

Axillary Electronic and Galinstan Thermometer Measurements: A Comparison of Their Consistency

Dr. John C. Lowe*

*Director of Research, Fibromyalgia Research Foundation
Contact: Dr. John C. Lowe drlowe@drlowe.com

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Abstract. Broda Barnes' publications have influenced many clinicians to use the basal body temperature in diagnosing hypothyroidism and determining patients' dosages of thyroid hormone. Barnes recommended that patients use inexpensive and reliable portable mercury-in-glass thermometers. These are no longer available, so many clinicians now recommend that patients use either electronic thermometers or Galinstan-in-glass thermometers that are mercury-free. Researchers have compared the temperature readings of mercury thermometers with both those of electronic and Galinstan thermometers. However, no studies could be found in which measurements with electronic thermometers were compared to those of Galinstan instruments. The purpose of this study was to compare measurements with these two types of thermometers.

Methods. To avoid variations between subjects and anatomical sites, measurements were taken by one subject using the left axilla. The subject took 10 measurements simultaneously with an electronic and a Galinstan thermometer. Two electronic thermometers (E-1 and E-2) were compared separately with two Galinstan thermometers (G-1 and G-2) so that four sets of 10 paired measurements were taken.

Results. The correlation between measurements with the four pairings of electronic and Galinstan thermometers was strong and statistically significant (E-1 & G-1, $r = 0.985 \pm 0.674$ vs 0.638 , $p < 0.0001$. E-1 & G-2, $r = 0.945 \pm 0.302$ vs 0.272 , $p < 0.0001$. E-2 & G-1, $r = 0.980 \pm 0.587$ vs 0.627 , $p < 0.0001$. E-2 & G-2, $r = 0.976 \pm 0.671$ vs 0.529 , $p < 0.0001$). Also, differences between mean measurements using pairs of thermometers were not statistically significant (E-1 & G-1, 97.266 ± 0.674 F vs 97.190 ± 0.638 F, $p = 0.798$. E-1 & G-2, 97.327 ± 0.302 F vs 97.193 ± 0.272 F, $p = 0.309$. E-2 & G-1, 97.016 ± 0.587 F vs 97.107 ± 0.627 F, $p = 0.743$. E-2 & G-2, 96.638 ± 0.671 F vs 96.841 ± 0.529 F, $p = 0.462$. For metric values, see Table 1).

Conclusion. Readings using electronic and Galinstan thermometers from the same axilla of one subject were consistent enough to be of reliable clinical use.

Keywords. Analog thermometer • Axillary temperature • Digital thermometer • Electronic thermometer • Galinstan thermometer • Mercury thermometer

Introduction

Mercury-in-glass thermometers have long been in clinical use, so long that some researchers have referred to them as "standard mercury thermometers,"^[1] the "standard clinical thermometer,"^[10,p.1550] and the "gold standard."^[11,p.1]

Because of the toxicity of mercury, the FDA and similar agencies in France and Scandinavia have banned mercury thermometers. Two other types of thermometers, electronic and Galinstan-containing instruments, now substitute for mercury-containing thermometers.

The "Geratherm"^[4] brand Galinstan thermometer is a traditional "shake-down" glass analog device. Galinstan is a fluid substitute for mercury. It is a mixture of three metallic elements: gallium, indium, and tin.^[5] The mixture is a eutectic alloy, meaning it is highly convertible from solid to liquid state because its melting point is lower than that of other mixtures of the same ingredients.

Electronic digital thermometers, powered by a button battery, are now in widespread use in the United States. An advantage of the instrument is the short time needed to obtain temperature measurements. Some patients, however, have expressed con-

cern over wide variations in their armpit temperature readings with electronic thermometers. Some clinicians also doubt the reliability of temperature measurements taken with electronic thermometers. For example, a physician wrote: “Currently, mercury thermometers are unavailable and I recommend one with gallium called Geratherm. (*Warning: Do not use a digital thermometer for the results may not be accurate.*)”^[7] [Italics mine.] On the other hand, some companies have promoted electronic thermometers as more accurate than mercury thermometers.^{[2][3]}

ments were most accurate.^[9]

Shanks et al. studied the accuracy of electronic thermometers.^[11] Using 20 hospital inpatients as subjects, they compared measurements using electronic thermometers with those of standard mercury thermometers. They compared two brands of electronic thermometers with the mercury thermometer. Subjects put all three thermometers under their tongues simultaneously. The researchers found no significant difference between the measurements of the three thermometers. The average difference between the pairs of thermometers was 0.07 F (0.026 C).

