REVIEW

Thermometry in paediatric practice

A S El-Radhi, W Barry

Arch Dis Child 2006;**91**:351–356. doi: 10.1136/adc.2005.088831

Body temperature is commonly measured to confirm the presence or absence of fever. However, there remains considerable controversy regarding the most appropriate thermometer and the best anatomical site for temperature measurement. Core temperature is generally defined as the temperature measured within the pulmonary artery. Other standard core temperature monitoring sites (distal oesophagus, bladder, and nasopharynx) are accurate to within 0.1–0.2°C of core temperature and are useful surrogates for deep body temperature. However, as deep-tissue measurement sites are clinically inaccessible, physicians have utilised other sites to monitor body temperature including the axilla, skin, under the tongue, rectum, and tympanic membrane. Recent studies have shown that tympanic temperature accurately reflects pulmonary artery temperature, even when body temperature is changing rapidly. Once outstanding issues are addressed, the tympanic site is likely to become the gold standard for measuring temperature in children.

Body temperature is usually measured to confirm the presence or absence of fever. Many decisions concerning the investigation and treatment of children are based on the results of temperature measurement alone. An incorrect temperature measurement could result in the delayed detection of a serious illness or, alternatively, an unnecessary septic workout.

Despite the plethora of instruments that have become available in the last 30 years, there remains considerable controversy as to the most appropriate thermometer and the best anatomical site for temperature measurement.

Different sites for temperature measurement and the advantages and disadvantages of currently available techniques are discussed below. Descriptions of how the instruments work together with comments on their accuracy are presented and recommendations based on available evidence and personal experience provided.

See end of article for authors' affiliations

Correspondence to: A Sahib El-Radhi, Queen Mary's Hospital, Sidcup, Kent, UK; sahib.el-radhi@qms.nhs.uk

Accepted 6 December 2005

THE VALUE OF TEMPERATURE MEASUREMENT

The presence of fever or hypothermia and its severity can be a vital indicator that its causes need careful investigation and prompt treatment.

The accuracy of body temperature measurement may be particularly important in the following situations:

- Fever in neutropenic children with cancer is frequently caused by bacterial infection which is among the leading causes of death in these patients. Admission to hospital and administration of intravenous antibiotics are often based on the presence of fever alone. Children with sickle cell anaemia are particularly susceptible to overwhelming bacterial infections and detection of fever in these children commonly has similar implications to fever in neutropenic children.
- Drowning and near-drowning can cause hypothermia. Cardiac arrhythmia and death may occur when the body temperature is <30°C.
- As epilepsy is defined by recurrent non-febrile seizures, the only outward difference at onset of seizure between a febrile and an epileptic seizure is the presence of fever in the febrile seizure. Since the investigation, treatment, and prognosis of children with febrile seizure and epilepsy are different, measurement of body temperature at the onset of a convulsion is of paramount importance.
- Accurate temperature measurement is especially important in critically ill children such as those in a paediatric ICU.
- Hypothermia (body temperature <35°C) has been recognised as a significant contributor to neonatal mortality in developing and developed countries.[1] There is an association between low body temperature of neonates on admission to neonatal ICU and increased mortality. Induced hypothermia has been used in recent years as a neuroprotectant in encephalopathic newborn infants after acute perinatal asphyxia, either as whole body hypothermia or selective brain cooling.
- Accurate temperature measurement is critical in infants under 3 months of age. In this age group, a temperature over 38°C has been associated with serious bacterial infection in 3% to 15% of patients.[2]

In clinical practice, accurate temperature measurement is often not possible or considered necessary as physicians are usually only interested in the presence or absence of fever. Also small differences between different sites and instruments may not be of clinical importance and often trends in body temperature are more important than actual values. The following may be examples of this category:

- Maternal intrapartum fever is a risk factor for neonatal sepsis and therefore it is essential to monitor maternal temperature during labour.

