VALIDITY OF INFRARED THERMAL MEASUREMENTS OF SEGMENTAL PARASPINAL SKIN SURFACE TEMPERATURE

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ABSTRACT

Objective: The purpose of this study was to evaluate the validity of thermal measurements by infrared camera thermometry.

Methods: Seventeen subjects underwent a 30-minute acclimatizing period in a controlled environment room. Thermal recordings were executed at the levels of C4 and L4. Fifteen recordings per segment were acquired in an alternating mode that always started at L4. Each subject was required to participate on 5 occasions. The exclusion criteria for the subjects included the following: no inflammatory disease or fever, no consumption of beverages containing caffeine, and no participation in physical activity 2 hours before the recording session; female subjects could not be menstruating on a day of recording.

Results: A total of 2550 recordings for the cervical area and the lumbar area was recorded. Strong significant correlations were found for the left ($r = .77$) and right ($r = .71$) lumbar sections ($P < .0001$) whereas weaker significant correlations were observed for the left ($r = .56$) and right ($r = .63$) cervical areas ($P < .0001$). The limits of agreement (Bland-Altman) showed good relationships but poor interchangeability.

Conclusions: In this study, the infrared cameras showed that they were valid tools in a controlled environment; however, the technique for the cervical measurements needs to be reassessed. (J Manipulative Physiol Ther 2006;29:150-155)

Key Indexing Terms: Chiropractic; Thermography

Thermal evaluation of patients dates back to the time of Socrates; since then, modern medicine had incorporated the use of thermometry as a tool for the evaluation of a patient’s health status.1-3 With thermometry, body temperature can be monitored precisely; the traditional normal value for oral temperature is $37^\circ$C (98.6°F).4 Oral temperature is typically 0.5°C lower than rectal temperature, which usually best represents the core temperature of an individual.5 Oral temperature is affected by numerous factors such as the ingestion of cold and hot fluids, whereas core temperature varies least to environmental temperature changes.4 The circadian rhythm oscillates the normal human core temperature by approximately 1.0°C over a 24-hour period.5 Exercise also influences the core temperature, where it may rise to as high as 40°C as a result of increased muscle activity.4 Body heat production is varied, with brown fat being a considerable source of heat, especially in infants. Brown fat is located between and around the scapulae and the neck.5 This fat has a function likened to that of a heating blanket, preventing shivering.5 The better known and clinically relevant form of heat production, however, is fever, and any deviation from the normal core temperature of $37.5^\circ$C is an indication of an underlying pathologic condition.5

In chiropractic, thermal evaluation of the surface skin temperature (SST) at the level of the spine has been in use since 1924.2,3 Surface skin temperature measurements, which attempt to differentiate between contralateral spinal segments, have been used extensively to identify somatotropic anomalies.6-12 Recently, new technologies have emerged to measure paraspinal SST with normative values based on spinal area thermography data obtained by Uematsu et al.6,7 Several studies using thermal recordings of the surface of the skin have shown that there are temperature gradients along the length of the spine.6-12 The cervical area diverges when compared with the dorsal and...
lumbar areas, with the lumbar area being the least elevated of the three areas. In addition, it has been hypothesized that hemispheric contralateral temperature differences may be indicative of somatopic inconsistencies requiring a chiropractic intervention.1-3 Thus, the goal of this study was to evaluate the validity of a commercially available dual-channel infrared camera (IRC) to measure SST. We hypothesized that the IRC SST measurements would compare closely with those obtained with thermistors.

Materials and Methods

Participants

Seventeen healthy subjects were recruited from the student population of the Université du Québec à Trois-Rivières. The distribution was 11 females and 6 males. The anthropometric characteristics of the subjects are shown in Table 1. The research protocols for the validity experiments of the dual-channel IRC were approved by the ethics committees of both the Université du Québec à Montréal and the Université du Québec à Trois-Rivières. Informed written consent was obtained from all subjects.

