Accuracy When Assessing and Evaluating Body Temperature in Clinical Practice: Time for a Change?

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SUMMARY

Evaluation of body temperature is one of the oldest known diagnostic methods and still is an important sign of health and disease, both in everyday life and in medical care. In clinical practice, assessment and evaluation of body temperature has great impact on decisions in nursing care as well as the laboratory test ordered, medical diagnosis and treatment. The definition of normal body temperature as 37° C and fever as > 38° C still is considered the norm world- wide, but in practice there is a widespread confusion of the evaluation of body temperature. When assessing body temperature, we have to consider several "errors", such as the influence of normal thermoregulation, gender, ageing and site of measurement. Actually, there is a lack of evidence for normal body temperature as 37°C, due to inter- and intra-individual variability. In addition, as normal body temperature shows individual variations, it is reasonable that the same should hold true for the febrile range. By tradition, the oral and axillary readings are adjusted to the rectal temperature by adding 0.3° C and 0.5°C, respectively. However, there is no evidence for adjusting one site to another, i.e. no factor does exist which allows accurate conversion of temperatures recorded at one site to estimate the temperature at another site. This raises the question about accuracy in measurement of body temperature. What precision can we expect in clinical practice? How is the unadjusted variation of body temperature in different sites related to health and disease? Taken together, it is time for a change when assessing and evaluating body temperature in clinical practice.

Keywords: Accuracy, assessment, normal body temperature, fever

1. INTRODUCTION

In clinical practice, assessment and evaluation of body temperature, i.e the presence of fever, has great impact on decisions in nursing care as well as medical diagnosis, treatment and the laboratory test ordered. From both a technical as well as a clinical view, accuracy of the reading is significant to ensure a correct assessment (32, 63). Accuracy indicates proximity of measurement results to the true value and precision of the measurement. However, when assessing body temperature, we have to consider several "errors", such as the influence of normal thermoregulation, gender, ageing and site of measurement.

This raises the question about accuracy in measurement of body temperature. What accuracy can we expect in clinical practice? In addition, is it accurate to convert a temperature measured at one site to in order to estimate the temperature at another site?

Therefore, the objective of this paper was to discuss accuracy of body temperature measurement and implications in clinical practice.

2. METHODS

2.1 Literature search

A literature search was performed in MEDLINE, CINAHL and manually from identified articles reference lists. The results of the literature search and implications for clinical practice is presented in an earlier paper (63). Briefly, the search included English or Swedish textbooks, original papers, reviews and scholarly papers, addressing the concept body temperature related to different constellations of key- words, such as measurement / normal / core/ human / review / adult / gender / tympanic / rectal/ oral / axillary / thermometers. Also hypothermia and elderly, thermoregulation, circadian rhythm, fever, febrile response and shivering was used to identify articles. No restriction was made concerning when the paper was published. For the purpose of the present paper we have added published papers focusing on accuracy from a technique point of view.

3. RESULTS

3.1 Accuracy and standardisation

According to the ISO (32) standard the clinical accuracy of a clinical thermometer is verified "*by comparing its output temperature with that of a reference thermometer, which has a specified uncertainty for measuring true temperature"*.

However, for an equilibrium clinical thermometer it is possible under laboratory conditions to adequately determine the clinical accuracy, i.e. equilibrium state between the two devices. For a clinical thermometer, operating in the adjusted mode, the output temperature includes characteristics of the patient and the environment. Hence, according to international standards, the clinical accuracy of a thermometer in the adjusted mode has to be clinically validated with statistical methods to compare its output temperature with a reference clinical thermometer. This clinical device, in turn, should have a specified clinical accuracy, representing a particular reference body temperature (32). In addition, the calibration has to be performed according to ISO standards in an accredited laboratory (30, 60). For electronic contact thermometers the standard states an operating range of 35.5° C to 42° C and a laboratory accuracy of $\pm$ 0.1° C (15).