Abbreviations: AT, axillary temperature; IRET, infrared ear-based thermometer; OT, oral temperature; RT, rectal temperature; TT, tympanic temperature

- During anaesthesia continuous body temperature monitoring is essential because of the common risk of perioperative hypothermia caused by inhibition of thermoregulation by the anaesthesia and the patient's exposure to a cool environment. Monitoring is also required to detect the rare complication of malignant hyperthermia.
- The pattern of fever may have diagnostic value such as the periodic paroxysms of fever in malaria, continuous fever in typhoid fever, hectic fever in Kawasaki disease, and double quotidian fever in kala azar. While the severity of hypothermia has been found to correlate closely with the rate of survival,[3] the higher the fever the greater the likelihood the infection has a bacterial aetiology. The height of fever also correlates with the severity of bacterial infection.[4]
- A body temperature of >42℃ suggests hyperthermia. Whereas fever (interleukin-1 mediated elevation of the thermoregulatory set point of the hypothalamic centre) does not increase relentlessly beyond 42℃, hyperthermia may exceed this level as a result of malfunction in the mechanisms modulating peripheral heat production and loss.
- The finding of a difference between core (central) and peripheral (skin) temperature is valuable in the diagnosis, management, and prognosis of shock and correlates with clinical criteria of brain death in children (>4.0℃).[5]

CORE TEMPERATURE

There is no uniform core temperature throughout the body. The hypothalamus is the site where body temperature is set and where the highest body temperature is recorded. Since the hypothalamus is inaccessible, core temperature is generally defined as the temperature measured within the pulmonary artery.[6] Other standard core temperature monitoring sites (distal oesophagus, bladder, and nasopharynx) are accurate to within 0.1–0.2℃ of core temperature[7] and are useful surrogates for deep body temperature. During anaesthesia, bladder temperatures correlated well with oesophageal and pulmonary artery temperatures. This correlation was maintained during rapid body re-warming, with only an insignificant bias of 0.04℃.[8] However, since these deep-tissue measurement sites are clinically inaccessible, physicians have utilised the rectum as a practical site to monitor body temperature in the belief that this site most accurately reflects core temperature.

MEASUREMENT OF BODY TEMPERATURE

Body temperature measurements vary depending on the measurement site. Table 1 shows the ranges and means of the temperatures.

Where relevant the medical history should include questions as to how the temperature was taken at home and with which particular device. The recordings of temperature by the parents should be noted.

We asked mothers attending our A&E department and our nurses and doctors whether they had a thermometer at home and if so what type (table 2). Most parents in our district have thermometers: approximately three out of four mothers, two out of three nurses, and one out of two of doctors have a thermometer.

Table 1 Normal temperatures at different sites[9 10]

Body site	Type of thermometer	Normal range, mean (℃)	Fever (℃)
Axilla	Hg in glass, electronic	34.7–37.3, 36.4	37.4
Sublingual	Hg in glass, electronic	35.5–37.5, 36.6	37.6
Rectal	Hg in glass, electronic	36.6–37.9, 37.0	38.0
Ear	Infrared emission	35.7–37.5, 36.6	37.6

TACTILE ASSESSMENT

Simple palpation has been used for thousands of years to assess body temperature. Even nowadays with the availability of electronic and infrared thermometers, tactile assessment is still the most widely used method of evaluating body temperature. Some physicians advocate its use on the grounds that the thermometer holds no advantage over tactile methods when evaluating children with fever.[11]

This method of palpation is far from accurate, mainly because of the lowering of skin temperature during the early phase of fever. When medical staff carried out palpation as a screening method, the presence of fever was accurately predicted in only 42% of cases.[12] Mothers, on the other hand, made the correct prediction in over 80% of cases.[13] Thus palpation by mothers was more sensitive than by medical personnel. A recent African study[14] investigated the ability of medical students and mothers to use touch to determine if 1090 children had fever. It was concluded that touch overestimated the incidence of fever and that a child who feels hot needs to have a temperature taken before fever is confirmed.

INSTRUMENTATION

An ideal thermometer should

- accurately reflect core body temperature in all age groups,
- be convenient, easy, and comfortable to use by patient and practitioner, without causing embarrassment,
- give rapid results,
- not result in cross infection,
- not be influenced by ambient temperature,
- be safe, and
- be cost effective.

In practice, the ideal thermometer involves a combination of the best instrument and the most appropriate site; the tympanic thermometer appears to offer such a combination (see below).

SITE OF TEMPERATURE MEASUREMENT

Body temperature measurements vary depending on the site where the temperature is taken. Table 1 shows the ranges and means of body temperature.

