Best practice in the measurement of body temperature

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Summary

In the last two decades, there has been a significant change in the technology of clinical thermometry. Mercury-in-glass thermometers have been replaced with electronic devices that offer faster readings with minimal inconvenience to the patient. Each user should be aware of the characteristics and limitations of these devices to interpret correctly the temperature reading on the display. The article provides an insight into commonly used clinical thermometers, how they determine each temperature reading and, crucially, how users affect the measurement process.

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BODY TEMPERATURE MEASUREMENT is one of the oldest methods of assessing health, yet confusion regarding the technology, accuracy and operational methodologies of clinical thermometry is widespread (Sund-Levander *et al* 2004, Crawford *et al* 2006). The development of alternatives to the traditional mercury-in-glass thermometer has been triggered by the hazardous nature of mercury and clinical requirements for rapid easy-to-acquire measurements. The European Council Directive 2007/51/EC (Medicines and Healthcare products Regulatory Agency (MHRA) 2010) now restricts the marketing of thermometers containing mercury.

The ideal thermometer should be mercury-free, minimally invasive, quick, reliable, accurate and safe, and it should minimise dependence on user technique. However, there is little agreement on the optimum thermometer. Infrared-sensing ear thermometers (commonly called tympanic thermometers) have been found to be accurate in some studies (Bock *et al* 2005), but inaccurate in others (Farnell *et al* 2005). The accuracy of temporal artery thermometry has also been questioned (Kistemaker *et al* 2006). There appears to be no modern clinical thermometers that are completely free from problems (Pearce 2002).

Background

Physicians since the ancient Greeks have been aware of the link between raised temperature and ill health, yet it was not until the 16th century that body temperature measurement was attempted (Ring 2006). The development of the thermometer and the introduction of temperature scales in the 18th century enabled objective measurements of temperature. Many people have contributed to subsequent progress, but the development of clinical thermometry is generally attributed to Carl Reinhold August Wunderlich.

Wunderlich (1871) stated that, for a physician, the use of a thermometer is 'both a duty and a valuable aid to diagnosis'. During his time at the University of Leipzig's medical clinic, Wunderlich collected tens of thousands of axillae measurements using his thermometer, which was more than one foot in length. It was the analysis of these data, taken from approximately 25,000 patients, that led to the widely accepted medical concept that normal body temperature for a healthy adult is approximately 37.0°C (Pearce 2002, Kelly 2006).

However, the most salient points of Wunderlich's research have often been disregarded. His work showed that, rather than being a fixed point, the normal temperature of his patients was actually within the range 36.2°C to 37.5°C (Mackowiak *et al* 1992). These limits are still the subject of critical debate, but the key principle is that normal temperature lies within a range.

Nonetheless, many physicians still believe that normal body temperature is 37.0°C. In the early 1990s, 268 physicians (including trainees) were questioned for a study on clinical thermometry. When asked to state the normal body temperature, 75% of respondents answered 37.0°C, rather than referring to a range. Only 4% of respondents specified a body site, for example oral, rectal or axilla (Mackowiak and Wasserman 1995).

Identifying the body site where the temperature measurement is made is vital. Mercury-in-glass thermometers were used to measure temperature under the arm (axilla), in the rectum or in the mouth. None of these sites directly correspond to the temperature of the vital organs, which is often referred to as 'core temperature' (Carroll 2000). Further, two simultaneous measurements at different sites from the same patient, using identical mercury-in-glass thermometers, would be likely to give two different readings.

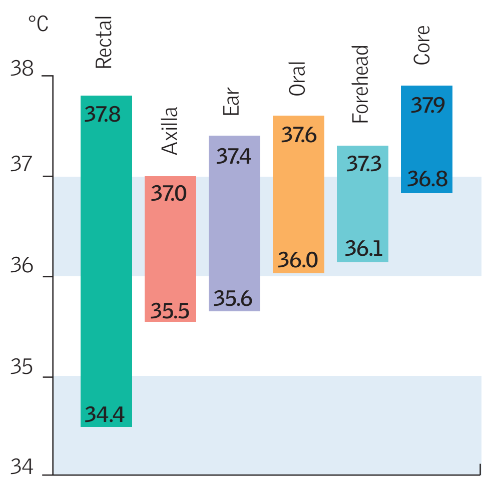
In 2005, the MHRA published a thermometry review that included normal temperature ranges for various measurement sites (Crawford *et al* 2005) (Table 1, Figure 1). The data summarise work from various sources (Mackowiak *et al* 1992, Chamberlain *et al* 1995, Health and Safety Executive 2002, Sund-Levander *et al* 2002, Roy *et al* 2003) and emphasise the variations in the range of 'normal' temperature at each measurement site (Crawford *et al* 2005).