Also, there are ISO standards for establishing clinical accuracy for infrared (IR) ear thermometers (31). According to this standard clinical accuracy is defined as the *"ability of an IR ear thermometer to give a reading close to the temperature of the site that it purports to represent as measured by the reference thermometer"*. Maximum permissible error shall not exceed $\pm$ 0.2° C operating from 35.5° C to 42° C (15). At present no manufacturing standards have been developed for the forehead thermometers (15).

For the clinicians accuracy is about a thermometer that accurately and consistently measures, or estimates the "actual" body temperature (15). McCarthy & Heusch (40) summarize that a site that quantitatively and rapidly reflect changes in arterial temperature and is independent of local blood flow or environmental changes appropriate estimate central temperature. Also, the repeatability of the thermometer is important in the clinical setting (50). The most important factor influencing the reading is probably a correct placement, as an incorrect placement can cause serious variations (15). The site should also be convenient for the clinician, pain free and harmless for the patient and reliable and traceably standardized. Also, bilateral sides should be compared, studies should be based on large populations and there should be scientific cut-off points for clinically relevant conditions, such as fever (40).

3.2 Definition of normal body temperature and fever

The definition of normal body temperature as 37° C and fever as $\geq$ 38.0°C was established in the middle of the 19th century (70). The axillary site, which estimates the periphery body temperature, was used as the reference temperature. Also, the fact that the measurements were performed on patients, indicate that a large number might have been febrile (38, 43). In 1869 the understanding about the influence of thermoregulation, hormones, metabolism and physical activity on body temperature was unknown. In addition, knowledge about immunology and microbiology and insight about the importance of calibration of thermometers were lacking. DuBois (16) pointed out that *"a range of temperatures may be found in perfectly normal persons"* and raised the question *"Would it not be wise to remove the little red arrows from our thermometers?"* Galen & Gambino (23) further stated that a concept of normality is itself inadequate for the proper interpretation of test results if it is not interpreted in relation to a reference value.

Today there is a general acceptance of body temperature as a range rather than a fixed temperature. Even so, the norm from the middle of the 19th century is still the basis for assessment and decisions about body temperature, causing a widespread confusion of the evaluation of body temperature in clinical practice (39). Also, there is a lack of studies performing temperature measurements in a standardised way (62).

3.3 Core body temperature

According to the International Union of Physiological Sciences (IUPS), Thermal Commission, a site providing a core temperature would be expected to be stable in relation to the temperature in internal organs, irrespective of circulatory changes or heat dissipation affecting the periphery, or external factors, such as environmental temperature and humidity. The ideal core temperature is the mean temperature of the thermal core. In changing core conditions the oesophageal or aortic temperature readings are recommended (42). Ring et al. (52) pointed out that there is not a single unique core temperature as there are temperature gradients between internal organs in the body. This was already suggested by

DuBois (16) who defined the core of the body as the thoracic and abdominal contents, some of the muscles and the brain, while the peripheral areas were defined as the skin and a small amount of subcutaneous tissue. He also pointed out the misconception of *the* body temperature and underlined that there is not one, but several core body temperatures depending on temperature gradients within the body.

Today, the temperature in the pulmonary artery (PA) is considered the gold standard of core temperature (35, 37), although, some suggests the nasopharynx and the bladder as gold standards for core temperature (15). However, still it is not clear what a clinically accessible core body temperature is (50). In clinical practice, as well as in research and stated by the IUPS, the rectal or the oral site is used as a surrogate for the core temperature (39, 50). This might be an explanation to the tradition, although without no scientific base, that the oral and axillary readings are adjusted to the rectal temperature adding 0.3°C and 0.5°C, respectively (2).

In order to make the reading more familiar to clinicians, this tradition has been applied also to ear based temperature measurements, which can be measured without adjustments to other sites, or readjusted in order to equalise the oral, rectal or PA temperature (2). These adjustments to other sites vary considerable between manufactures (5, 19, 57, 59, 66), and there is a lack of studies supporting these offsets (40). Also, thermometers estimating the tempory artery temperature are adjusted with pre- decided offsets to equalize a temperature at a reference site.