Axilla

Measurement of the axillary temperature (AT) has several advantages. It is safe, easily accessible, and reasonably comfortable. In neonatal units, where ambient temperatures are stable, AT measurements were found to be as accurate as rectal measurements.[15] However, these studies involved afebrile neonates in a nursery where environmental temperatures and humidity were maintained at optimal levels.

However, there are several disadvantages. AT measurement requires supervision in case displacement occurs and it takes longer than rectal or sublingual measurement (it takes 5 min with mercury in glass and 40–80 s with an electronic thermometer) which is not cost effective with regard to nursing time. Also, temperature measurement at this site is notoriously inaccurate. At the onset of fever when peripheral vasoconstriction is intense, the skin temperature may cool as the core temperature rises. In addition, the effects of sweating and evaporation cause the AT to be lower than the core body temperature. Therefore, correlation between AT and core temperature is poor. The sensitivity of AT to detect fever has been reported to be only 27.8% to 33%.[16 17] In the

Table 2 Presence and type of home thermometers in non-medical households compared to those households where a parent was a doctor or nurse

	Hg in glass, n (%)	Electronic (axillary), n (%)	Fever scan, n (%)	Ear thermometer, n (%)	No thermometer, n (%)
Mothers (n = 126)	9 (7)	26 (21)	37 (29)	17 (13)	37 (26)
Nurses (n = 62)	25 (40)	11 (18)	4 (6)	0 (0)	22 (35)
Doctors (n = 77)	25 (32)	9 (12)	4 (5)	2 (2.5)	37 (48)
Total (n = 265)	59 (22)	46 (17)	45 (17)	19 (7)	96 (36)

study by Kresh, rectal temperature (RT) and AT differed by up to 3℃ and AT was occasionally very low.

In summary, the evidence suggests that AT with its low sensitivity should not be relied upon to detect fever in children and should be avoided if possible. We do not recommend AT measurement as a method to screen for fever and certainly not where accurate temperature measurement is required (except on a neonatal unit), since the aim of temperature measurement is usually to detect or exclude the presence of fever and measurement at this site has a poor fever detection rate.

Skin

Several companies have introduced re-usable or single use disposable plastic-encased thermophototropic liquid crystals for forehead application; the substance changes colour as the temperature rises. These thermometers are most suitable for home use and their advantages over conventional thermometers are obvious: convenient instruction, ease of use, safety, comfort, and rapid results.

Estimation of body temperature is limited at the onset of fever because skin temperature is not elevated (and may even be decreased) due to vasoconstriction. Several studies have shown that measurement of skin temperature by these devices is inaccurate and frequently records a normal temperature despite elevated body temperature.[18] In the sick neonate, the skin temperature is usually monitored in addition to regular AT readings. As the infant responds to cold stress by vasoconstriction, a drop in skin temperature may be the first sign of hypothermia; the core temperature may not fall until the infant is no longer able to compensate.

Recently, liquid crystal skin surface thermometers were used for intra-operative temperature monitoring. The correlation between skin and core temperatures was reported to be poor.[19] High false positive rates were associated with continuous temperature measurement in emergency department patients.[20]

Sublingual (oral temperature, OT)

The sublingual site is often used in children over 5 years of age. As it is less affected by ambient temperature, it is more accurate than the axillary site. It is also easily accessible. The mean OT measured by an electronic thermometer or a chemical indicator was found to be about 0.4℃ below simultaneously measured mean pulmonary arterial temperature.[19]

There are several disadvantages to this method. The measurement requires the co-operation of the child and is therefore not suitable for use in children less than 5 years of age, in some children with developmental delay, or in comatose or intubated patients. Hot baths, exercise, hot and cold drinks, and mouth breathing all influence the results. The site should not be used if patients have tachypnoea which causes increased evaporative cooling of the oral cavity and therefore results in a misleadingly low temperature estimation.[21] There is variation in the temperature recorded from the sublingual area depending on exactly where the bulb of the thermometer is placed. Finally, oral laceration and mouth-to-mouth cross infection may occur.[22]

Rectum

The rectal route remained unchallenged for a century as the preferred site for the measurement of core temperature. However, in the 1960s it began to be replaced by axillary and sublingual measurement.