Early warning scoring systems are now used in many hospitals to assist in the timely recognition of acutely unwell patients, by triggering appropriate medical review and treatment (Oakey and Slade 2006, Duckitt *et al* 2007). Within these systems, interventional temperature thresholds are used to initiate further investigation. For example, blood cultures will be taken if a patient's temperature exceeds a predetermined level. Thus, intervention levels should be set carefully, considering the range of normal temperature and the measurement site used.

To achieve more accurate thermometry, all factors that affect temperature measurement should be considered, including: technical factors, such as device configuration and

FIGURE 1

Normal temperature ranges for measurement sites



(Adapted from Crawford et al 2005)

TABLE 1

Measurement sites and evidence for normal temperature ranges

Site	Reference	Comments
Core	Health and Safety Executive (2002)	Health and safety guidance material. Temperature data is not included in the latest edition.
Rectal	Sund-Levander *et al* (2002)	A systematic review. Only data from studies with strong or fairly strong evidence were used to establish this temperature range.
Oral	Mackowiak *et al* (1992)	Oral temperature measurements were taken for three consecutive days from 148 healthy men and women aged between 18 and 40 years.
Ear	Chamberlain *et al* (1995)	Right ear temperature measurements were taken from 2,447 participants aged 12 hours to 103 years. Only one type of thermometer was used. No 'offset' (conversion of a measured temperature into an estimated temperature) was applied.
Forehead	Roy et al (2003)	Temporal artery measurements were taken from 2,346 healthy subjects aged 0–18 years.
Axilla	Sund-Levander *et al* (2002)	A systematic review. Only data from studies with strong or fairly strong evidence was used to establish used to establish this temperature range.

device characteristics; physiological factors; user technique – the extent to which the measurement is affected by the user; and calibration and maintenance (Figure 2).

Physiological factors

Normal temperature ranges vary with site, with higher temperatures at the core of the body and lower temperatures at the periphery. Core temperature can only be measured invasively (often using a pulmonary artery catheter), which is impractical for all but specialised clinical care.

A number of sites are used for non-invasive temperature measurement. The ideal site would be:

- Independent of environmental changes.
- Sensitive to physiological and pathological changes.
- Convenient.
- Pain-free.
- Responsive to core temperature changes.
- Defined by a normal range.

None of the available (relatively non-invasive) measurement sites (mouth, ear, axilla, forehead or rectum) meet all these criteria. Each user should therefore be aware of the limitations of the measurements taken and be able to interpret the results accordingly (McCarthy and Heusch 2006).

The data in Table 1 showing the normal temperature ranges at different measurement sites are derived from clinical studies. These are limited by factors such as the range of subjects involved, the measurement sites investigated and the number of devices assessed. For example, one study assessed only patients under the age of 18 years (Roy *et al* 2003) while another assessed data from the right ear only with only one type of ear thermometer (Chamberlain *et al* 1995).

As well as site dependency, studies have shown differences in normal temperature ranges between participant groups (Sund-Levander *et al* 2004, Crawford *et al* 2006, Kelly 2006). Women and men have different normal temperature ranges, which may be explained by physiological differences such as ovulation and the thicker layer of subcutaneous fat found in women. However, there is no consensus as to whether this difference is consistently high or low in favour of men or women (Sund-Levander *et al* 2002, 2004).

Age should be considered when assessing 'normal' temperatures. It is agreed that mean temperature is lower in older adults (Crawford *et al* 2006, Kelly 2006). However, underlying factors, including low levels of activity and deterioration of the circulatory and nervous systems, may affect the normal temperature in this group (Sund-Levander *et al* 2002, McCarthy and Heusch 2006).

Temperature variations throughout the day were noted by Wunderlich (1871) and by subsequent investigators (Waterhouse *et al* 2001, Edwards *et al* 2002). It is now widely accepted that mean temperature varies diurnally, with a 2-8am nadir (minimum) and a 4-9pm zenith (maximum) (Crawford *et al* 2006, Kelly 2006). The magnitude of these daily variations is not well defined (Mackowiak and Wasserman 1995).