Materials

Core temperature was estimated with a tympanic thermistor (TT; model MA-100 BF 103 A, General Electric via Digi-Key, Thief River Falls, Minn) and a rectal thermistor (TR; model MA-100 GG 103 A, General Electric via Digi-Key). The TT and TR, respectively, had a precision of ±0.1°C at 37°C. In addition, SST was recorded with thermistors (model Et-016-SP/OWL-ET-016-STP, General Electric via Digi-Key, Thief River Falls, Minn; precision = ±0.05°C at 37°C) placed directly on the skin at 4 sites. The sites of interest were defined at the level of the lumbar spine, left and right L4 (L4LTS and L4RTS, respectively), and at the level of the cervical spine, left and right C4 (C4LTS and C4RTS, respectively). Detailed placement is described in the “Experimental Protocol” section. The TT, TR, and SST measurements were recorded directly into an 8-channel data logger (Smart Reader Plus 8, 128 kb, ACR Systems Inc, Surrey, BC, Canada) at a rate of 0.125 Hz.

The sterilization of the TRs and TTs was performed by washing with antibacterial soap, rinsing with alcohol, and then immersing for 60 minutes in a solution of CIDEX (Johnson & Johnson, Toronto, Ont, Canada). This was followed by another rinsing with alcohol and washing with antibacterial soap.

The IRCs evaluated were part of a multiunit system that is commercially available (Subluxation Station Insight 7000, EMG Consultant, Inc, Paterson, NJ). This instrument has three properties. It can be used to evaluate an electromyogram signal, the range of motion, and the thermal signal from the skin surface. The scope of our experiment was to evaluate the thermal signal of the commercially available unit.

Both the left and right IRCs were used in conjunction with the L4LTS and C4LTS as well as the L4RTS and C4RTS, respectively. The SST measurements obtained with the IRCs were compared with those obtained with the thermistors. Unlike the thermistors, the cameras had no direct contact on the skin. All data were collected at room temperature. The room temperature and relative humidity were recorded with a THR-1000 (ACR Systems Inc).

Experimental Protocol

The exclusion criteria were that all subjects be free of any underlying condition (acute or chronic diseases, colds, menses, and/or any thermogenic disease) that would have affected their core temperature. Before the day of the experiment, the subjects were instructed not to drink any coffee or any other beverage containing caffeine (eg, cola soft drink and tea). Subjects were also instructed not to smoke or chew tobacco or perform physical activity for a period of at least 2 hours before the recording session. On every recording day, subjects were asked if they had complied with the exclusion criteria.

When the subjects arrived for a recording session, they were asked to take off their clothing, keeping on only their underpants, as well as the bras for the female subjects. They were provided with a cotton gown that had an opened slit at the back. The subjects were then gloved and asked to insert the TR to record core temperature. The TR was inserted for a length of 15 cm beyond the anal sphincter by the subjects. After TR placement, the chronometer was started to ISO-time document body temperature measurements. The TT was then inserted in the left ear held in place with a foam antinoise plug surrounding it to estimate core temperature as a fail-safe precaution to the TR. The antinoise plug isolated the tympanic probe from the environment air temperature. The subjects then proceeded to lie down on a chiropractic table. Each subject’s head was placed in a neutral position with adjustments to the headrest piece of the table.

We then proceeded to install the spinal thermistors at each of the following sites: L4LTS, L4RTS, C4LTS, and C4RTS. All thermistors were installed on the skin 4 cm lateral to the spinous process at the lumbar site, one on the left side and one on the right, and 2 cm lateral to the spinous

| Table 1. Anthropometric measurements of the subjects |
|---------------------------------|-----------|-----------|-----------|
|                                 | Females (n = 11) | Males (n = 6) | Group (N = 17) |
| Age (y)                        | 25.6 (5.66)     | 25.5 (5.22) | 25.6 (5.39)   |
| Height (m)                     | 1.66 (0.08)     | 1.79 (0.07) | 1.70 (0.10)   |
| Weight (kg)                    | 60.2 (6.35)     | 80.1 (11.43)| 67.14 (12.72)|