3.4 Comparison between sites in assessment of body temperature

A large amount of papers have focused on accuracy by comparing non-invasive measurements to a reference site, often PA or the rectal site. However, the question is if this is the best approach to describe clinical accuracy (63). There is no evidence for adjusting one site to another, i.e. no factor does exist which allows accurate conversion of temperatures recorded at one site to estimate the temperature at another site (34, 64).

Simply adding an offset, assuming that the differences between different sites and methods are linear do not consider thermoregulation and the complexity of the human body (40). Lack of agreement between measurements does not necessarily mean that one site is true and the other one false, due to different thermal influences and profiles (50). However, this is often the conclusion in studies on body temperature measurement. As an example, a world-wide cited systematic review, including 45 studies (14) found that the ear temperature could be 0.2°C to 1.4°C below and 0.1°C to 1.9°C over the rectal temperature in children. They therefore concluded that the ear site is not an acceptable approximation of rectal temperature, due to the wide limits of agreement. The pooled limits of agreement for all reviewed studies are presented in Table 1.

Table 1. Comparison between ear based and rectal temperature. The difference is presented as the pooled limits of agreement in °C. Adapted from Craig et al. (2002).

Mode	Pooled limits of agreement °C
Rectal mode	-1.0 to 1.3
Actual mode	-0.2 to 1.6
Core mode	-0.8 to 1.3
Oral mode	-0.9 to 1.5
Tympanic mode	-0.4 to 1.6
Mode not stated	-0.6 to 1.2

A positive number means that the measured temperature overestimates, and a negative number that the temperature reading underestimates the rectal site.

Another study (6) summarize comparison of ear, oral, axillary and tempory artery with PA, as the reference temperature, in intensive care patients. They found that the ear thermometers could underestimate and overestimate the PA temperature with -1.7°C to -0.4 ° C and 0.3°C to 1.5°C, respectively. For oral thermometers the corresponding figures were -1.6°C to -0.4°C and 0.6°C to 4.5°C, for the axillary devices -1.9° C to -0.4°C and 0.2°C to 1.2°C and for tempory artery -2.5° C to -0.8°C and 0.8°C to 3.3°C, respectively. (table 2).

The mode of the ear thermometers included in the study by Craig et al (14) varied (table 1). In the review by Bridges & Thomas (6) unfortunately the mode was not reported at all.

A positive number means that the measured temperature overestimates, and a negative number that the temperature reading underestimates the pulmonary site.

A third study, comparing simultaneously measured rectal, oral, ear and axillary temperatures, without adjustments, in healthy adult subjects, reported deviations for rectal - ear of – 0.7°C to + 2.8°C, for rectal - axillary – 1.4°C to + 2.3°C and for rectal - oral temperatures - 1.5°C to + 2.3°C . These three studies all compare different sites to a reference temperature.

Table 2. Comparison between pulmonary artery and ear, oral, axillary and tempory artery temperature in adult patients in the intensive care unit. The difference is presented as limits of agreement in °C. Adapted from Bridges & Thomas (2009).

Ear based	Oral	Axillary	Tempory artery
-1.2 to 1.2	-1.6 to 4.5	-1.6 to 1.2	-1.3 to 3.3
-1.3 to 0.6	-1.4 to 1.0	-1.9 to 0.5	-2.1 to 2.3
-0.7 to 1.5	-0.5 to 1.3	-1.2 to 0.6	-2.3 to 2.0
-1.2 to 1.3	-0.9 to 0.8	-1.1 to 0.6	-2.5 to -0.1
-1.6 to 0.5	-0.9 to 0.6	-1.2 to 0.3	-1.1 to 0.8
-1.7 to 0.3	-0.5 to 0.6	-1.0 to 0.4	-0.9 to 0.9
-0.9 to 1.1	-0 3 to 0.7	-0.5 to 0.9	
-0.7 to 0.9	-0.5 to -0.4	-0.4 to 0.2	
-1.2 to 1.0		-0.8 to- 0.6	
-0.8 to 1.1			
-1.2 to 0.8			
-0.4 to 0.6			
-0.4 to 1.2			