Table 1. Insignificant differences between the mean measurements with four sets of electronic and Galinstan thermometers.

Thermometers compared	Number*	Means and SD of thermometer measurements	Differences between means and SDs	P value
Electronic-1 & Galinstan-1	10	97.266 ± 0.674 F vs 97.190 ± 0.638 F (36.259 ± 0.374 C vs 36.217 ± 0.354 C)	0.076 ± 0.036 F (0.042 ± 0.020 C)	0.798
Electronic-1 & Galinstan-2	10	97.327 ± 0.302 F vs 97.193 ± 0.272 F (36.293 ± 0.168 C vs 36.218 ± 0.151 C)	0.134 ± 0.030 F (0.074 ± 0.017 C)	0.309
Electronic-2 & Galinstan-1	10	97.016 ± 0.587 F vs 97.107 ± 0.627 F (36.120 ± 0.326 C vs 36.171 ± 0.348 C)	0.091 ± 0.040 F (0.050 ± 0.022 C)	0.743
Electronic-2 & Galinstan-2	10	96.638 ± 0.671 F vs 96.841 ± 0.529 F (35.910 ± 0.373 C vs 36.023 ± 0.294 C)	0.203 ± 0.142 F (0.113 ± 0.079 C)	0.462

* of paired measurements.

Several research groups have reported comparisons of temperature measurements using electronic and mercury thermometers.^{[1][8][9][10]} Davies et al.^[8] compared the two types of thermometers in a hospital ward. They wrote, “Both laboratory and clinical studies show that there is no significant difference in the average accuracy of the two types of thermometers. They stated, however, that temperature readings with electronic thermometers had greater fluctuation. “In clinical studies, they wrote, “between 9 and 23% of repeated measurements using an electronic thermometer differ by 0.5°C or more, whilst the corresponding range for mercury thermometers is 0-6%.

Jensen et al.^[9] compared measurements with mercury thermometers to electronic thermometers in a hospital setting. Unlike the finding of Davies et al.,^[8] Jensen et al. reported that electronic measure-

To the author’s knowledge, no one has reported a comparative study of the consistency of temperature readings with electronic and Galinstan thermometers. One purpose of this study was to fill this information gap in the field of thermometry. A corollary purpose was to determine whether measurements of the axillary temperature, using one armpit of one subject, would be consistent enough with the two types of thermometers to be of reliable clinical use.

Methods

Single Subject

So that intersubject variability was not an issue, only one subject participated in the study. The purpose was to quantify the consistency of temperature measurements by different types of thermometers;

this purpose was best served by avoiding variability in measurements due to different anatomical sites. Because of this, the subject's left axilla was selected as the single anatomic site at which to obtain measurements. Temperature measurements were taken simultaneously with two thermometers, one electronic thermometer and one Galinstan thermometer. The subject took some basal temperature measurements, but most were taken while the subject was sitting at rest.

Statistical Computation, and Microsoft Excel 2002 were used for statistical analyses.

Results

More measurements with electronic thermometers were outside two standard deviations from the mean measurements. Two readings with electronic-1 were below two standard deviations, and one reading with electronic-2 was below two standard deviations.

Table 2. Correlations between the measurements with four sets of electronic and Galinstan thermometers.

Thermometers compared	Number*	Pearson r	SD	Significance (2-tailed)
Electronic-1 & Galinstan-1	10	0.985	0.674 vs 0.638	< 0.0001
Electronic-1 & Galinstan-2	10	0.945	0.302 vs 0.272	< 0.0001
Electronic-2 & Galinstan-1	10	0.980	0.587 vs 0.627	< 0.0001
Electronic-2 & Galinstan-2	10	0.976	0.671 vs 0.529	< 0.0001

* of paired measurements.

