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Temperature Monitoring

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Learning Objective: 1) to ascertain what is considered at present the most appropriate temperature monitoring site and the technology one should use.

Abstract

Correct temperature measurement depends on selection of appropriate measurement site, and the relationship between the site and the body's core temperature, as well as the appropriate measuring device. This article reviews how to make these measurement selections as well as new technologies to assure accurate values.

The English surgeon John Hunter has been credited with introducing the measuring of body temperature in 1776. He used a mercury-in-glass thermometer, which was placed under the patient's tongue. Harvey Cushing initiated the recording of temperature as part of the anesthetic record in 1895.1 Since then, measurement of temperature has remained an important part of clinical care.2 However, since the times of Hunter and Cushing, the devices for temperature monitoring have changed dramatically. This article considers what is the "gold standard" for the monitoring site and the device for patients who require continuous temperature monitoring.

The goal of temperature monitoring is to obtain, as far as possible, an accurate measure of the hypothalamus. Therefore, the "normal" individual temperature measurement depends on the proximity to the core, i.e., the hypothalamus. What, then, is the appropriate value? The reader is referred to the accompanying article by Grahn and Heller, which clearly shows there is a large variation in normal temperature, from 36.1°C to 38°C, within each individual. Furthermore, there are large variations between individuals. This means that a single temperature reading is really of no clinical significance; what is required is a look at the change in body temperature over a period of time.

Measuring Sites

The different measuring sites available to the clinician are shown in Table 1. As mentioned by Grahn and Heller (page 52), rectal and bladder temperature may well be outside the thermal shell. Hence, these readings will give a variable reflection of the current core temperature. The bladder and rectal temperatures are also affected by feces, peritoneal lavage, cystoscopy, and CO_2 insufflation during laparoscopic surgery. The frequently reprinted figure from the 1971 work of Benzinger and Benzinger,[3] which addresses this temperature

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Table 1. Sites of Temperature Measurement		
Site	**Advantages**	**Disadvantages**
Tympanic nembrane	Close to core (hypothalamus) via internal carotid artery	Rare risk of tympanic perforation. Bleeding may occur in heparinized patients.
Nasopharyngeal	Closest to core (hypothalamus) via internal carotid artery	Affected by drafts, inspired gas. A real danger of epistaxis.
Esophageal	Convenient, close to great vessels and heart	Needs to be placed 24 cm below larynx or to a depth of maximum heart sounds. Affected by anesthetic gas, thoracic surgery. Possible inadvertent placement of probe into trachea.
Rectal	Traditional	Variable reflection of core temperature. Affected by feces, peritoneal lavage, cystoscopy.
Bladder	Incorporated into urinary drainage catheter	Variable reflection of core temperature. Affected by cystoscopy and peritoneal lavage. Affected by rate of urine flow. Cannot be used in genitourinary procedures.
Oral	Convenient	Affected by food, hyperventilation. Not practical during anesthesia.
Axillary	Convenient	Must be placed over axillary artery. Affected by blood pressure cuff and intravenous solutions. Takes time to equilibrate (>2 min).
Skin	Convenient Useful in children. (Liquid crystal thermometry)	Forehead temperature correlates modestly with central temperature, and only when environmental temperature is constant. Affected by peripheral perfusion – inaccurate with vasoconstriction and sweating. Not a reliable warning of malignant hyperthermia because of cutaneous vasoconstriction (based on animal study). In adults, no advantage except maybe during mask anesthesia.
Superior vena cava	Mixed venous blood temperature	Affected by temperature of infused fluids.[a]
Pulmonary artery catheter	Mixed venous blood temperature	Affected by thoracic surgery and infused fluids.

[a]R. A. Jaffe, personal communication, 1993.

variation, is shown in Figure 1. The tympanic and surface brain temperature closely track each other in a piglet model during cardiopulmonary bypass. Again, the rectal temperature lagged behind during both cooling and rewarming. Hence, if rectal temperature is used as the target for achieving hypothermia, then initially the brain will be cooler and during rewarming this phenomenon is reversed. The latter can impact neurological outcomes as the brain may be excessively warmed in an attempt to achieve satisfactory rectal temperature.[4]

The use of the nasopharyngeal monitoring site is not recommended unless absolutely essential because of the danger of epistaxis. Clinicians who have not encountered epistaxis associated with the insertion of nasopharyngeal probes will certainly do so at some stage of their career. Esophageal measuring sites are convenient, but the probe needs to be placed at least 24 cm below the larynx. At present, esophageal temperature probes do not have any markings to indicate depth. The temperature measurement is also affected by thoracic surgery, anesthetic gases, and operations in the upper abdomen. Furthermore, the esophageal monitoring device can very easily pass into the trachea, which will result in a tracheal air leak in a patient with an endotracheal tube in place. If such a situation is unrecognized, inadequate ventilation and hypoxia will quickly ensue.