RT has been widely viewed as the gold standard for routine measurement of body temperature. The site is not influenced by ambient temperature and its use is not limited by age. RT measurement with a low reading thermometer is considered best clinical practice when dealing with potential hypothermia, for example near drowning, neonatal cold injury, or, on occasion, neonatal sepsis. While the ear-based infrared thermometer (see next section) can read as low as 20℃, there has been insufficient research with this technique and until further evidence is available we continue to recommend the rectal site for this group of patients.

However, there are numerous practical disadvantages to its routine use. It is frightening for small children and may be psychologically harmful for older children. The procedure may cause discomfort and is painful for patients with perirectal infection or irritation. The site is not hygienic and presents an infectious hazard; an outbreak of Salmonella cross infection has been reported in newborn infants[23] and the transmission of human immunodeficiency virus through this route remains a concern. For the same reason this site should not be used in patients with neutropenia or other immunologic impairments; oncology centres routinely avoid RT measurement. In addition, RT measurement is time consuming, requires privacy, and has been reported to cause rectal perforation,[24] calculated to occur in less than one in 2 million measurements.[25] RT varies depending how deeply the thermometer is inserted into the rectum, local blood flow, and the presence of stool and diarrhoea.

Furthermore, RT may lag significantly behind a rapidly rising or falling core temperature, possibly because of relatively poor blood flow to the rectum. Even in a stable state, RT has been shown to differ significantly from pulmonary artery temperature.[26] Moreover, when body temperature is changing, the temperature in the rectum takes twice as long to change as that in the pulmonary artery.[27] Therefore, RT should not be used for patient monitoring during anaesthesia. For the same reason, a misleadingly high temperature may be recorded after defervescence following antipyretic administration. In the presence of shock, perfusion of the bowel, including the rectum, may be markedly impaired, and RT will lag significantly behind a rapidly rising or falling core temperature.

In summary, it is questionable whether RT should be regarded as the gold standard for core temperature measurement.

Tympanic thermometry

Under normal conditions, 60% of total heat loss from the body occurs via radiation in the form of infrared heat rays, a form of electromagnetic energy. This heat loss is increased during fever. As the tympanic membrane receives its blood

Table 3 Outcome of comparison studies between core temperature

Author	No of patients	Core site	Other sites	Main outcome/conclusion
Group A				
Robinson *et al*[40]	15 C	PA/O	AT/RT	TT more accurate than RT
Robinson *et al*[41]	18 A	PA/O	AT/RT	TT 2nd to O, TT is the reading of choice
Shinozaki *et al*[42]	27 A	PA	RT	TT tracks PA closely
Erickson *et al*[43]	30 C	B	AT/RT	TT correlates relatively well with PA
Erickson *et al*[44]	38 A	PA/B	AT/OT	TT is relatively close estimate of PA
Erickson *et al*[45]	50 A	B	AT/OT	TT has good correlation with B
Summers[46]	96 A	O	AT	No difference between TT and O
Amoateng-Adjepong *et al*[47]	51 A	PA	RT	Both TT and RT are accurate
Klein *et al*[48]	128 A	PA	AT/RT	PA and TT are highly correlated
Schmitz *et al*[49]	13 A	PA	AT/OT/RT	If RT contraindicated, OT or TT acceptable
Milewski *et al*[50]	9 A	PA	RT	PA and TT: not significantly different
Romano *et al*[51]	20 C	PA	AT/RT	TT may be used instead of PA
Chang *et al*[52]	32 A	PA	AT/RT	TT reflects PA more accurately than RT and AT
Group B				
Nierman[53]	15 A	PA/B	None	TT appears to give high readings
Fullbrook[54]	60 A	PA	AT	TT is clinically not reliable
Giuliano *et al*[55]	102 A	PA	OT	OT is most accurate
Giuliano *et al*[56]	72 A	PA	OT	OT more accurate
Lattavo *et al*[57]	32 A	PA	AT/OT	TT is not ideal
Heidenreich *et al*[58]	25 A	PA/B/O	AT/OT/FS	No non-invasive method is valid

(PA, pulmonary artery; O, oesophageal; B, bladder temperatures) as reference standard and ear-based temperature. Group A: studies found TT to be accurate or close to accurate. Group B: studies found TT to be less or not accurate. A, adults; AT, axillary temperature; C, children; CT, core temperature; FS, forehead skin temperature; OT, oral temperature; TT, tympanic temperature.

supply from the carotid artery, its temperature may reflect that of blood flowing into the hypothalamus, thereby correlating closely with core body temperature. A suitable detector without a probe contact can measure the infrared rays emitted by the tympanic membrane. This is the basic principle of infrared thermometry (see below).

