Oesophageal, rectal, axillary, tympanic and pulmonary artery temperatures during cardiac surgery

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Purpose: The gradient between temperatures measured at different body sites is not constant; one factor which will change this gradient is rapid changes in body temperature. Measurement of this gradient was done in patients undergoing rapid changes in body temperature to establish the best site to measure temperature and to compare two brands of commercial tympanic thermometers.

Method: A total of 228 sets of temperatures were measured from probes in the oesophagus, rectum, and axilla and from two brands of tympanic thermometer and compared with pulmonary artery (PA) temperature in 18 adults during cardiac surgery.

Results: Measurements from the oesophageal site was closest to PA readings (mean difference 0.0 ± 0.5°C) compared with IVAC tympanic thermometer (mean difference -0.3 ± 0.5°C), Genius tympanic thermometer (mean difference -0.4 ± 0.5°C), axillary (mean difference 0.2 ± 1.0°C) and rectal (mean difference -0.4 ± 1.0°C) readings. When data during cooling were analysed separately, all sites had similar gradients from PA except for rectal, which was larger. On rewarming, oesophageal readings were closest to PA readings; tympanic readings were closer to PA than were rectal or axillary readings. Readings from the two brands of tympanic thermometer were equivalent.

Conclusion: Oesophageal temperature is more accurate and will reflect rapid changes in body temperature better than tympanic, axillary, or rectal temperature. When oesophageal temperature cannot be measured, tympanic temperature done by a trained operator should become the reading of choice.

Objectif : Le gradient entre les mesures de température réalisées à différents endroits du corps n'est pas constant; les changements rapides de la température corporelle représentent un des facteurs modifiant ce gradient. Ce dernier a été mesuré chez des patients subissant des changements rapides de la température corporelle dans le but d'identifier le meilleur endroit où mesurer la température et dans le but de comparer deux marques de thermomètre tympanique sur le marché.

Méthode : Un total de 228 groupes de mesures de la température ont été obtenues à partir des sites oesophagien, rectal, axillaire et tympanique (deux marques de thermomètre) et ont été comparés aux mesures réalisées dans l'artère pulmonaire chez 18 adultes subissant une chirurgie cardiaque.

Résultats : Les mesures oesophagiennes étaient les plus proches de celles de l'artère pulmonaire (différence moyenne (0,0 ± 0,5°C), comparativement aux mesures tympaniques par thermomètre IVAC(-0,3 ± 0,5°C) et Genius (-0,4 ± 0,5°C), aux mesures axillaires (0,2 ± 1°C) et aux mesures rectales (-0,4 ± 1°C). Lorsque les mesures durant le refroidissement étaient analysées séparément, tous les sites démontraient des gradients analogues par rapport à l'artère pulmonaire, sauf le rectum qui démontrait un gradient plus considérable. Lors du réchauffement, les mesures oesophagiennes étaient plus proches de celles de l'artère pulmonaire, suivies des mesures tympaniques, avant les mesures axillaires ou rectales. Les lectures obtenues avec les deux marques de thermomètre tympanique se sont avérées équivalentes.

Conclusion : La température oesophagienne est plus précise et reflète mieux les changements rapides de température corporelle que les sites tympanique, axillaire ou rectal. Lorsqu'on ne peut mesurer la température oesophagienne, la mesure tympanique réalisée par un opérateur entraîné devrait être la mesure de choix.

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MANY decisions regarding investigation, treatment, and hospital discharge of patients are influenced by measurement of body temperature. Ideally, one would use the temperature of the blood perfusing the hypothalamus (core body temperature) to make these decisions.[1] This site is not accessible so oral, rectal, axillary, and tympanic temperatures are measured in awake patients. In addition, oesophageal, pulmonary artery (PA), tracheal, nasopharyngeal, and bladder temperatures can be measured in anaesthetised patients. All sites have gradients when compared with core temperature but PA temperature would be predicted to be closest to core temperature; it has been shown to be only 0.18°C lower than the temperature in the high internal jugular vein at steady state.[2]

In this study, measurements were taken from the rectum, axilla, oesophagus, and tympanic membrane for comparison with PA readings in adults undergoing cardiac surgery. The goals were to determine which site would be best for measuring temperature and to compare two brands of tympanic thermometers.