However, Craig et al. (14) recommend and condemns different sites. Bridges & Thomas (6) do not conclude about "best site", but illuminate factors that affect accuracy and precision of different sites. In the third example Sund-Levander et al. (64) confirm that there are large variations between sites due to intra-individual variation. The authors conclude that, in order to improve evaluation of body temperature, the assessment should be based on the individual variation, the same site of measurement and no adjustment between sites. Hence, these three studies exemplify three different approaches and interpretation of results that might have a great impact on assessment and evaluation of body temperature in clinical practice. Recently Pursell et al. (50) published a study with a somewhat different approach. They focused on normal variation, stability and repeatability of an ear based thermometer, without comparing with a reference temperature at another site. This is more in line with the approach of Sund-Levander et al. (64) i.e. intra- and inter individual differences makes it a hazard to compare or adjust different sites when assessing body temperature.

3.5 Thermoregulation

Temperature regulation is defined as the maintenance of the temperature or temperatures of a body within a restricted range under conditions involving variable internal and/or external heat loads (42). In order to maintain the body temperature within an individual temperature range, the set point, thermosensitive neurons in the preoptic anterior area of the hypothalamus (POAH) assimilate information from the surrounding blood and peripheral receptors (4, 11). In the midbrain reticular formation and in the spinal cord neurons respond to thermal stimulation of the skin (68). Another pathway from the periphery to the brain is through the vagus nerve (46).
In a thermally neutral environment, warming of the POAH above the set point activate heat loss responses, and cooling below set point, stimulate heat production responses. Several factors, such as diurnal variation, cellular metabolism (61, 68), exercise (47) and ambient temperature (69) influence thermoregulation. The diurnal rhythm is consistent within the individual both in health and disease. For each 4 mm of depth, from the body surface there is a rise in temperature of approximately 1°C (26).

3.6 Gender

In general, women have a higher average body temperature compared to men (10, 29), explained by female hormones (8). Resent research indicate that postmenopausal women have a lower body temperature compared with premenopausal women (64). Females also have a lower baseline metabolic rate (20) and it is suggested that they have a higher sweat onset and lower sweating capacity compared to men when exposed to heat (7). Furthermore, the thicker layer of subcutaneous fat helps to insulate the core from heat gain during hot conditions in women (20).

3.7 Ageing

A recently published review showed large variations in different non-invasive sites in older people (36). Others have also reported an increased frequency of hypothermia (41) and an altered shivering response(12, 22). Cognitive decline, dependency in activities in daily living and a body mass index ≤ 20 have been observed to be associated to an increased risk of a lower body temperature, while daily medication with paracetamol was related with increased temperature(62). Age-related factors, such as reduced proportion of heat-producing cells, decrease in total body water, delayed and reduced vasoconstriction and vasodilation response, a decreased metabolic rate and secondary to impairment and disease may also affect thermoregulation in old aged (17, 22, 33, 44, 49).

3.8 Body temperature measurement - The rectal site

The rectal temperature is in general higher than at other places in steady state (71), because of the low blood flow and high isolation of the area, which cause a low heat loss (48). It significantly lags behind changes at other sites, especially during rapid temperature changes (54, 55). The temperature increase by 0.8°C with each 2.54 cm the device is inserted (54, 67) a standardised depth of 4 cm in adults is recommended (3).

3.9 Body temperature measurement - The oral site

The sublingual temperatures differ between the posterior pocket and the front area (18), as well as between the posterior pockets (45). Other influencing factors are vasomotor activity in the sublingual area, salivation, previous intake of hot or cold food and fluids, gum chewing, smoking and rapid breathing (3, 13, 51).

3.10 Body temperature measurement- The axillary site

Several factors affect the accuracy of axillary measurement, such as ambient temperature, local blood flow, evaporation, inappropriate placing or closure of the axillary cavity, and inadequate period of the reading (3). Even with careful positioning, axillary measurements are slow to register changes in temperature, which cause a wide deviation from other sites (54). During fever, the skin temperature varies dynamically due to vasomotor activity. Therefore, monitoring the skin temperature is an insensitive technique for estimating the body temperature (38, 43).