There are many potential benefits to infrared ear thermometry. The technique is fast and easy to use without risk of cross infection and is not influenced by environmental temperature. Parents and nurses rated tympanic thermometers as being more favourable in terms of ease, speed, cleanliness, and safety than oral or rectal thermometers.[28] A reduction in the numbers involved in a nosocomial outbreak of vancomycin-resistant enterococcus and *Clostridium difficile* infection was been achieved by replacing rectal and oral thermometers with tympanic membrane thermometers.[29] The use of tympanic thermometers saves nursing time and is therefore cost effective.[30] In recent years, tympanic thermometers have become very popular both with health professionals and in the home setting. In the USA 65% of paediatricians and 64% of family practice physicians regularly use infrared ear-based thermometers (IRETs).[31]

The main reason why the tympanic thermometer has yet to be regarded as the gold standard for body temperature measurement is that some studies have reported inaccuracies mainly in children under 3 years of age.[32] These studies compared ear measurements with RT or OT as the reference standard. There is no evidence that either of these sites represents the core body temperature.[33 34]

It has been known for about 40 years that the tympanic membrane can provide accurate measurement of core body temperature.[35] Recent studies (see next section) have shown that tympanic temperature (TT) accurately reflects pulmonary artery temperature, even when body temperature is changing rapidly. For this reason infrared temperature measurement has been found to be a reliable way of monitoring body temperature during anaesthesia when the patient might be at risk of developing malignant hyperthermia or hypothermia.[36]

EVIDENCE-BASED TEMPERATURE MEASUREMENT

We searched all EBM reviews (Cochrane DSR, ACP Journal Club, DARE, and CCTR for systematic reviews 1991–2003: 39 articles; CINAHL 1982–2003: 83 articles; and PubMed 1980–2003: 582 articles on temperature measurements) for EBM and systematic review studies for measurement of body temperature. There is universal agreement that AT is inaccurate and insensitive when compared to any core temperature (that is from the pulmonary artery, oesophagus, or bladder) with the exception of afebrile neonates in neonatal units where the environmental temperature and humidity are maintained at optimum levels for neonates. A systematic review of 20 studies with 3201 children confirmed the inaccuracy of AT.[37] A systematic review of 44 studies with 5935 patients comparing TT and RT concluded that infrared ear-based temperature is not a good approximation of RT although the mean differences between rectal and ear temperature measurements were small.[38] A third systematic review of the literature to determine optimal methods of temperature measurement in children concluded that RT measurement is the optimal method until the child is old enough to co-operate with OT measurement.[39]

The question remains: is the RT the satisfactory reference standard for core temperature? RT is reliable only if the body is in thermal balance and reacts slowly to changes in temperature. As there is a consensus that the temperature of the pulmonary artery, oesophagus, and bladder is representative of core temperature, we searched PubMed for all studies comparing TT with these sites as shown in table 3. The majority of these studies (which included febrile patients or patients who underwent cooling and re-warming during cardiac surgery) show TT to be accurate, including the three studies with children (accuracy is defined as an ear-based thermometer measurement within 0.1 to 0.6℃ or a high correlation: $r>0.80$ of pulmonary artery temperature)[40 45 46 49 58] (table 4).

As RT is not favoured in this country and OT is not used in younger patients, the option is usually between AT or TT. There is strong evidence in support of TT for routine temperature measurement in young children.