Instruments

Temperature measurements were made with two Geratherm (Geratherm-1 and Geratherm-2) thermometers and two inexpensive model VT-820W5T Walgreens electronic thermometers (electronic-1 and electronic-2). Temperature readings of each of the Geratherm thermometers were compared with those of each of the electronic thermometers (see Table 1 for the raw data).

Procedure

The subject's left axilla was the site of all measurements. The protocol followed was that of using more than one thermometer simultaneously, as used in other studies comparing different instruments.^{[1][11]}

Statistical Analysis

Data sets were compared and analyzed for variance by the Pearson product-moment correlation coefficient, by standard deviations, and by mean differences. Means of the measurements with paired thermometers were analyzed by t-tests. The level of significance was set at $p = 0.05$. SPSS for Windows (SPSS, Inc., Chicago, IL), VassarStats: Website for

One reading with Galinstan-2 was more than two standard deviations below the mean. All readings with Galinstan-1 were within two standard deviations.

The mean measurement with electronic thermometers (97.062 F; 36.146 C, ± 0.6201) closely correlated with the mean measurement with Galinstan thermometers (97.083 F; 36.157 C, ± 0.5362). The Pearson correlation coefficient of the two sets of measurements was high and positive ($r = 0.956$, $p < 0.0001$).

Levene's test for equality of variances showed that the variances of the measurements with paired thermometers were not significantly different. Because of this, t-tests for independent means with equal variances were used to test for differences between the mean measurements. The p values in Table 1 show that none of the mean measurements with paired thermometers were significantly different.

Table 1 also shows the differences between the means and standard deviations of temperature readings with paired measurements. The smallest difference was between the electronic-1 thermometer and the Galinstan-1 instrument. The largest difference

was between the electronic-2 and Galinstan-2 thermometers. However, the differences were not statistically significant.

Table 3 shows the mean standard deviations for the two sets of temperature measurements with each thermometer, and those for the combined standard deviations for the two thermometers for each type of instrument. The mean standard deviation of electronic-1 was relatively low and that of electronic-2 was relatively high, while that of Galinstan-2 was relatively low and Galinstan-1 relatively high.

To show the variability of mean differences for all paired thermometers combined, a scatter plot was formulated in Figure 1. Figure 2 shows the mean differences for the four pairs of thermometers. In a study by Smith comparing mercury and Galinstan thermometers,^[11,p.7] the mean difference between axillary temperatures by the two types of ther-

Discussion

Some clinicians have reported that electronic thermometers are not as accurate as Galinstan thermometers,^[7] and some companies that market electronic thermometers have reported that they are more accurate.^{[2][3]} When a study compares measurements by different instruments as this one does, accuracy cannot be determined because we do not know the true value of the measured variable.^[12] So, the focus of the study must be the agreement, that is, the relative consistency, of measurements by the different instruments.^{[13][14]} Accordingly, the focus of this study was the relative consistency of temperature measurements by electronic and Galinstan thermometers. Reformulating the reports of greater accuracy of the two types of thermometers into that of greater consistency, the results of this study refute the re-

Table 3. Standard deviations for individual thermometers and mean standard deviations for combinations of thermometers.*

E1	E2	G1	G2	E1 & E2	G1 & G2	E1 & G2	E2 & G1
0.510	0.643	0.617	0.447	0.620	0.536	0.494	0.643

*(E1) Electronic-1, (E2) Electronic-2, (G1) Galinstan-1, (G2) Galinstan-2, (E1 & E2) Electronic-1 & -2, (G1 & G2) Galinstan-1 & -2, (E1 & G2) Electronic-1 & Galinstan-2, (E2 & G1) Electronic-2 & Galinstan-1.

ometers was 0.253 F (0.141 C). This is a lower difference than the 0.36 F (0.2 C) demarcation for including thermometers in several clinical studies with humans.^{[20][21][22][23]} In this study, mean differences between axillary temperature measurements with different thermometers were less than in the Smith study. The combined mean difference for all paired thermometers was 0.126 F (0.070 C). The mean difference with E1 and G1 was 0.076 F (0.042 C), with E1 and G2 was 0.134 F (0.074 C), with E2 and G1 was 0.091 F (0.051 C), and with E2 and G2 was 0.203 F (0.113 C).