3.11 Body temperature measurement - The ear site

The tympanic membrane and hypothalamus share their blood supply from the internal and external carotid arteries (1, 24) and the area is relatively devoid of metabolic activity. As the probe is placed about 1.5 cm away from the tympanic membrane (67), the reading is a mix of heat from the tympanic membrane and the aural canal (21). No affect was found during facial cooling or fanning (56, 58). The influence of cerumen and otitis media is uncertain (9, 45, 53).

3.12 Body temperature measurement - forehead thermometers

Forehead thermometers estimate the temporal artery temperature by repeatedly sample the temperature of the overlying skin (15). This site fluctuates considerably due to perspiration, make-up, lotions, oils, hair and environmental factors need to be carefully controlled. In addition vasopressive medication may affect the accuracy (6).

4. CONCLUSION

This literature cited revealed that there is considerable scientific knowledge about thermoregulation, factors influencing normal body temperature, and technology for measuring body temperature. In spite of all this knowledge many studies have focused on the degree of closeness between different sites of measurement in order to define the best choice for estimating the core temperature non-invasively (63). To define acceptable accuracy (25), between sites or to use the term equivalence only contributes to misunderstandings and confusion (2). Hence, still there is a shortage in the application and assessment of the body temperature in clinical practice.

As body temperature varies with age, gender and site of measurement, our interpretation is that body temperature should be evaluated in relation to individual variability, i.e. a baseline value, and that the best approach is to use the same site, without adjustments to other sites. Also, as normal body temperature shows individual variations, it is reasonable that the same should hold true for the febrile range (38). In addition, all methods require careful handling and experienced users (28, 66).

We approve with others have observed the lack of studies based on large populations divided into subgroups such as age, sex and cut-off points for clinically relevant conditions, such as fever (27). Additionally others have also noted the need to study stability and repeatability and to define normal range in various environmental conditions (50).

We also agree with the conclusion from McCarthy & Heusch (40) about designing equipment measuring body temperature in line with today's data set, instead of out-of-date data.

In addition, in order to promote evidence-based practice we suggest that the future research pay attention to the following questions:

- instead of a fixed cut-off value can an increase of x° C from individual baseline body temperature be assessed as fever?
- how is the unadjusted variation of body temperature in different sites related to health and disease?

REFERENCES

1. Benzinger, M. (1969). Tympanic thermometry in anaesthesia and surgery The Journal of the American Medical Association 1969; 209, 1207-1211.

2. Betta V, Cascetta F, Sepe D. An assessment of infrared tympanic thermometers for body temperature measurement Physiological Measurement 1997; 18, 215-225.