Values are expressed as mean (SD).
Table 2. The mean temperature of the 4 recording sites on 5 occasions as measured with the IRCs

<table>
<thead>
<tr>
<th></th>
<th>Day 1</th>
<th>Day 2</th>
<th>Day 3</th>
<th>Day 4</th>
<th>Day 5</th>
<th>Overall</th>
</tr>
</thead>
<tbody>
<tr>
<td>L4L</td>
<td>91.86 (1.43)</td>
<td>92.17 (1.51)</td>
<td>92.58 (1.13)</td>
<td>92.43 (1.38)</td>
<td>92.81 (1.53)</td>
<td>92.37 (1.39)</td>
</tr>
<tr>
<td>L4R</td>
<td>91.54 (1.74)</td>
<td>91.85 (1.85)</td>
<td>92.24 (1.68)</td>
<td>92.29 (2.12)</td>
<td>93.35 (2.06)</td>
<td>92.25 (1.89)</td>
</tr>
<tr>
<td>C4L</td>
<td>92.25 (1.30)</td>
<td>92.35 (1.40)</td>
<td>92.69 (1.41)</td>
<td>92.51 (1.44)</td>
<td>93.15 (1.15)</td>
<td>92.59 (1.34)</td>
</tr>
<tr>
<td>C4R</td>
<td>91.46 (1.51)</td>
<td>92.01 (1.31)</td>
<td>92.24 (1.51)</td>
<td>92.37 (1.70)</td>
<td>93.38 (1.75)</td>
<td>92.29 (1.56)</td>
</tr>
</tbody>
</table>

Values are expressed as mean (SD). L4L, Left fourth lumbar vertebra; L4R, right fourth lumbar vertebra; C4L, left fourth cervical vertebra; C4R, right fourth cervical vertebra.

Table 3. The mean temperature of the 4 recording sites on 5 occasions as measured with the thermistors

<table>
<thead>
<tr>
<th></th>
<th>Day 1</th>
<th>Day 2</th>
<th>Day 3</th>
<th>Day 4</th>
<th>Day 5</th>
<th>Overall</th>
</tr>
</thead>
<tbody>
<tr>
<td>L4LTS</td>
<td>89.16 (1.32)</td>
<td>89.38 (1.30)</td>
<td>89.77 (1.21)</td>
<td>89.89 (1.58)</td>
<td>89.80 (1.49)</td>
<td>89.60 (1.41)</td>
</tr>
<tr>
<td>L4RTS</td>
<td>88.61 (1.88)</td>
<td>88.82 (1.28)</td>
<td>89.68 (1.51)</td>
<td>89.69 (1.54)</td>
<td>89.91 (1.42)</td>
<td>89.34 (1.62)</td>
</tr>
<tr>
<td>C4LTS</td>
<td>90.16 (1.91)</td>
<td>90.48 (1.20)</td>
<td>90.38 (1.90)</td>
<td>90.17 (1.90)</td>
<td>90.58 (1.64)</td>
<td>90.35 (1.74)</td>
</tr>
<tr>
<td>C4RTS</td>
<td>88.67 (2.32)</td>
<td>89.75 (1.91)</td>
<td>90.14 (1.65)</td>
<td>90.16 (1.68)</td>
<td>90.27 (2.47)</td>
<td>89.80 (2.12)</td>
</tr>
</tbody>
</table>

Values are expressed as mean (SD). TS, thermostors.

process at the cervical site, one on the left side and one on the right. Once all thermistors were in place, there was a 20-minute acclimatization period, during which the subjects remained in the same position.

Wooden popsicle sticks were attached to the side of each IRC casing, one on the medial aspect and one on the lateral, to respect the distance between the IRC and the skin. The sticks were held in place by ventilation duct tape. The tips of the sticks extended half an inch beyond the IRC’s lens to maintain a constant distance between the IRC and the skin surface, according to the manufacturer’s recommendations. The IRCs were synchronized to the manufacturer’s standard before recording. All temperatures were recorded in Fahrenheit degrees.