The 95% confidence interval for difference scores was 0.152 F to 0.304 F. By comparison, the 95% confidence interval for axillary temperatures in the Smith study was 0.167 F to 0.339 F. The assumption of a normal distribution, however, is dubious, considering the skewed histogram of the difference scores (-1.807).^{[13][25]}

ports of both the clinicians and the companies.

Variability of temperatures measured by two types of thermometers was assessed by correlations and standard deviations of raw measurements. Variability was also assessed by the standard deviations of mean differences between measurements by paired thermometers.

Correlations of Raw Scores

Table 2 shows the correlations between the temperatures measured by paired electronic and Galinstan thermometers. The correlation coefficient, r , (degrees of correlation) of the four paired temperatures ranged between 0.945 and 0.985. All four strong positive correlations were highly significant with p values of <0.0001 . The mean r value was 0.972.

Standard Deviations of Raw Scores

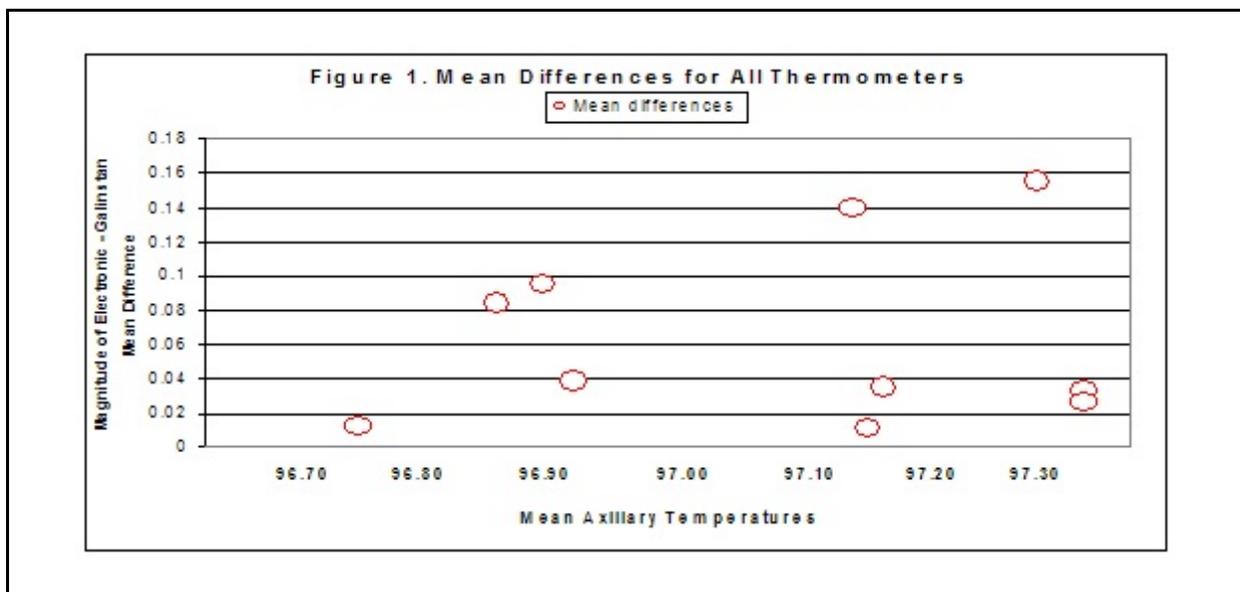
According to Shanks et al.,^[1,p.1263] the consis-

tency of different measurements with two types of thermometers can be measured by the standard deviations of their different measurements. (The standard deviation can loosely be considered the average distance of measurements from the mean of all measurements with same thermometers.) In the four following subsections, analyses of standard deviations are used to interpret the results of the measurements taken in this study.

Reliability of Measurements by Electronic and Galinstan Thermometers. As noted above, some clinicians contend that electronic thermometers are less accurate than Galinstan thermometers,^[7] and that electronic thermometers are less reliable than mercury and alcohol-in-glass thermometers.^[24,p.17] Statistically, some results of this study are consistent with this view. However, the magnitude of the differences between measurements with electronic and Galinstan thermometers are of no practical clinical significance.

of readings with individual thermometers show that one electronic thermometer (E1) and one Galinstan thermometer (G2) had the smallest spreads of readings. The other electronic (E2) and Galinstan (G1) thermometers had the widest spreads. If the aim in selecting thermometers, then, is less variability in readings, the electronic-1 and the Galinstan-2 thermometers would be preferable.