Methods

After approval from the Research Ethics Board of the University of Alberta Hospital and following written consent, 18 adults admitted for elective cardiac surgery were entered in the study. Patients were excluded if they had local infections involving the ear, incisions adjacent to the ear, or ear drainage. Hi-Lo Temp probes (Mallinckrodt Critical Care, St. Louis, MO) were taped over the axillary artery, inserted 5 cm into the rectum, and placed behind the heart in the oesophagus (as determined by auscultation by the anaesthetist). Baxter Edwards Swan Ganz 7 French adult thermodilution catheters were placed in the PA. Hypothermia and cold cardioplegia were used. Intravenous fluids were warmed.

Temperature readings were taken at convenient intervals (about every 5 to 10 min) from the oesophagus, rectum, and PA (when not on cardiopulmonary bypass) as well as a reading from the right ear using both the Genius® (Intelligent Medical Systems Inc., Carlsbad CA) and the Core-Check® by IVAC (IVAC Inc, San Diego CA) tympanic thermometers. Genius was used in tympanic mode on the core equivalence setting (which is calibrated to read 0.3°C higher than rectal and 1.0°C higher than oral). The IVAC gives readings only in a core equivalence setting. There was a one minute interval between readings by the two tympanic thermometers. It took approximately one minute to note the readings from the other four sites. Temperatures recorded during cardiopulmonary bypass were not used in calculations as the absence of pulmonary blood flow would interfere with the accuracy of PA readings. All readings were taken by a single investigator (JC) who had been trained in the operation of both types of tympanic thermometer. Rectal, oesophageal, and PA temperatures were displayed on a 78534C Hewlett Packard monitor. Axillary temperatures were displayed on a Hi-Lo temperature monitor. (Mallinckrodt Critical Care, St. Louis, MO). Calibration was performed by the Clinical Engineering Department of the University of Alberta Hospital. Monitors and tympanic thermometers were calibrated initially and confirmed to still be accurate at the end of the study.

All sets of readings where the PA was < 25°C were eliminated from calculations as the measurement range for IVAC is 25.0 to 43.3°C (Measurement range for Genius 21.2 to 43.4°C). Measurements at all sites were compared with PA readings by examining mean differences and standard deviation of the differences. Data on cooling and on rewarming were then analysed. The two brands of tympanic thermometer were compared by looking at mean difference and standard deviation of the differences. A difference of 0.5°C was considered to be clinically significant as this degree of error could result in inappropriate patient management.

Results

A total of 234 sets of readings were taken from all sites except axillary from which 228 sets of readings were taken. Ambient temperature of 17.1 to 22.7°C was sometimes below the range specified for IVAC (18.3 to 43.3°C) and often below the ambient temperature for Genius (21.2 to 40.0°C). The PA temperature ranged from 34.1 to 40.0°C in the sets of readings which were used for calculations. Readings from a typical patient are shown in Figure 1; readings from when the patient was on cardiopulmonary by-pass are shown but were not used in calculations. With rapid changes in temperature, rectal measurements lagged behind all other sites. Differences from PA temperature are shown in Table I for all sites. Mean difference from PA was smallest for the esophageal site (0.0°C). The other four sites had mean differences from PA which were comparable (ranging from -0.4°C to 0.2°C), but the standard deviation was wider for rectal and axillary sites (± 1.0) than for the other 3 sites (± 0.5).