The tympanic membrane is, in the authors' opinion, the gold standard for the site of temperature measurement because of proximity to CNS and the ease of insertion. Both tympanic perforation and ear canal bleeding in heparinized patients have been reported with use of this site. The authors have not seen these problems. The probe may be dislodged from the tympanic membrane if the patient becomes agitated and shakes his or her head. Air that is introduced between the probe and the drum may lead to a drop in temperature readings. This fall in temperature is quickly corrected (within seconds) when the patient's head is still. Occasionally, the probe may have to be reinserted. Mallinckrodt tympanic membrane probes (Mallinckrodt Medical Inc., St. Louis, MO) have a flange, which is intended to prevent the probe from being inserted too far into the ear canal.

Temperature Technologies

The temperature-monitoring procedures employed in anesthesia, critical care, and trauma management are easy to implement. They consist of selecting a type of probe that is applicable to the monitoring site, inserting and attaching the probe, and connecting it to the monitor. The performance of any measuring instrument is defined in terms of its precision and accuracy. Precision is defined as the variability of the measurements, and accuracy is defined as the difference between the value obtained and the "true value." [5] The different types of technology, with their advantages and disadvantages, that are available to the clinician are shown in Table 2.

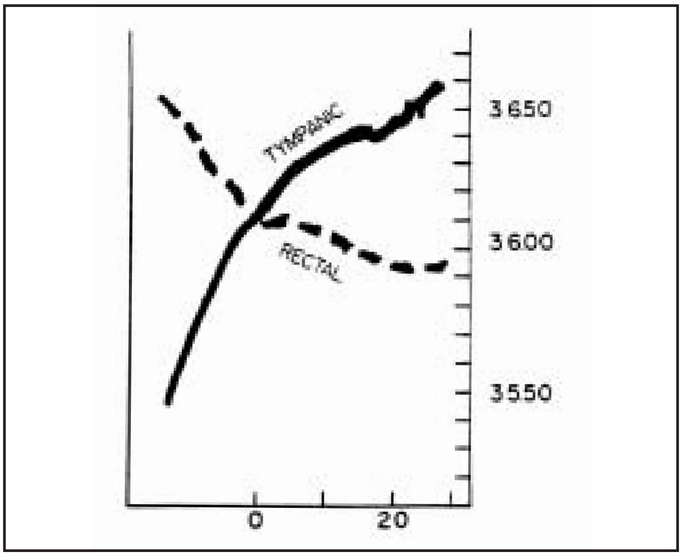

Figure 1. Rectal temperatures (*dashed line*) and tympanic temperatures (*continuous line*) of a diver during rewarming in 40°C air after 1 hour, 20 minutes submersion in 20°C water. The X axis reflects minutes and the Y axis indicates temperature in degrees Celsius. The central hypothermia is indicated by the tympanic probe (35.5°C). The rapid recovery due to rewarming is also shown by the tympanic probe. None of this is recognized by the rectal measurements. The tympanic recording would seem to reflect more correctly the initial hypothermic state of 35.5°C and a near-exponential rise of central temperature with the warming of the diver in a hot chamber. (Redrawn from Benzinger and Benzinger[3]).

Thermistor Thermometers. The thermistor is a semiconducting element consisting of a heavy metal oxide. Various oxides, such as manganese, cobalt, iron, zinc, and nickel, have been used in their manufacture. Thermistors are produced by compressing the oxides into the shape of beads or rods. Available thermistor thermometers range in diameter from 0.006 to 0.1 inch. The beads may be sealed into the tip of a hypodermic needle. Their advantage, besides their small size, is the fact that they can respond rapidly to temperature change. However, they have been shown not to be stable over periods of months as increased resistance occurs. They should be recalibrated frequently. An additional disadvantage of this type of thermometer is that temperature variations between beads of the same type may give different results. Ideally, one should use several beads. The thermistor is very sensitive and is well suited to measure small temperature changes, as those within the pulmonary artery during thermal dilution for measuring cardiac output.

Infrared Sensors. The infrared ear thermometer is used as an otoscope. The procedure is noninvasive, quick, and easy. It has gained popularity in emergency departments and in postanesthesia recovery units. Response time is less than 5 seconds, and it has a disposable plastic tip that covers the probe to reduce cross-contamination between patients. The main disadvantage of this probe is that it gives only intermittent spot checks, and if the probe is not aimed accurately at the tympanic membrane, erroneous readings will be obtained. There is great individual variation in readings between the operators of this thermometer. There may also be temperature differences from the right to the left ear if the patient has been lying on one side or the other. The difference can be as much as 1°C to 2°C.