CONCLUSION

Disagreement still exists as to the best anatomical site for temperature measurement. There is a consensus that AT does not provide accurate temperature measurements except in environments where the temperature is stable such as in

Table 4 Accuracy between core temperature site and TT and RT as reported from the 10 studies in table 3 using RT as a measurement

TT accuracy			RT accuracy		
Correlation	Mean °C	±SD (°C)	Correlation	Mean °C	±SD (°C)
	0.6	1.0		0.7	1.7
	−0.3	0.5		−0.4	0.5
0.98	0.2	0.2		−0.2–0.5	0.1–0.4
0.80–0.87	−0.3 to −0.7	0.4	0.93–0.97	0.2	0.2
	0.07	0.4	–	–	–
0.87–0.91	0.5	0.5	–	–	–
0.90–0.98	0.1	0.3	0.100	0.04	0.36
0.90	0.4	0–1.0		0.5	0 to −1.0
0.74	−0.1	0.06	0.93	0.4	0.07
	−0.06	0.58		0.07	0.32
0.94			0.94		

Accuracy as defined by correlation coefficient >0.80 and/or differences of the mean temperatures and SD.

neonatal units and where neonates are afebrile. RT measurement is not favoured by parents and nurses and many hospitals such as ours have abandoned this method. The reluctance to take RT is cultural and is particularly widespread in Britain, Australia, and New Zealand. In all other countries, mothers usually take their babies' temperature rectally.[59] RT is contraindicated in neutropenic oncology patients as this group needs particular accuracy with regard to temperature measurement since intravenous antibiotics may be administered solely on the basis of a raised temperature. The OT is not used in children less than 5 years of age, which is the group with the highest incidence of fever. The tympanic site appears to be the most suitable for use in hospitals, GP surgeries, and at home. Evidence confirming the accuracy of the IRETs is incomplete; this is probably because ear measurements were compared with rectal or oral measurements, neither of which represent the true core temperature.

There remain a few unresolved issues. Errors can occur with TT if the probe is not directed towards the tympanic membrane. It is anticipated that in future a visible signal (for example a green light) will indicate when the probe of the tympanic thermometer is correctly positioned. There are only a few small trials comparing TT with core temperature in neonates. Efforts should continue to find a suitable IRET for this age group. Once these concerns are addressed, the tympanic site is likely to become the gold standard for all children.