Mean Differences Between Readings with Electronic and Galinstan thermometers. Jensen et al.,^[9] based on their study results, wrote that a standard deviation of temperature differences as low as 0.41°C (0.74°F) was unacceptable.^[9] This unacceptable value is markedly larger than those in this study with both electronic and Galinstan thermometers. In this study, the mean difference for different pairs of thermometers ranged from 0.076 F (0.042 C) to 0.203 F (0.113 C), and the combined mean difference for all paired thermometers was 0.126 F (0.070 C).



Three readings with electronic thermometers and one with Galinstan thermometers were outside two standard deviations from the mean. By the statistical-outlier criterion of consistency of measurements, then, Galinstan thermometers were more consistent.

Table 3 shows that the combined mean standard deviation of readings with the two electronic thermometers (E1 and E2) was wider than that of the two Galinstan thermometers (0.620 vs 0.536); the difference was only 0.084. The standard deviations

In this study, the mean standard deviation for the four sets of measurements with Galinstan thermometers was 0.52 F (0.29 C). This is slightly less than the mean standard deviations of measurements with two brands of electronic thermometers and a mercury thermometer reported by Shanks et al.,^[1] which they considered acceptable. Measurements with the three instruments in their study had standard deviations of the order of only 0.54 F (0.30 C). This is the same value as the standard deviations of the

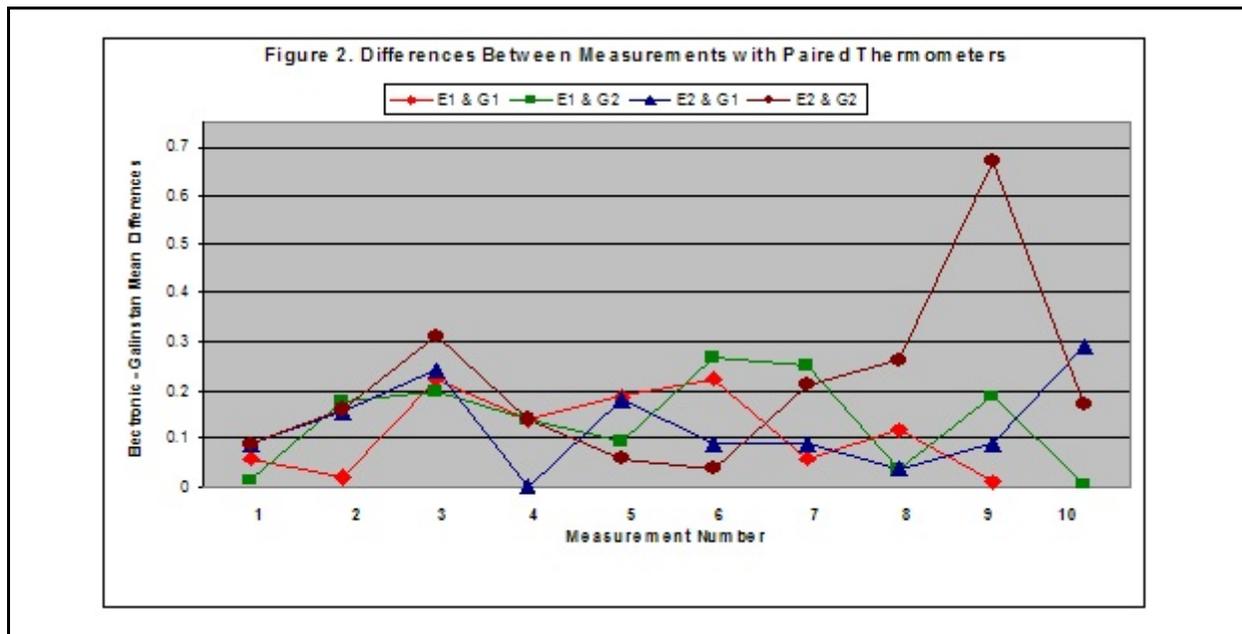
measurements in this study with the Galinstan thermometers, 0.54 F (0.30 C), and less than the mean standard deviation of readings with the electronic thermometers, 0.62 F (0.34 C). These mean standard deviations, however, should *not* lead to the conclusion that electronic thermometers are less consistent than Galinstan thermometers: as noted in the above section, one electronic and one Galinstan thermometer had a smaller spread of readings than did the other electronic and Galinstan thermometers.