Body temperature is also affected by recent exercise (Crawford *et al* 2005). Not only does exercise have an obvious immediate effect, it can also affect the daily variation in normal temperature, with the difference between the maximum and minimum daily temperature greater in physically active individuals (Atkinson *et al* 1993).

Technical factors

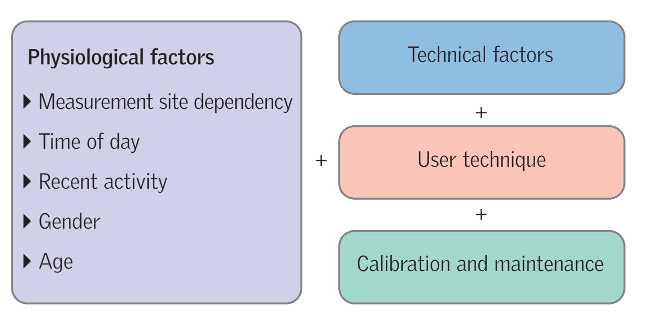
Three main non-invasive methods of measuring temperature are used clinically in the UK (Crawford *et al* 2005). These are electronic contact, chemical or infrared-sensing. A number of clinical thermometers can be used to measure temperature (Figure 3).

Electronic contact thermometers These thermometers use thermistor properties to measure temperature indirectly. A thermistor is a type of resistor (electronic component) in which resistance varies with temperature. The thermistor resistance varies considerably as its temperature changes, allowing for high sensitivity over a narrow temperature range (Crawford *et al* 2006).

The thermometer consists of one or two metal probes connected to electronic circuitry. The circuit

FIGURE 2

Factors affecting temperature measurement



measures the resistance of the probe, compares this value against stored calibration data and displays the corresponding temperature. Where two probes are provided, the red probe is for rectal use and the blue probe for use in oral sites and axillae.

Electronic contact thermometers typically have two operating modes. Monitoring mode allows the thermometer to function as a temperature monitor, continually displaying the current temperature. Predictive mode allows a quick prediction of the temperature of the measurement site (Figure 4).

Predictive mode relies on the known predictable temperature rise of the probe when placed in the measurement site. The probe's initial temperature change is recorded and used to calculate (predict) the temperature. It enables an oral measurement to be taken within a few seconds, much faster than the time required for the thermometer to equilibrate with the temperature in the mouth. Consider, for example, the 1-12 minutes that were recommended when using a mercury thermometer (Carroll 2000). The predictive mode may work only within certain temperature ranges, and if the thermometer is not able to make a prediction it may revert to monitor mode. This can delay the thermometer's ability to take a measurement by up to one minute.

Some electronic thermometers heat the tip of the probe, which reduces the cooling effect of the thermometer on the tissue – a process called temperature draw-down.

Chemical thermometers Chemical or phase change thermometers (Figure 3) are contact thermometers consisting of a matrix of temperature-sensitive dots. Each dot is a small cavity in a plastic strip containing a mixture of chemicals, sealed in place by a clear film, which change colour at a specific temperature dependent on the melting point of the chemicals (Macqueen 2001, Creagh-Brown *et al* 2005, Crawford *et al* 2006). The chemicals are mixed such that each dot changes colour at a temperature 0.1°C higher than the preceding dot, thus allowing the temperature to be read from a numeric scale.

Chemical thermometers are typically used for oral or axillae measurements and are either single use or single patient use (Macqueen 2001, Frommelt *et al* 2008). They take three minutes to record an axilla temperature and one minute for an oral temperature, and the temperature should be read within 30 seconds. The cost of each unit is small, being less than 10p for some brands, but each is more expensive than a disposable cover for most electronic or tympanic thermometers (Crawford *et al* 2006). Consequently, their use within a large hospital may be impractical because of the cost.

FIGURE 3

Examples of clinical thermometers

Electronic contact thermometer

Chemical thermometer

Infrared-sensing ear thermometer (tympanic)

Temporal artery thermometer

Infrared-sensing ear thermometers These thermometers, also called tympanic thermometers (Figure 3), detect infrared energy emanating from the ear canal and tympanic membrane. Often a large number of measurements are performed rapidly to calculate the temperature in the auditory canal.