Authors' affiliations

A S El-Radhi, W Barry, Queen Mary's Hospital, Sidcup, Kent, UK

Competing interests: none declared

REFERENCES

1 **El-Radhi AS**, Jawad MH, Mansor N, *et al*. Sepsis and hypothermia in the newborn infant: value of gastric aspirate examination. *J Pediatr* 1983;**103**:300–2.
2 **Baskin MN**, O'Rourke EJ, Fleisher GR. Outpatient treatment of febrile infants 28 to 89 days of age with intramuscular administration of ceftriaxone. *J Pediatr* 1992;**120**:22–7.
3 **El-Radhi AS**, Jawad MH, Mansor N, *et al*. Infection in neonatal hypothermia. *Arch Dis Child* 1983;**58**:143–5.
4 **El-Radhi AS**. Hyperpyrexia in paediatric intensive care. *Br J Int Care* 1996;**6**:305–8.
5 **Miller G**, Stein F, Trevino R, *et al*. Rectal-scalp temperature difference predicts brain death in children. *Pediatr Neurol* 1999;**20**:267–9.
6 **Lorin MI**. Measurement of body temperature. *Semin Pediatr Infect Dis* 1993;**4**:4–8.
7 **Webb GE**. Comparison of oesophageal and tympanic membrane monitoring during cardiopulmonary bypass. *Analg Anesth* 1973;**52**:729–33.
8 **Lilly JK**, Boland JP, Zekan S. Urinary bladder temperature monitoring: a new index of body core temperature. *Crit Care Med* 1980;**8**:742–4.
9 **Chamberlain JM**, Terndrup TE. New light on ear thermometer readings. *Contemp Pediatr* 1994;**11**(3):66–76.
10 **El-Radhi AS**, Carroll J. *Fever in paediatric practice*. Oxford: Blackwell Scientific, 1994:68–84.
11 **Coffin LA**. The taking of temperature. *Pediatrics* 1971;**48**:493–4.
12 **Bergeson PS**, Steinfeld HJ. How dependable is palpation as screening method for fever. *Clin Pediatr* 1974;**13**:350–1.
13 **Banco L**, Veltri D. Ability of mothers to subjectively assess the presence of fever in their children. *Am J Dis Child* 1984;**138**:976–8.
14 **Whybrew K**, Murray M, Morley C. Diagnosing fever by touch. *BMJ* 1998;**317**:321.
15 **Mayfield SR**, Bahtia J, Makamura KT, *et al*. Temperature measurement in term and preterm infants. *J Pediatr* 1984;**104**:271–5.
16 **Haddock BJ**, Merow DL, Swanson MS. The falling grace of axillary temperatures. *Pediatr Nurs* 1996;**22**:121–5.
17 **Kresh MJ**. Axillary temperature as a screening test for fever in children. *J Pediatr* 1984;**104**:596–9.
18 **Scholefield JH**, Gerber MA, Dwyer P. Liquid crystal forehead temperature strips. *Am J Dis Child* 1982;**136**:198–201.
19 **Ilsley AH**, Rutten AJ, Runciman WB. An evaluation of body temperature measurement. *Anaesth Intensive Care* 1983;**11**:31–9.
20 **Dart RC**, Lee SC, Joyce SM, *et al*. Liquid crystal thermometry for continuous temperature measurement in emergency department patients. *Ann Emerg Med* 1985;**14**:1188–90.
21 **Tandberg D**, Sklar D. Effect of tachypnoea on the estimation of body temperature by an oral thermometer. *N Engl J Med* 1983;**308**:945–6.
22 **Shimoyama T**, Kaneko T, Horie N. Floor of mouth injury by mercury from a broken glass. *J Oral Maxillofac Surg* 1998;**56**:96–8.
23 **McAllister TA**, Roud JA, Marshall A, *et al*. Outbreak of Salmonella eimsbuettel in newborn infants spread by rectal thermometer. *Lancet* 1986;**2**:1262–4.
24 **Smiddy FG**, Benson EA. Rectal perforation by thermometer. *Lancet* 1969;**3**:805–6.
25 **Morley CJ**, Hewson PH, Thornton AJ, *et al*. Axillary and rectal temperature measurements in infants. *Arch Dis Child* 1992;**67**:122–5.
26 **Hayward JS**, Eckerson JD, Kemna D. Thermal and cardiovascular changes during three methods of resuscitation from mild hypothermia. *Resuscitation* 1984;**11**:21–33.
27 **Molnar GW**, Read RC. Studies during open heart surgery on the special characteristics of rectal temperature. *J Appl Physiol* 1974;**36**:333–6.
28 **Barber N**, Kilmon CA. Reaction to tympanic temperature measurement in an ambulatory setting. *Pediatr Nurs* 1989;**15**:477–81.
29 **Brooks S**, Khan A, Stoica D, *et al*. Reduction of vancomycin-resistant Enterococcus and Clostridium difficile infections following change to tympanic thermometers. *Infect Control Hosp Epidemiol* 1998;**19**:333–6.
30 **Brown S**. Temperature taking--getting it right. *Nurs Stand* 1990;**5**:4–5.
31 **Silverman BG**, Daley WR, Rubin JD. The use of infrared ear thermometers in pediatric and family practice offices. *Public Health Rep* 1998;**113**:268–72.
32 **Peterson-Smith A**, Barbar N, Coody DK, *et al*. Comparison of aural infrared with traditional rectal temperatures in children from birth to age three years. *J Pediatr* 1994;**125**:83–5.
33 **Iaizzo PA**, Kehler CH, Zink RS, *et al*. Thermal response in acute porcine malignant hyperthermia. *Anesth Analg* 1969;**82**:803–9.
34 **Buck SH**, Zaritsky AL. Occult core hyperthermia complicating cardiogenic shock. *Pediatrics* 1989;**83**:782–3.
35 **Benzinger M**. Tympanic thermometry in surgery and anaesthesia. *JAMA* 1969;**209**:1207–11.
36 **Holdcroft A**, Hall GM, Cooper GM. Redistribution of body heat during anaesthesia. A comparison of halothane, fentanyl and epidural anaesthesia. *Anaesthesia* 1979;**34**:758–64.
37 **Craig JV**, Lancaster GA, Williamson PR, *et al*. Temperature measured at the axilla compared with rectum in children and young people: systematic review. *BMJ* 2000;**320**:1174–8.
38 **Craig JV**, Lancaster GA, Taylor S, *et al*. Infrared ear thermometry compared with rectal thermometry in children: a systematic review. *Lancet* 2002;**360**:603–9.