Consistency of Measurements with Individual Thermometers of Each Type. The mean standard deviations of measurements with Galinstan thermometers, compared to those with electronic thermometers, give a false impression that the readings with Galinstan thermometers are markedly more consistent. A more definitive analysis, however, shows that this is not true.

The standard deviations in Table 1, Table 2, and Table 3 show that the mean standard deviation of the four sets of measurements with Galinstan thermom-

each type of thermometer shown in Table 3. The standard deviation of measurements with the electronic-1 thermometer was 0.510; that of the electronic-2 thermometer was 0.643. The standard deviation of measurements with the Galinstan-1 thermometer was 0.617, and that of the Galinstan-2 thermometer was 0.447. These standard deviations indicate that of the two electronic instruments, the electronic-1 thermometer was more consistent than the electronic-2 thermometer; and of the two Galinstan thermometers, the Galinstan-2 thermometer was more consistent. Of importance in considering whether Galinstan thermometers are more consistent than electronic thermometers is this: the spread of readings around the mean for the electronic-1 thermometer was less than that for the Galinstan-1. One electronic thermometer (E1) and one Galinstan thermometer (G2) had narrower spreads of readings than did the other electronic thermometer (E2) and the other Galinstan thermometer (G1).

There is no way to determine from the data in



eters was 0.517; the mean standard deviation of readings with electronic thermometers was 0.559. Obviously, the *mean* spread of readings with Galinstan thermometers around the mean measurement is less than that with electronic thermometers. However, this mean spread is a product of the grouping of the two Galinstan thermometers' readings.

Consider the standard deviations of readings for

this study why measurements with one instrument were more or less consistent than those of another. For practical clinical purposes, the relative inconsistency of the readings with the different instruments may not be important. Measurements with all the thermometers were so close that, as Table 1 shows, the means of measurements with different thermometers did not significantly differ. Moreover, as Table

2 shows, because the measurements positively correlated so tightly, the probability that the correlations were due to happenstance is less than 1 in 10,000. Galinstan thermometers as a type of instrument, then, did not reliably give more consistent readings that did electronic thermometers.

Standard Deviations of Mean Differences Between Paired Thermometers. The differences between the mean axillary temperatures by pairs of electronic and Galinstan thermometers was less than the mean difference reported by Smith.^[11,p.7] The mean differences in this study were well below the 0.36 F (0.2 C) criterion for including thermometers in human studies. Because of this, the electronic and Galinstan thermometers studied should be considered acceptable for both research and clinical use.

Limitations and Qualifications

The study was unblinded and therefore possibly involved observer bias. There was no vested interest in the outcome of the study. However, when a study is not randomized and at least some of the measurements are not digitalized, some terminal digits tend to be preferred (most often 0 and 5) and others not (1 and 9).^[19] Such preferences may have contaminated the interpretation of some temperature readings of the Galinstan analog thermometers.

This study was *in vivo*, which means that variables extraneous to the thermometers used may account for much of the variation in temperature readings that are reflected in at least some of the statistical outcomes. The precision of measurements with the electronic and Galinstan thermometers would best be determined by *in vitro* testing, such as thermostatically-controlled water baths.^[10,p.1550]

The small degrees of inconsistency in temperature readings with both types of thermometers may have been due to factors other than the technical precision of the devices. Collins and Exton-Smith noted that the readings of mercury thermometers usually do not significantly differ from the digital readouts of electronic instruments. Differences in readings typically result from how the thermometers are used.^[10,p.1550] They noted that the patient may place the thermometer in a slightly different anatomical location on two different occasions, the thermometer may not be left in place long enough for it to equilibrate, or the ambient temperature may vary. A number of researchers have reported that rectal temperature readings are the most consistent with dif-

ferent types of thermometers.^{[9][11][15][18]} Compared to the rectum, the less compact axilla may have differences in macro- and microcirculation, fatty layers, skin pockets, or adjacent muscle tissue, and these may cause variations in temperature readings even when a thermometer is carefully placed deep in the armpit. Such factors may account for much of the inconsistency in temperature measurements in this study.