The tympanic membrane was initially adopted as a measurement site because its blood supply from the internal carotid artery was thought to reflect the temperature at the hypothalamus, which regulates body temperature. However, the blood supply is more complex than this, as the external carotid artery also supplies the tympanic membrane. Further, the mechanism by which temperature is controlled is not necessarily related to the temperature of the hypothalamus itself (Bratincsák and Palkovits 2005). There has been much debate on the advantages and disadvantages of ear thermometry (Giuliano *et al* 2000, McCarthy and Heusch 2006).

The thermometer probe, which is not in contact with the tympanic membrane, contains optical sensors, usually thermopiles (electronic devices that convert thermal energy into electrical energy) that can detect infrared emissions. The received energy is converted into a temperature reading (Crawford *et al* 2006).

The appropriate disposable probe cover should be used and the nurse should inspect the cover to ensure that it has been fitted correctly and that there are no wrinkles over the tip end. This will ensure the most accurate reading possible is achieved. The cover is also used to help keep the probe tip clean and for infection control purposes.

Some tympanic thermometers include algorithms, often referred to as 'offsets', which convert a measured temperature into an estimated equivalent. For example, the temperature may be displayed as an oral, rectal, axilla, or core equivalent (Table 2). In theory, such algorithms allow clinicians to use the tympanic thermometer while retaining clinical protocols based on the temperature of an alternate measurement site.

It is important to remember when using offsets that the temperature displayed is an estimate based on clinical trials carried out by the manufacturer. It is not possible to know an oral temperature, for example, unless the user is physically recording a measurement in the mouth. The offset or algorithm assumes fixed relationships between different measurement sites in everyone, whether healthy or unwell (McCarthy and Heusch 2006). There has been little research on the effect of using offsets, which vary between manufacturers depending on their clinical trial data (Dodd *et al* 2006).

Temporal artery thermometers These thermometers (Figure 3) repeatedly sample the skin temperature of the forehead and the ambient temperature. The thermometer is moved across the skin overlying the temporal artery, seeking a peak value. An algorithm then calculates the temperature within seconds. These algorithms are based on clinical trial data and consequently vary between manufacturers.

Although optional caps or sheaths can be supplied for some temporal artery thermometers, the manufacturers generally recommend cleaning them with alcohol wipes. This represents a significant saving in running costs, but the thermometer should be given time to stabilise between wipes.

Non-touch temporal artery thermometers These thermometers measure infrared emissions from the temporal artery. They are held just above the skin surface of the forehead and use a tracking

FIGURE 4

Predictive thermometry

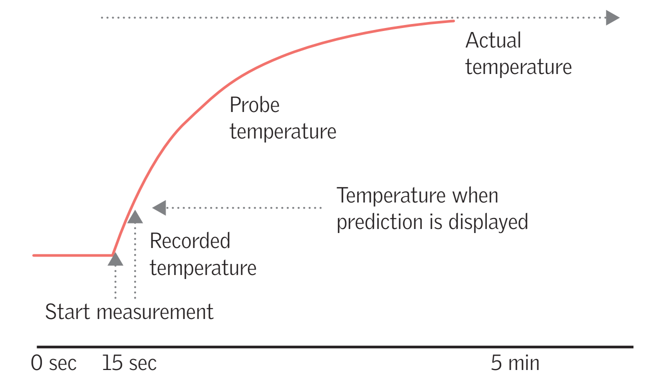


TABLE 1

Measurement sites and evidence for normal temperature ranges

Site	Offset applied by Genius 3000A ear thermometer	Offset applied by Genius 2 ear thermometer
Core	Ear +1.39°C	Ear +1.04°C
Rectal	Ear +1.45°C	Ear +1.16°C
Oral	Ear +0.89°C	Ear +0.6°C
Ear	Not available	Device displays the absolute temperature measurement without adjustment
Forehead	Not available	Not available
Axilla	Not available	Ear +0.04°C

The Genius 2 thermometer is a newer model, replacing the Genius 3000A. This type of data should be considered by healthcare professionals before the introduction of new technology. Data supplied by the manufacturer (Covidien, Ireland).

light to indicate the measurement area. As this type of thermometer can be used to measure the temperature of a sleeping child, it is generally marketed for home use.

This device does not come into contact with the patient, so the risk of cross-infection is reduced. Further, the running costs of the thermometer are low because no disposable covers are required. However, there is limited evidence for clinical reliability, and these devices cannot be used interchangeably with other infrared-sensing thermometers (Woodrow *et al* 2006).