Comparisons of temperatures at other sites with PA temperatures during cooling are shown on the left side of Figure 2. Differences from PA were smallest for axillary and oesophageal sites and largest for rectal site. A mean difference of -0.8°C suggests that the majority of rectal readings differed from PA readings

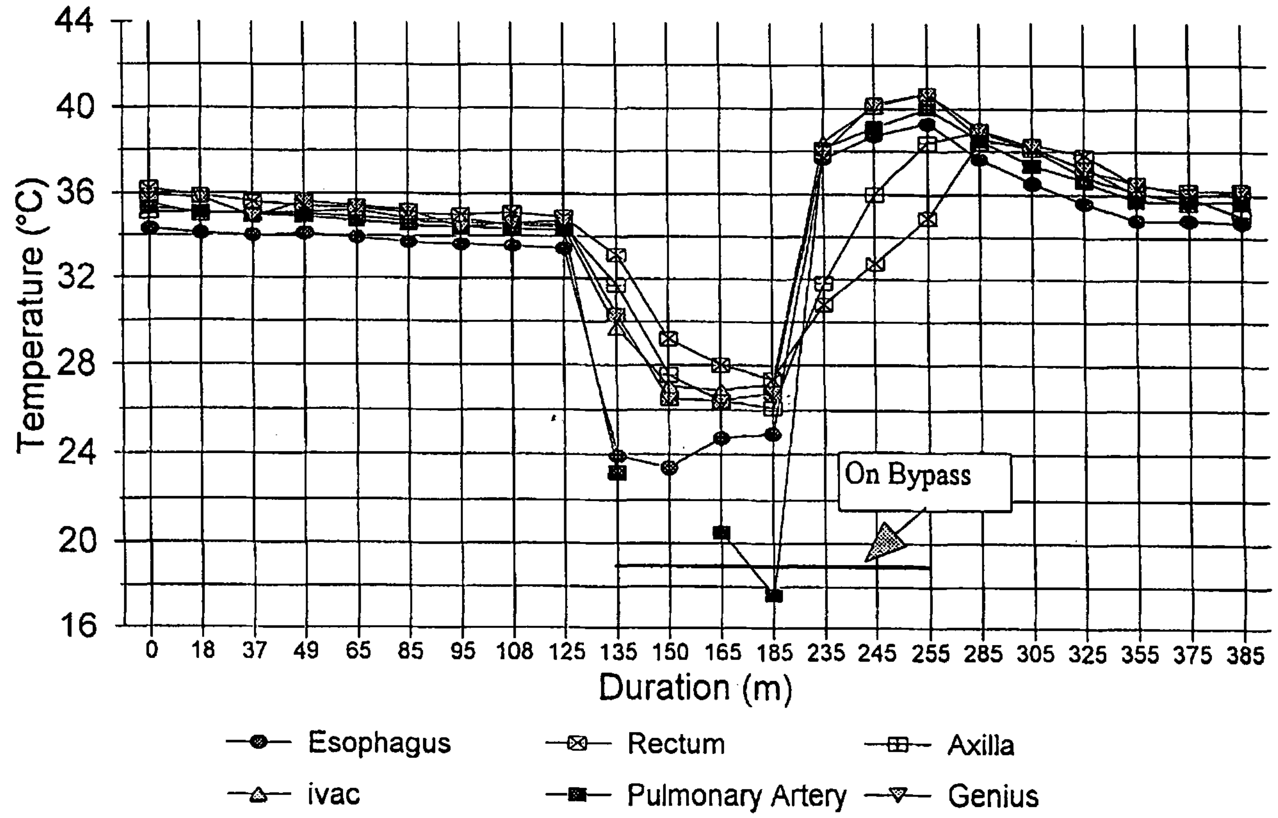

FIGURE 1 Comparison of body temperature measured at different sites in a typical patient during cardiac surgery.

TABLE I Comparison with PA reading of readings taken at different sites from adults during open-heart surgery.