The protocol of using more than one thermometer simultaneously was followed, as it was in other studies comparing different instruments.^{[11][11]} In one study, subjects placed the tips of three thermometers under the tongue.^[1,p.1263] The subjects positioned the thermometer tips as close to one another as possible. In another study, subjects used a Galinstan-in-glass thermometer beneath the tongue on one side of the mouth close to the sublingual artery; at the same time, a mercury thermometer was used on the contralateral side of the mouth.^[11,p.3] Whether these procedures ensure maximally close temperature readings is not certain. In this study, it is possible that some closely adjacent anatomical sites in the subject's left axilla had enough difference in artery distribution that one thermometer accurately recorded a real temperature difference. Alterations in readings with different thermometers on different occasions may account for some of the variability in measurements that is reflected in some statistical outcomes of this study.

A criticism of axillary temperature measurement, expressed by Schmitz et al.,^[15] is that it does not correlate well with the core temperature using the pulmonary artery temperature (determined by artery catheterization) as a point of reference. They found that rectal temperature correlated best, followed by the oral and ear canal temperatures.^[15] Lefrant et al.^[18] reported that axillary temperatures differed from pulmonary artery temperatures (measured through pulmonary artery catheter) by 0.27 C (0.49 F). They studied critically ill patients in intensive care hospital units. In this patient population, obtaining temperatures as close to the core temperature (operationally defined as the pulmonary artery temperature) may be crucially important. But in the diagnosis and treatment of hypothyroid and peripheral thyroid hormone resistance patients, knowing the core temperature as closely as possible is not crucial. Instead, what is of importance is to quantify the mean basal temperatures during treatment and to

compare these with the mean baseline basal temperature. The changes in temperature, then, are what is important rather than the relationship of the axillary temperature to the core temperature.

The value of using the axillary temperature in the diagnosis and treatment of hypothyroidism and peripheral thyroid hormone resistance is not diminished by its putative lower correlation with the core temperature. The rectum and the mouth are less preferable for different reasons. Most patients to whom rectal measurements have been recommended have declined to use the anatomical site. The oral temperature is reported to vary more than the axillary temperature because of intermittent subclinical inflammation of the nose, sinuses, or the mucosa of the mouth.^[16,p.45] A recent study in Tel Aviv showed that oral mucositis raised the oral temperature but did not raise the systemic temperature.^[17] It is possible that a high concentration of inhaled particulate matter in urban areas and allergens in rural areas may cause oral mucositis and a variably raised oral temperature.

Schmitz et al.^[15] wrote that their study of thermometry underscored the importance of consistency in the method of measuring the temperature to establish temperature trends.^[15] For this purpose, basal axillary temperatures, measured with either electronic or Galinstan thermometers, seem well suited.

Cost and Relative Merits of Electronic and Galinstan Thermometers

Galinstan thermometers (such as the Geratherm) and electronic thermometers are inexpensive, but the former usually costs less. Both types generally cost fewer than \$15.00. Historically, mercury thermometers have been the least expensive, Geratherm thermometers have been midrange, and electronic thermometers have been the highest-priced.^[6,p.25]

Advantages of electronic thermometers over Galinstan thermometers are that less time is needed to record temperatures (this is called “temporal convenience”^[10,p.1550]), and they are designed to beep when the peak temperature is reached.^[6,p.25] A disadvantage of these instruments is that the power contained in their button batteries is eventually expended. An advantage of the Geratherm Galinstan-containing “hypothyroid thermometer” is that, between its degree marks, it contains marks for 10^{ths} of a degree that are highly visible. The Galinstan thermometer, then, allows for finer graduations of

temperature measurement than is provided by electronic thermometers.

Conclusion

In this comparative study, temperature measurements with electronic and Galinstan thermometers were consistent enough to be of reliable clinical use. A corollary finding is that the use of the same axilla of one subject provided the consistent temperature readings. This indicates that careful placement of either type of thermometer deep in the same armpit is a reliable clinical procedure for patients.

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