The authors are not aware of any hospitals that use non-touch thermometers in the UK.

User technique

The accuracy of a temperature measurement is influenced by how well the person uses the equipment – for example how the probe is positioned and whether the probe is held steadily in place for the correct period of time. This applies to direct contact devices, such as electronic thermometers measuring oral or axillae temperatures, and to non-contact radiant energy measurement devices, such as ear thermometers.

The importance of accurate positioning is appreciated when considering the temperature profiles of the mouth (Figure 5) and ear canal (Figure 6).

The user should also consider patient-dependent factors. These include recent consumption of food or drink; physical exercise; environmental conditions, such as draughts affecting the measurement site; and other factors, such as pressure resulting from the patient's head resting on an ear when lying down.

The ideal thermometer would eliminate user-dependent factors, minimising the effects of incorrect placement of the probe and/or eliminating errors caused by selecting the incorrect mode of operation. Such a device would permit accurate temperature measurement to be made simply by 'pointing and clicking'. However, all modern clinical thermometers have their own user-dependent factors, and concerns have been expressed about user competence (Mackowiak and Wasserman 1995, Carroll 2000). Creagh-Brown *et al* (2005) reported that only 23% of qualified nurses correctly identified the temperature on an image of a chemical thermometer that was presented to them.

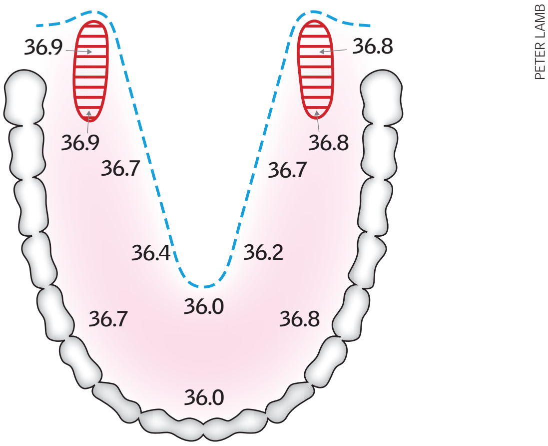
User-associated errors may be minimised through effective training. This should be structured to provide knowledge of the characteristics and limitations of the thermometer along with the technique required to operate it correctly. This type of training allows the nurse to interpret the output of the device, troubleshoot where necessary and use the device with care.

Oral measurements The placement of the thermometer probe under the tongue can result in substantial differences in recorded temperature. There is a range of possible tissue temperatures as a result of the physiology of the oral cavity. Incorrect probe placement within the mouth has reportedly resulted in temperature differences of 1.7°C (Erickson 1980).

The probe should remain in the sublingual pocket for the full period of measurement to ensure accurate oral measurement. This period is generally a few seconds for electronic contact thermometers in predictive mode, but in monitor mode, the same measurement may take three minutes or more. One minute is required for

FIGURE 5

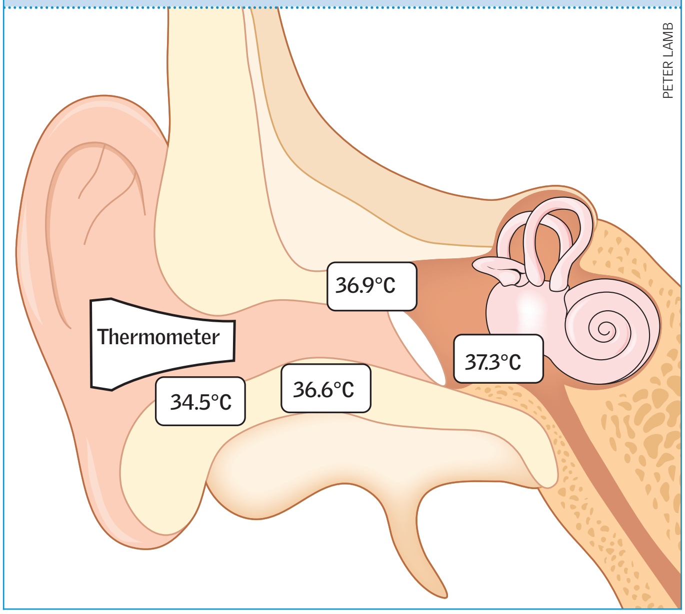
Temperature profile of the mouth (°C)



(Reproduced with permission from Braun)

FIGURE 6

Temperature profile of the ear canal



chemical phase change thermometers. The measurement time required is determined by the time needed for the temperature of the probe to equilibrate with that of the contact area.