Variable	*n*	*Mean difference (°C) ± SD*
PA-Oeso	234	0.0 ± 0.5
PA-IVAC	234	-0.3 ± 0.5
PA-Gen	234	-0.4 ± 0.5
PA-Rect	234	-0.4 ± 1.0
PA-Axil	228	0.2 ± 1.0

n - number of readings; °C - degrees Celsius;
SD - standard deviation;
PA - pulmonary artery; Oeso - oesophageal; Axil - axillary;
IVAC - tympanic thermometer #1; Gen - tympanic thermometer #2

by a clinically significant amount. Comparison of other sites to PA on rewarming is shown on the right side of Figure 2. Mean difference was lowest for rectal and oesophageal readings but standard deviation was smaller for oesophageal readings than for any other site The figure demonstrates that this occurred as all other sites were slower than the oesophageal site to register change as temperature rose.

The performance of the two tympanic thermometers was remarkably similar throughout the study. The mean difference between IVAC and Genius was 0.1°C on both cooling and rewarming with a standard deviation of 0.3°C on cooling and 0.4°C on rewarming. There was remarkable consistency between Genius and IVAC in all comparisons with PA.

Discussion

We found oesophageal readings to be closer to PA readings than were tympanic, axillary or rectal readings when temperatures were measured during cardiac surgery. Readings taken by either of two brands of tympanic thermometer were closer to PA readings than were either rectal or axillary readings. Differences in performance were most apparent with rewarming when rectal and axillary readings were slow to register change. There were no differences between the two tympanic thermometers.

For most of this century, rectal temperature has been used as the "gold standard" for comparison of temperatures measured at other sites. It has previously been shown that stool can affect rectal readings,[3] rectal temperatures are slow to change with rapid

