments for Clinical Health-Care Research Sudbury. Jones and Bartlett, Boston, MA, pp. 65–80.

Giuliano, K.K., Scott, S.S., Elliot, S., Giuliano, A.J., 1999. Temperature measurement in critically ill orally intubated adults: a comparison of pulmonary artery core, tympanic, and oral methods. Critical Care Medicine 27 (10), 2188–2193.

Hanneman, S.K., 2008. Design, analysis, and interpretation of method-comparison studies. Advanced Critical Care 19 (2), 223–234.

Hasel, K.L., Erickson, R.S., 1995. Effect of cerumen on infrared ear temperature measurement. Journal of Gerontological Nursing 21 (12), 6–14.

Henker, R., Coyne, C., 1995. Comparison of peripheral temperature measurements with core temperature. AACN Clinical Issues 6 (1), 21–30.

Heusch, A.I., McCarthy, P.W., 2005. The patient: a novel source of error in clinical temperature measurement using infrared aural thermometry. Journal of Alternative & Complementary Medicine 11 (3), 473–476.

Holtzclaw, B.J., 1993. Monitoring body temperature. AACN Clinical Issues in Critical Care Nursing 4 (1), 44–55.

Holtzclaw, B.J., 2002. Use of thermoregulatory principles in patient care: fever management. Online Journal of Clinical Innovations 5 (5), 1–64.

Klein, D.G., Mitchell, C., Petrinec, A., Monroe, M.K., Oblak, M., Ross, B., Youngblut, J.M., 1993. A comparison of pulmonary artery, rectal, and tympanic membrane temperature measurement in the ICU. Heart & Lung 22 (5), 435–441.

Lattavo, K., Britt, J., Dobal, M., 1995. Agreement between measures of pulmonary artery and tympanic temperatures. Research in Nursing & Health 18 (4), 365–370.

Lawson, L., Bridges, E.J., Ballou, I., Eraker, R., Greco, S., Shively, J., Sochulak, V., 2007. Accuracy and precision of noninvasive temperature measurement in adult intensive care patients. American Journal of Critical Care 16 (5), 485–496.

Marion, G.S., McGann, K.P., Camp, D.L., 1991. Core body temperature in the elderly and factors which influence its measurement. Gerontology 37 (4), 225–232.

Moran, D.S., Mendal, L., 2002. Core temperature measurement: methods and current insights. Sports Medicine 32 (14), 879–885.

Polit, D.F., Beck, C.T., 2004. Assessing data quality. In: Polit, D.F., Beck, C.T. (Eds.), Nursing Research: Principles and Methods. Lippincott Williams & Wilkins, Philadelphia, pp. 413–447.

Quatrara, B., Coffman, J., Jenkins, T., Mann, K., McGough, K., Conaway, M., Burns, S., 2007. The effect of respiratory rate and ingestion of hot and cold beverages on the accuracy of oral temperatures measured by electronic thermometers. MEDSURG Nursing 16 (2) 105–108, 100.

Smith, L.S., 2003. Assessment. Using low-tech thermometers to measure body temperatures in older adults: a pilot study. Journal of Gerontological Nursing 29 (11), 26–33.

Smitz, S., Giagoultsis, T., Dewe, W., Albert, A., 2000. Comparison of rectal and infrared ear temperatures in older hospital inpatients. Journal of the American Geriatrics Society 48 (1), 63–66.

Sugarek, N.J., 1986. Temperature lowering after iced water. Enhanced effects in the elderly. Journal of the American Geriatrics Society 34 (7), 526–529.

Terndrup, T.E., Rajk, J., 1992. Impact of operator technique and device on infrared emission detection tympanic thermometry. Journal of Emergency Medicine 10 (6), 683–687.

Varney, S.M., Manthey, D.E., Culpepper, V.E., Creedon Jr., J.F., Varney, S.M., Manthey, D.E., Culpepper, V.E., Creedon Jr., J.F., 2002. A comparison of

oral, tympanic, and rectal temperature measurement in the elderly. Journal of Emergency Medicine 22 (2), 153–157.
Washington, G.T., Matney, J.L., 2008. Comparison of temperature measurement devices in post anesthesia patients. Journal of PeriAnesthesia Nursing 23 (1), 36–48.
Zehner, W.J., Terndrup, T.E., 1991. The impact of moderate ambient temperature variance on the relationship between oral, rectal, and tympanic membrane temperatures. Clinical Pediatrics 30 (4 Suppl.), 61–64 discussion 71–62.