Liquid Crystal Thermometers. This device is liquid crystal contained in an adhesive strip that is attached to the patient's forehead. The temperature can be read from the adhesive strip as the color of the liquid crystal changes with temperature. This device is obviously disposable and very simple to use; however, it correlates poorly with tympanic membrane measurements.[6]

Thermocouples. The thermocouple is a circuit of two dissimilar metals. The two junctions are maintained at different temperatures, causing an electromotive force (EMF) to develop (a phenomenon called the Seebeck effect). To obtain a measurement, the temperature of one junction must be maintained constant. The other junction can be used to determine the temperature, provided the EMF of the thermocouple is measured. The advantages of this type of equipment is that the junctions can be made very small and versatile, and the thermocouples respond rapidly because of their low thermal capacity. The disadvantage of the thermocouple, although the accuracy is adequate, is that the resistance of the detecting element does not vary linearly with temperature. For platinum, for example, the maximum error arising from assuming a linear relationship is approximately 0.4°C between 0°C and 100°C. This problem has been solved in one of three ways: by use of a nonlinear scale, the selection of bridge parameters, or electronic linearization.

Table 2. Technology of Temperature Measurement

Technology	Advantages	Disadvantages
Thermistor thermometers	Small size (0.006 to 0.1 inch) Rapid response (0.2 sec)	Expensive to produce. Calibration problems. Not stable over time.
Infrared sensors	Response time <5 sec Disposable plastic tips.	Only intermittent checks. Probe must be aimed at tympanic membrane. Variable results. Temperature difference from right to left ear.
Liquid crystal thermometry	Disposable Simple	Correlates poorly with tympanic membrane NOTE: A heating lamp on a child can give erroneously increased temperature readings.
Thermocouples	Adequate accuracy Rapid response time Small and versatile	Is this the “gold standard”?

Conclusion

Most temperature-measuring devices are accurate and precise within a range. The problems are 1) the site where they are used and 2) the relationship between the site and the body's core temperature. Based on current knowledge, the tympanic membrane using the thermocouple technology would seem to be the present gold standard.

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Pathophysiology and Consequences of Hypothermia

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Learning Objectives: 1) to review the importance of body temperature in the perioperative period, with a focus on the effects of anesthesia on thermoregulation, and the physiologic effects of hypothermia, and 2) to review the various outcome studies that correlate body temperature and clinical outcomes.

Abstract

The role of anesthesiologists is to maintain physiologic homeostasis during the perioperative period, a time when alteration in body temperature is common, especially in patients with traumatic injuries. Anesthetics create a state of poikilothermia in which body temperature tends to equilibrate with ambient temperature. Body temperature should be managed in a similar fashion as the other vital signs, with efforts made to maintain normothermia.

Patients suffering traumatic injuries are subjected to dramatic alterations in body temperature during both the intraoperative and postoperative periods. Patients often arrive at the hospital with hypothermia that has developed in the field, or they develop hypothermia in the operating room during surgery. For many years, body temperature has been considered to be the vital sign of least importance during the perioperative period.

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Despite the common occurrence of hypothermia during surgery,[1,2] few studies have examined the relationship between body temperature and outcome, and only recently have such studies been performed.

Virtually all anesthetics that have been tested impair thermoregulation. Patients are thus rendered poikilothermic, and body temperature decreases in the typically cool operating room environment. Opioids, inhalational anesthetics, propofol, spinal, and epidural anesthetics have all been shown to impair thermoregulatory mechanisms either through the central effects on the brain and the hypothalamus, or through impairment of the vasoconstriction and shivering responses. Patients receiving regional anesthesia are at similar risk for developing hypothermia as are those receiving general anesthesia.[1] The elderly and the very young are at greatest risk for developing perioperative hypothermia, as are those patients anesthetized in cold operating rooms, less than ≈21°C (70°F).[1]

Shivering and Metabolism

One of the most commonly recognized effects of hypothermia is postoperative shivering. Despite earlier suggestions that inhalational anesthetics cause shivering by disassociation of spinal reflexes from cortical centers in the brain, it is now believed that virtually all perioperative shivering (with general or regional anesthesia) is thermoregulatory in origin.

Based on studies from 20 to 30 years ago with very small numbers of patients and questionable methods, the myth has been perpetuated that shivering dramatically increases total body oxygen consumption by 400% above baseline.[4,5] In these earlier studies, there were single patients who reportedly increased their metabolic rates by more than 400%, but the methods used to measure oxygen consumption were inferior, and the average increase with shivering was 100%.[5] In general, these were young patients receiving little or no opioid analgesia. More carefully conducted studies have shown that shivering increases oxygen consumption, but the average increase is ≈40%, with a maximum increase of ≈100%.[6] Evidence shows that predictors of increased total body oxygen consumption in the early postoperative period are 1) the presence of shivering, 2) male gender, and 3) increased core temperature (Fig. 1).[6] Although shivering is uncomfortable for most patients, it is unlikely that this relatively small increase in total body oxygen consumption in the average shivering patient is associated with perioperative morbidity.