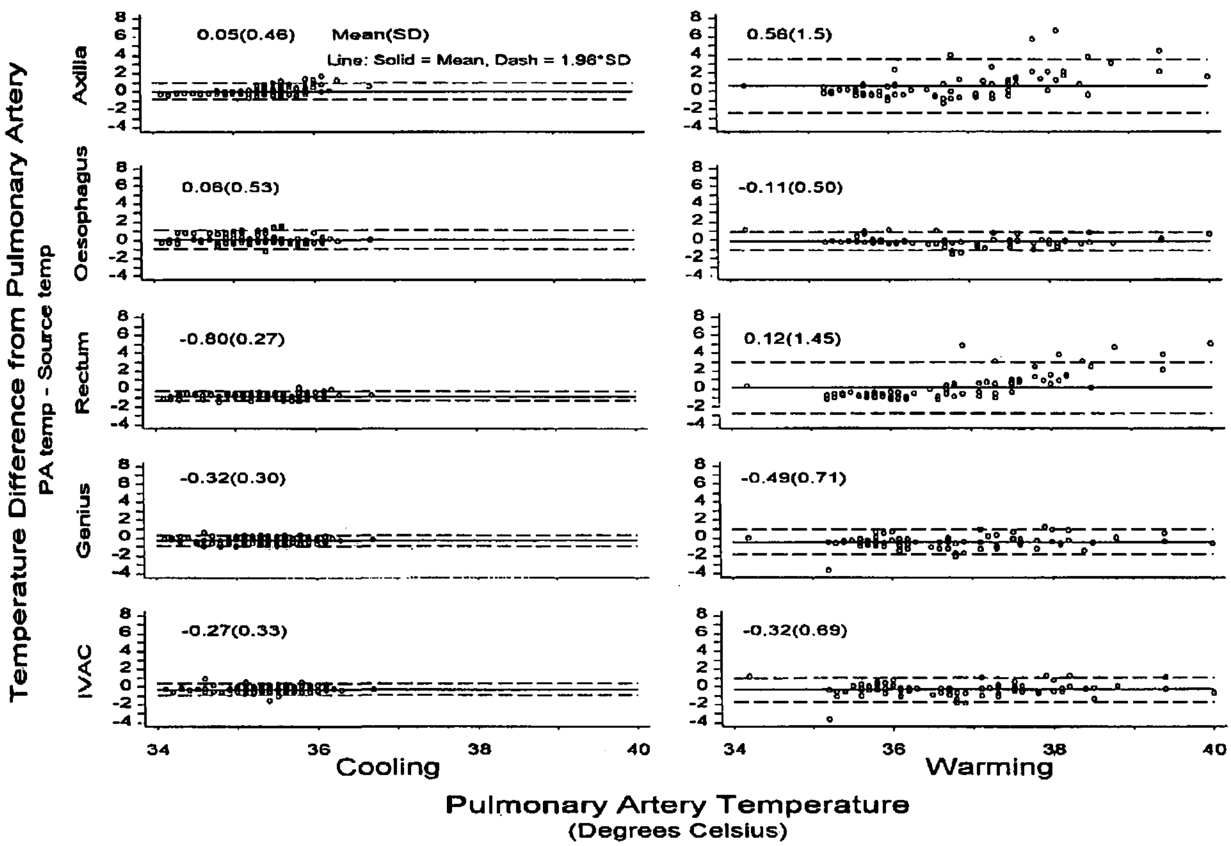

FIGURE 2 Comparison to PA reading of readings taken at different sites during cooling and rewarming for open-heart surgery.

changes in body temperature,[4] and rectal temperature does not always approximate core temperature even at steady state.[4] Our study confirmed rectal temperature to be very slow to change – especially on rewarming.

Previous studies have demonstrated oesophageal temperature to compare favourably with PA[5,6] and cerebral[7,8] temperature. Proper positioning of the oesophageal probe in the lowest quarter of the esophagus is vital if accurate results are to be obtained.[9] Our study showed that both on cooling and on rewarming, oesophageal temperature had a low mean difference when compared with PA temperature. Oesophageal temperature was as accurate as all other sites on rapid cooling and was quickest to register change on rewarming. Oral temperature readings cannot be obtained in uncooperative patients and are affected by respiratory rate,[10] use of oxygen, smoking, and ingestion of cold liquids.[11] Reaching equilibrium with a glass mercury thermometer takes about seven minutes.[12] Electronic thermometers allow a reading to be taken in a shorter time. A study published in 1986 suggested that readings from electronic thermometers were less reliable than from glass mercury thermometers,[13] but technology has changed markedly since then. Oral temperature was not used in this study.

Axillary readings exhibit a wide deviation from rectal, tympanic, and oesophageal sites. They would be more accurate if the thermometer were placed directly over the axillary artery and if glass mercury thermometers were held in place for at least five minutes,[14] but this is not what occurs in practice. In our study, even with careful positioning axillary readings were slow to register change on rewarming.

Measurement of temperature by tympanic thermometers is non-invasive, takes less than three seconds, and poses no risk of nosocomial infection. The temperature of the tympanic membrane should approximate the hypothalamic temperature as the blood supply from both comes fairly directly off the aorta, blood flow is profuse, and heat-production by the brain is minimal at both sites.[15] Tympanic thermometers convert the temperature of the tympanic membrane as measured by infrared emissions to rectal, oral, or core temperatures based on built-in offsets which take into account the average gradients between these sites and the tympanic membrane tem-

TABLE II Comparison of PA temperature to other sites in studies which included infrared tympanic thermometers set in core mode.

Author reference	*n*	*Brand of tym thermometer*	*PA-tym*	*PA-blad*	*PA-rect*	*PA-oral*	*PA-axil*	*PA-oeso*	*Temp range*
Nierman 1991 (23)	21	First Temp	-0.4 ± 0.4	0.0 ± 0.3					35.3–39.4
Klein 1993 (24)	68	Genius	-0.4 ± 0.4						35.8–41.1
Romano 1993 (25)	20 20	First Temp Thermoscan	-0.1 ± 0.6 -0.1 ± 0.4		-0.1 ± 0.3				33.5–39.5
Erickson 1993 (26)	347	IVAC	-0.1 ± 0.4	0.0 ± 0.2		0.0 ± 0.3	+0.7 ± 0.6		34.3–38.8
White 1994 (27)	19 (R) 19 (L) 19 (R) 19 (L)	First Temp*	-0.3 ± 0.6 -0.2 ± 0.5 -0.4 ± 0.3 -0.2 ± 0.3						NR
Erickson 1994 (28)	100 100 100	IVAC Genius Thermoscan	0.1 ± 0.5 -0.1 ± 0.5 -0.4 ± 0.5	0.0 ± 0.2		+0.2 ± 0.6	+0.7 ± 0.6		34.2–38.8
Robinson 1997 (cooling)	144 144	IVAC Genius	-0.3 ± 0.3 -0.3 ± 0.3		-0.8 ± 0.3		0.1 ± 0.5	0.1 ± 0.5	34.1.–36.7
Robinson 1997 (warming)	90 90	IVAC Genius	-0.3 ± 0.7 -0.5 ± 0.7		-0.1 ± 1.4		0.6 ± 1.5	-0.1 ± 0.5	34.2–40.0