There is an onus on the user to follow operating instructions closely, a requirement that is often not met, which can artificially reduce temperature readings (Carroll 2000, Kimberger *et al* 2007).

Axilla measurements Correct placement of the thermometer to measure an axilla temperature is vital, and direct skin contact is essential. The measurement site should be as high as possible in the axilla with the patient's arm pressed against his or her side. The probe should remain in this position for the duration of the measurement, which can be difficult with thin, frail patients.

Electronic contact thermometers require approximately five minutes to calculate a direct measurement. Temperature differences between left and right axillae have been found, and so the measurement site should be noted along with the temperature recorded (Fulbrook 1993, Sund-Levander *et al* 2004).

Tympanic measurements The wide temperature range in the ear canal (Figure 6) makes tympanic thermometers particularly susceptible to user error. Incorrect positioning may result in falsely low readings, as the ear canal may be 2°C lower than the tympanic membrane (MHRA 2003). The challenge for manufacturers is to reduce this user-dependent error by device design.

The correct technique is dependent on how the device is used. The thermometer probe on some models should be inserted only far enough to achieve a light seal, whereas other models require a full seal and a twist of the thermometer. It is therefore essential that nurses are trained in the correct use of the tympanic thermometer in their clinical area and that this training is reinforced regularly.

In 2003, the MHRA published a medical device alert following reports of tympanic thermometers providing low temperature readings (MHRA 2003). The sources of the inaccuracies were attributed to dirty lenses and poor user technique. The thermometer lens should be clean before use, or the thermometer will record artificially low temperatures because the infrared emissions from the tympanic membrane will be attenuated. The thermometer should be checked visually to ensure that there is no obvious dirt or damage both before and after use. Caution should be exercised if wet cloths or alcohol wipes are used to clean the probe tip, as these can have a cooling effect. The thermometer should be left unused to allow for tip stabilisation, typically requiring about 45 minutes.

Probe covers provide an infection control barrier between the patient and thermometer. They are also an important functional part of the thermometer since energy, in the form of infrared radiation, is transferred from patient to thermometer via the probe cover. The algorithm that converts the received energy into a temperature includes the effects of a new probe cover and therefore probe covers should not be used more than once, even if they have never been used to take a patient's temperature (MHRA 2003).

Calibration and maintenance

Clinical thermometry is governed by International Standard BS EN 12470 (British Standards Institution 2001). This sets out the maximum permissible errors for thermometers, as measured using calibrated temperature sources under laboratory conditions (Table 3). User-dependent errors are provided for in the standard, and the document describes a procedure for assessing clinical repeatability.

Thermometers should be calibrated routinely using equipment and procedures that are traceable to national and international standards (Mackechnie and Simpson 2006, Simpson *et al* 2006). Suppliers should provide guidance protocols and calibration instruments to enable verification of a thermometer's accuracy. Thermometers should be cleaned regularly and maintained to ensure that they are operating correctly. The nurse should ensure that the probe or lens of the thermometer is free from dirt and debris. This is particularly important for infrared-sensing thermometers, in which a dirty lens will result in an artificially low temperature reading.

Conclusion

It is too easy to assume that temperature measurement is straightforward. People have been taking the temperature of patients and family members for many years and, until the recent demise of mercury thermometers, little had changed in the equipment or techniques used

TABLE 3

Maximum permissible errors for thermometers

Type of thermometer	Maximum error	Range
Electronic (in monitor mode)	±0.1°C	35.5-42.0°C
Chemical	+0.1°C and -0.2°C	35.4-40.4°C
Ear (tympanic)	±0.2°C	35.5-42.0°C

(British Standards Institution 2001)

for this seemingly simple practice. However, new technology has changed this. The introduction of modern, mercury-free thermometers has decreased the time required for the measurement process, but also prompted an appraisal of approaches to thermometry. Nurses should be trained and competent in using the thermometers in their clinical area, particularly as none of the modern thermometers or measurement sites available offer the ideal solution. Until technology has advanced sufficiently to produce an ideal thermometer, adopting best practice with existing thermometers is essential to move towards accurate thermometry **NS**

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