3. Blatties, C. Methods of temperature measurement. Physiology and Pathophysiology of Temperature Regulation. Blatties C (ed.). World Scientific Publishing Co. Pte. Ltd, Singapore 1998; 273-279.
4. Boulant J. Thermoregulation. Fever. Basic Mechanisms and Management. P. A. Mackowiak. Philadelphia, New York, Lippincott Raven 1997; 35-58.
5. Brennan D, Falk J, Rothbrock S, Kerr R. Reliability of infrared tympanic thermometry in the detection of rectal fever in children Annals of Emergency Medicine 1995; 25(1), 21-30.
6. Bridges E, Thomas K. Noninvasive measurement of body temperature in critically ill patients Critical Care Nurse 2009; 29, 94-97.
7. Cabanac M. Thermiatrics and behaviour. Physiology and Pathophysiology of Temperature Regulation. C. M. Blatties. Singapore, World Scientific Publishing Co. Pte. Ltd: 1998; 108-125.
8. Cagnacci A, Soldani R, Laughlin G, Yen S. Modification of circadian body temperature rhythm during the luteal menstrual phase: role of melatonin Journal of Applied Physiology 1996; 80(1), 26-29.
9. Chamberlain JM, Grandmer J, Rubinoff JL, Klein BL, Waisman Y, Huey M. Comparison of a tympanic thermometer to rectal thermometer and oral thermometers in a pediatric emergency department Clinical Pediatrics 1991; 4(Suppl), 124-129.
10. Chamberlain JM, Torndrup TE, Alexander DT, Silverstone FA, Wolf-Klein G, O'Donell R, Grandner J. Determination of normal ear temperature with an infrared emission detection thermometer Annals of Emergency Medicine 1995; 25, 15-20.
11. Charkouidan N. Skin blood flow in adult human thermoregulation: how it works, when it does not, and why Mayo Clinic Proceedings 2003; 12(108), 729-735.
12. Collins KJ, Abdel-Rahman TA, Goodwin J, McTiffin L. Circadian body temperatures and the effects of a cold stress in elderly and young subjects Age and Ageing 1995; 24, 485-489.
13. Cooper K, Cranston W, Snell E. Temperature in the external auditory meatus as an index of central temperature changes Journal of Applied Physiology 1964; 19, 1032-1035.
14. Craig J, Lancaster G, Taylor S, Williiamsson P, Smyth R. Infrared ear thermometry compared with rectal thermometry in children: a systematic review The Lancet 2002; 360, 603-609.
15. Crawford D, Hicks B, Thompdon M. Which thermometer? Factors influencing best choise for intermittent clinical temperature assessment Journal of Medical Engineering & Technology 2006; 30(4), 199-211.
16. DuBois EF. The many different temperatures of the human body and its parts Western Journal of Surgery 1951; 59, 476-490.
17. Elia M, Ritz P, Stubbs R. Total energy expenditure in the elderly European Journal of Clinical Nutrition 2000; 54(Suppl 3), S92-103.
18. Erickson R. Oral temperature differences in relation to thermometer and technique Nursing research 1980; 29, 157-164.
19. Erickson RS, Kirklin SK. Comparison of ear-based, bladder, oral and axillary methods for core temperature measurement Critical Care Medicine 1993; 21(10), 1528-1534.
20. Fox RH, Lofstedt BE, Woodward PM, Eriksson E, Werkström B. Comparison of thermoregulatory function in men and women Journal of Applied Physiology 1969; 26(4), 444-453.
21. Fraden J. The development of Thermoscan instant thermometer Clinical Pediatrics Suppl 1991; 11-12.
22. Frank S, Raja S, Bulcao C, Goldstein D. Age-related thermoregulatory differences during core cooling in humans American Journal of Physiology. Regulatory, Integrative and Comparative Physiology 2000; 279, 349-354.
23. Galen R, Gambino S. Beyond Normality: The Predictive Value and Efficiency of Medical Diagnosis. New York, Colombia University College of Physicians and Surgeons John Willey & Sons 1975.
24. Giuliano K, Giuliano A, Scott S, MacLachlan E, Pysznik E, Elliot S, Woytowicz D. Temperature measurement in critically ill adults: A comparison of tympanic and oral methods American Journal of Critical Care 2000; 9(4), 254-261.
25. Giuliano K, Scott S, Elliot S, Giuliano A. Temperature measurement in critically ill orally intubated adults: A comparison of pulmonary artery core, tympanic, and oral methods Critical Care Medicine 1999; 27(10), 2188-2193.
26. Hasday JD. The influence of temperature on host defences. Fever. Basic Mechanisms and Management. P. A. Mackowiak. Philadelphia New York, Lippincott Raven 1997; 177-196.
27. Heusch AI, Suresh V, McCarthy P. The effect of factors such as handness, sex and age on body temperature measured by infrared "tympanic" thermometer Journal of Medical Engineering & Technology 2006; 30(4), 235-241.
28. Holtzclaw BJ. New trends in thermometry for the patient in the ICU Critical Care Nursing Quarterly 1998; 21(13), 12-25.
29. Horwath SM, Menduke H, Pierson GM. Oral and rectal temperatures of man Journal of the American Medical Association 1950; 144, 1562-1565.