The differences between PA temperature and other sites are recorded as mean difference ± standard deviation of difference. All subjects were adults except for those in the Romano study, which were all children.

*Two different instruments were each used in left and right ear

n = number of readings; Temp = temperature; R = right ear; L = left ear; tym = tympanic; blad = bladder; rect = rectal; axil = axillary; oeso = oesophageal; NR = not reported

perature; these offsets vary for different brands of tympanic thermometers. The effect of cerumen and of otitis media on readings is not yet established, but seems to be of minimal clinical importance.[16] The effect of peripheral vasoconstriction on readings has not been investigated.

There have been multiple human studies published in the English literature from 1988 to present looking at the relationship between tympanic readings and readings from other sites. Many of these compared tympanic readings with rectal or oral readings, both of which may be less accurate than tympanic readings when compared to true core temperature so interpretation of results is questionable. There are six studies which compared tympanic with PA temperature but did not have tympanic thermometers set in the core mode[17,18] or did not state what mode the tympanic thermometers were set in[19–22] which again makes interpretation of data difficult. Table II compares our data with the six previous studies which compared commercial tympanic thermometers set in the core mode to PA temperatures. Ours is the first study to use commercial tympanic thermometers to look at rapid changes in body temperature. This probably accounts for the larger differences between PA and other sites in our study than in the other studies. In our study, tympanic readings were clearly superior to rectal or axillary readings. However, they usually read higher than PA readings even on rewarming when one would expect there to be some lag – suggesting that the built-in offset may need to be changed to give a closer approximation of core temperature. This fits with the results of previous studies using FirstTemp (the Intelligent Medical Systems product which preceded Genius)[20,23,25,27] and Genius.[20,24,26,28] The conversion of tympanic temperatures to rectal or oral equivalents is not accurate as the gradient is not constant. Therefore, perhaps it is time we started using tympanic thermometers in the core mode and stopped converting the results to correspond to less accurate methods of measuring temperature.

Nasopharyngeal temperature was not measured in our centre at the time of this study because of the potential for bleeding into the nasopharynx in heparinised patients. However, it appears to be a safe site in these patients and has been reported to be as accurate as oesophageal temperature.[1,29]

In conclusion, over a wide range of temperatures with rapid change, all sites for measuring temperature demonstrated a gradient when compared to the PA site. Oesophageal temperature had a low mean difference and standard deviation when compared with PA temperature and most accurately reflected these rapid changes on rewarming so is the preferred method of measuring temperature in anaesthetised patients that do not have a PA catheter. This agrees with a previous study with a probe in the cerebral cortex which showed the esophageal site to register changes in temperature more rapidly than did the rectal, bladder, axillary, or tympanic membrane sites.[29] In awake patients, the most accurate temperature will be obtained by using a tympanic thermometer. We were able to use ideal conditions for our study (a trained operator and immobile patients) but the proper technique for taking tympanic temperatures is easy to demonstrate, and the patient only has to remain immobile for a few seconds. Both tympanic thermometers may have performed better at a higher ambient temperature, but the room temperature was always within the range suggested by American Standards for Testing Materials for thermometers (16 to 40°C). We found no clinically important differences between measurements from the IVAC or Genius products.

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