When we started the recording sessions, the IRCs were positioned at the immediate inferior aspect of the SST already on the skin and maintained in place by skin tape. When the representation of the curve was stable on the computer screen, which would take between 5 and 14 seconds, the recording pedal was activated and the computer recorded the temperature at that moment. The SST was simultaneously recorded with the data logger.

We always started our recording session at L4. We then moved the IRCs to the C4 site and repeated the procedure. We repeated this alternative site recording until we had 15 recordings from each site. We would then have 15 bilateral recordings from each site. This exact procedure was repeated on each of the 5 days of recording.

When the recording session was terminated, we immediately disconnected the TR from the data logger. This gave us a clear break in the recording trace representing the end of the recording session. All thermistors were removed from the subjects. The subjects were then gloved and instructed to remove the TR and get dressed.

Descriptive Statistics

All data are presented as mean values with standard deviations. One-way analysis of variance was used to identify differences between segmental sites and temperature measurement methods (IRC vs Ther). The general linear model post hoc test was used to identify significant differences at the P < .05 level. Pearson’s correlation was used to verify the validity of the IRC to the measurements obtained with the skin thermistors. Bland-Altman plots were used to determine the IRC variance in relationship to the skin thermistors.

RESULTS

A total of 2550 recordings for the cervical area and the lumbar area was recorded from 17 subjects. As shown in Table 2, the L4L, L4R, C4L, and C4R sites indicate that the average for the 17 subjects with 15 trials per day for 5 days varies from one site to the next and from one side of a site in relation to the other side. The averages for each site are as follows: L4L, 92.4°F ± 1.40°F; L4R, 92.3°F ± 1.90°F; C4L, 92.6°F ± 1.34°F; and C4R, 92.3°F ± 1.56°F. The difference between L4L and L4R (P < .05) and between C4L and C4R (Δ0.26°F; P < .05) is statistically significant. In addition, there was a significant difference in temperature recordings between L4L and L4R (Δ0.12°F; P < .05) and between C4L and C4R (Δ0.26°F; P < .05).

The thermistors (Table 3) located at the L4LTS, L4RTS, C4LTS, and C4RTS sites show the following relationships. The average for L4LTS is 89.6°F ± 1.41°F; for L4RTS, 89.34°F ± 1.62°F; for C4LTS, 89.35°F ± 1.74°F; and for C4RTS, 89.80°F ± 2.12°F. The difference between L4LTS and L4RTS is 0.26°F (significant at P < .05). As for the cervical area, the difference between C4LTS and C4RTS is 0.55°F (significant at P < .05).
The temperature readings (Tables 2 and 3) indicate the site-per-site variability in the SSTs of repeated measures on 5 occasions. The IRC temperature measurements vary significantly in the lumbar area by 0.12°F and in the cervical area by 0.26°F. Similarly, the thermistor temperature measurements vary significantly in the lumbar area by 0.26°F and in the cervical area by 0.55°F. The temperature difference ratio of the cervical and lumbar areas of the IRCs is 0.46; that of the thermistors, 0.47.

DISCUSSION

The lumbar and cervical variabilities show the individual human factor in addition to the side-to-side individual requirements for the maintenance of proper thermoregulation at the segmental level. This is different from previous thermography research that showed a more general heat pattern per region (cervical and lumbar). Where this becomes important in a clinical setting is that from one patient to the next, no normative value exists for digitized infrared segmental thermometry. The values that most manufacturers use are from a thermography database. This could be unsettling if a clinician desires to evaluate a patient using absolute values instead of relative values. The difference from one site to the next is not significant and reflects the segmental adaptability specific to the local requirements of thermoregulation. The side-to-side variability from the same site can be perplexing. It most likely indicates adaptability to the environment, an evaluator’s position, and sudden drafts from the ventilation system or an opening door. Moreover, human beings are not machines and the human physiology is highly responsive to all inputs received at the level of the peripheral and central nervous systems.