30. ISO. General requiments for the competence of testing and calibration laboratories. ISO /TECI17023 1999.
31. ISO. Clinical thermometers - Part 5: Performance of infra-red ear thermometers (With maximum device). Brissels, CEN. EN-12470-5:2003E.
32. ISO. Medical electrical equipment_ Par 2-56: Particular requirements för basic safety and essential performance of clinical thermometers for body temperature measurement. Switzerland. ISO 80601-2-56: 2009:E.
33. Kenney W, Munce T. Invited review: Aging and human temperature regulation Journal of Applied Physiology 2003; 95(6), 2598-2603.
34. Konopad E, Kerr JR, Noseworthy T, Peng MG. A comparison of oral, axillary, rectal and tympanic-membrane temperatures of intensive care patients with and without an oral endotracheal tube Journal of Advanced Nursing 1994; 20, 77-84.
35. Lattawo K, Britt J, Dobal M. Agreement between measures of pulmonary artery and tympanic temperatures Research in Nursing & Health 1995; 18, 365-370.
36. Lu SS, Leasure A, Dai Y. A systematic review of body temperature variations in older people. Journal of Clinical Nursing 2010; 19(1-2), 4-16.
37. Mackowiak PA. Clinical thermometric measurements. Fever. Basic Mechanisms and Management. P. A. Mackowiak. Philadelphia, New York,, Lippincott Raven 1997; 27-33.
38. Mackowiak PA. Fever's upper limit. Fever. Basic Mechanisms and Management. P. A. Mackowiak. Philadelphia, New York, Lippincott Raven 1997; 147-163.
39. Mackowiak PA, Wassermann SS. Physicians perceptions regarding body temperature in health and disease Southern Medical Journal 1995; 88(9), 934-938.
40. McCarthy P, Heusch A. The vagaries of ear temperature assessment Journal of Medical Engineering & Technology 2006; 30(4), 242-251.
41. Mercer, J. Hypothermia and cold injuries in man. Physiology and Pathophysiology of Temperature Regulation. Blatties C (ed.). Singapore, World Scientific Publishing Co. Pte. LtD 1998; 246-257.
42. Mercer J. Glossary of terms for thermal physiology, Third edition Japanese Journal of Physiology 2001; 51, 245-280.
43. Metlay J, Schulz R, Li Y, DE S, Marrie T, Coley C, Houg Obrosky D, Kapoor W, Fine M. Influence of age on symptoms at presentation in patients with community-acquired pneumonia Archives of Internal Medicine 1997; 157(13), 1453-1459.
44. Minson C, Holowatz L; Wong B. Decreased nitrit oxide- and axon reflex-mediated cutaneous vasodilation with age during local heating Journal of Applied Physiology 2002; 93, 1644-1649.
45. Modell J, Katholi C, Kumaramangalam S, Hudson E, Graham D. Unreliability of the infrared tympanic thermometer in clinical practice: A comparative study with oral mercury and oral electronic thermometers Southern Medical Journal 1998; 91(7), 649-654.
46. Nagashima K, Nakai S, Tanaka M, Kanosue K. Neuronal circuitries involved in thermoregulation Autonomic Neuroscience: Basic & Clinical 2000; 85, 18-25.
47. Nielsen B, Kaciuba-Uscilko H. Temperature regulation in exercise. Physiology and pathophysiology of temperature regulation. C. Blatteis. Singapore, World Scientific Publishing Co. Pte. Ltd: 1998; 128-143.
48. Petersen M, Hauge H. Can training improve the results with infrared tympanic thermometers? Acta Anaesthesiologica Scandinavica 1997; 41, 1066-1070.
49. Pierzga J, Frymoyer A, Kenney W. Delayed distribution of active vasodilation and altered vascular conductance in aged skin Journal of Applied Physiology 2003; 94, 1045-1053.
50. Pursell E, While A, Coomber B. Tympanic thermometry- normal temperature and reliabolity Paediric nursing 2009; 21(6), 40-43.
51. Rabinowitz RP, Cookson SY, Wasserman SS, et al. Effects of anatomic site, oral stimulation, and body position on estimates of body temperature Archives of Internal Medicine 1996; 6, 777-780.
52. Ring EFJ, McEvoy H, Jungs A, Ubers J, Nachin M. New standards for devices used for the measurement of human body temperature Journal of Medical Engineering & Technology 2010; 34(4), 249-253.
53. Robb P, Shahab R. Infrared transtympanic temperature measurement and otitis media with effusion International Journal of Otorhinolaryngology 2001; 59, 195-200.
54. Robinson J, Charlton J, Seal R, Spady D, Joffres M. Oesophageal, rectal, axillary, tympanic and pulmonary artery temperatures during cardiac surgery Canadian Journal of Anaesthesia 1998; 45(4), 317-323.
55. Rotello L, Crawford L, Terndrup T. Comparison of infrared ear thermometer derived and equilibrated rectal temperatures in estimating pulmonary artery temperatures Critical Care Medicine 1996; 24(9), 1501-1506.
56. Sato K, Kane N, Soos G, Gisolfi C, Kondo N, K S. Reexamination of tympanic membrane temperature as a core temperature Journal of Applied Physiology 1996; 80, 1233-1239.
57. Schmitz B, Bair N, Falk M, Levine C. A comparison of five methods of temperature