39 **Duce SJ**. A systematic review of the literature to determine optimal methods of temperature measurement in neonates, infants and children. *DARE Rev* 1994;**4**:1–124.
40 **Robinson JL**, Seal RF, Spady DW, *et al*. Comparison of oesophageal, rectal, axillary, bladder, tympanic and pulmonary artery temperatures in children. *J Pediatr* 1998;**133**:553–6.
41 **Robinson J**, Charlton J, Seal R, *et al*. Oesophageal, rectal, axillary, tympanic and pulmonary artery temperatures during cardiac surgery [comment]. *Can J Anaesth* 1998;**45**:1133–4.
42 **Shinozaki T**, Deane R, Perkins FM. Infrared tympanic thermometer: evaluation of a new clinical thermometer. *Crit Care Med* 1988;**16**:148–50.
43 **Erickson RS**, Woo TM. Accuracy of infrared ear thermometry and traditional temperature methods in young children. *Heart Lung* 1994;**23**:181–95.
44 **Erickson RS**, Kirklin SK. Comparison of ear-based, bladder, oral and axillary methods for core temperature measurement. *Crit Care Med* 1993;**21**:1528–34.
45 **Erickson RS**, Meyer LT. Accuracy of infrared thermometry and other temperature methods in adults. *Am J Crit Care* 1994;**3**:40–54.
46 **Summers S**. Axillary, tympanic and oesophageal temperature measurement: descriptive comparisons in postanesthesia patients. *J Post Anesth Nurs* 1991;**6**:420–5.
47 **Amoateng-Adjepong Y**, Del Mundo J, Manthous CA. Accuracy of an infrared tympanic thermometer. *Chest* 1999;**115**:1002–5.
48 **Klein DG**, Mitchell C, Petrinec A, *et al*. A comparison of pulmonary artery, rectal and tympanic membrane temperature measurement in the ICU. *Heart Lung* 1993;**22**:435–1.
49 **Schmitz T**, Bair N, Falk M, *et al*. A comparison of five methods of temperature measurement in febrile intensive care patients. *Am J Crit Care* 1995;**4**:286–92.
50 **Milewski A**, Ferguson KL, Terndrup TE. Comparison of pulmonary artery, rectal and tympanic membrane temperatures in adult intensive care unit patients. *Clin Pediatr* 1991;**30**:13–16.
51 **Romano MJ**, Fortenberry JD, Autry E, *et al*. Infrared tympanic thermometry in the paediatric intensive care unit. *Crit Care Med* 1993;**21**:1181–5.
52 **Chang Y**, Ho L, Huang T, *et al*. Accuracy of infrared ear thermometry and traditional body temperatures for medical intensive care unit patients. *J Nurs (China)* 2000;**47**:53–63.
53 **Nierman DM**. Core temperature measurement in the intensive care unit. *Crit Care Med* 1991;**19**:818–23.
54 **Fullbrook P**. Core temperature measurement: a comparison of rectal, axillary and pulmonary artery blood temperature. *Int Crit Care Nurs* 1993;**9**:217–25.
55 **Giuliano KK**, Guiliano AJ, Scott SS, *et al*. Temperature measurement in critically ill adults: a comparison of tympanic and oral methods. *Am J Crit Care* 2000;**9**:254–61.
56 **Giuliano KK**, Scott SS, Elliot S, *et al*. Temperature measurement in critically ill orally intubated adults: a comparison of pulmonary artery core, tympanic and oral methods. *Crit Care Med* 1999;**27**:2188–93.
57 **Lattavo K**, Britt J, Dobal M. Agreement between measures of pulmonary artery and tympanic temperatures. *Res Nurs Health* 1995;**18**:365–70.
58 **Heidenreich T**, Giuffre M, Doorley J. Temperature and temperature measurement after induced hypothermia. *Nurs Res* 1992;**41**:296–300.
59 **Morley C**. Babies' rectal temperature: parents' reluctance reflects poorly on our culture. *BMJ* 1993;**307**:1005.

Thermometry in paediatric practice

A S El-Radhi and W Barry

Arch Dis Child 2006 91: 351-356
doi: 10.1136/adc.2005.088831