measurement in febrile intensive care patients American Journal of Critical Care 1995; 4(4), 286-292.
58. Shibasaki M, Kondo N, Tominaga H, Aoki K, Hasegawa E, Idota Y, Moriwaki T. Continuous measurement of tympanic temperature with a new infrared method using an optical fiber Journal of Applied Physiology 1998; 85(3), 921-926.
59. Shinozaki T, Deane R, Perkins FM. Infrared tympanic thermometer. Evaluation of a new clinical thermometer Critical Care Medicine 1988; 16, 148-150.
60. Simpson R, Machin G, McEvoy H, Frusby R. Traceability and calibration in temperature measurement: a clinical necessity Journal of Medical Engineering & Technology 2006; 30(4), 212-217.
61. Stephenson LA. Circadian timekeeping. Fever. Basic Mechanisms and Management. Mackowiak PA. Philadelphia, New York, Lippincott Raven 1997; 59-77.
62. Sund-Levander M, Forsberg C, Wahren LK. Normal oral, rectal, tympanic and axillary body temperature in adult men and women: A systematic literature review Scandinavian Journal of Caring Sciences 2002; 16(2), 122-128.
63. Sund-Levander M, Grodzinsky E. Time for a change to assess and evaluate body temperature in clinical practice International Journal of Nursing Practice 2009; 15, 241-249.
64. Sund-Levander M, Grodzinsky E, Loyd D, Wahren LK. Error in body temperature assessment related to individual variation, measuring technique and equipment International Journal of Nursing Practice 2004; 10, 216-223.
65. Sund-Levander M, Wahren LK. The impact of ADL-status, dementia and body mass index on normal body temperature in elderly nursing home residents Archives of Gerontology and Geriatrics 2002; 35, 161-169.
66. Terndrup TE. An appraisal of temperature assessment by infrared emission detection tympanic thermometry Annals of Emergency Medicine 1992; 21(12), 1483-1492.
67. Togawa T. Body temperature measurement Clinical Physiological Measurement 1985; 6(2), 83-102.
68. Van Someren E, Raymann R, Scherder E, Daanen H, Swaab D. Circadian and age-related modulation of thermoreception and temperature regulation: mechanisms and functional implications Ageing Research Reviews 2002; 1(4), 721-778.
69. Werner J. Biophysics of heat exchange between body and environment. Physiology and Pathophysiology of Temperature Regulation. C. Blatteis. Singapore, World Scientific Publishing Co. Pte. Ltd: 1998; 25-45.
70. Wunderlich CA, Reeve JC. The course of the temperature in diseases: a guide to clinical thermometry American Journal of Medical Science 1869; 57, 423-447.
71. Zehner WJ, Terndrup TE. The impact of moderate ambient temperature variance on the relationship between oral, rectal, and tympanic membrane temperatures Clinical Pediatrics 1991; 4, 61-64.

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