Intrasubject and Interday Variability

The standard deviation allows us to determine the variability between subjects and the variability applicable from a day to the next. The temperature difference between sides for both sites is less with the IRCs than with the thermistors. The standard deviation is not the same for both measuring technologies. The IRC SDs for C4L and C4R, respectively, are 1.34°F and 1.54°F. The IRC SDs for L4L and L4R, respectively, are 1.39°F and 1.89°F. The right lumbar and cervical sites are warmer with the IRC. The thermistor SDs for C4L and C4R, respectively, are 1.74°F and 2.12°F. The thermistor SDs for L4L and L4R, respectively, are 1.41°F and 1.62°F. The right lumbar and cervical sites are also warmer with the thermistors. When we consider that the SST thermistor measuring instruments have an error of ±0.05°C at 37°C, our results do not fall within a normal machine error. We therefore have to assume that thermoregulation at the SST is very responsive and adaptable. We also have to advise the readers that our data differ strongly from the established database being used currently by the manufacturer of the thermal scanning instrument. The database in use is from the research conducted by Uematsu et al on thermography with a measurement technology that is different and not readily comparable. Uematsu et al. evaluated each spinal region (cervical, dorsal, and lumbar) as a separate global entity whereas we looked into specific segmental levels.

Infrared Camera Validity

Traditionally, Pearson’s statistical calculation has been the method of choice to determine the relationship between different instruments. Pearson’s $r$ is a measure of the extent to which paired scores occupy the same or opposite positions within their own distribution. The calculation of the correlation coefficient helps determine the direction and order of grandeur of the relationship, from +1 (direct) to −1 (opposite). A high correlation between the two methods of measurement does not necessarily mean that the two methods agree or are interchangeable. If their values are not identical numerically, then Pearson’s test gives an order of grandeur of their differences.
When we look at the identity plot for the lumbar site, we obtain Pearson’s $r$ correlations for L4L and L4R of .77 ($P < .0001$) and .71 ($P < .0001$), respectively. For the cervical site, we obtain Pearson’s $r$ correlations for C4L and C4R of .56 ($P < .0001$) and .63 ($P < .0001$), respectively (Fig 1). This Pearson’s coefficient correlation from the identity plot indicates good correlation coefficient reliability for the lumbar spine. The cervical spine Pearson’s coefficient correlation from the identity plot indicates weaker correlation coefficient reliability. This would then show more of a technical issue with evaluating the smaller surface of the cervical spine than an inconsistent instrument. The instrument is constant in its error in the lumbar site and the cervical site. We obtain results that are not congruent with the thermistors in the cervical spine. This noncongruence indicates to us that the relationship of the numerical values for each measuring instrument is adequate although they are not identical. Our opinion is maintained that the relationship for the cervical spine indicates that a methodological error was observed with the improper use of the IRC.

**Limits of Agreement (Bland-Altman)**

The Bland-Altman statistical test helps us determine the agreement between the two thermal measuring instruments from our experiment (MedCalc Software version 8.0, Mariaerke, Belgium). This statistical evaluation gives us a more accurate view of the agreement between the two tools being tested against one another. The limits of agreement between the IRCs and the thermistors (Fig 2) were determined by graphing the data as well as by calculating the mean values and standard deviations for the two methods of temperature recording. In normally distributed data, 95% of the data will fall between 2 SDs from the mean, which are the limits of agreement between two methods. The mean differences between IRCs and thermistors for each site are as follows: L4L, 2.8°F; L4R, 2.9°F; C4L, 2.2°F; and C4R, 3.0°F. The SDs were 2.0°F, 2.9°F, 3.0°F, and 3.4°F, respectively, making the limits of agreement 0.8°F/4.7°F, 0.1°F/5.7°F, −0.8°F/5.2°F, and −0.4°F/6.4°F, respectively. Thus, for our study, we found that some of the data are outside the limits of agreement. Even if the limits of agreement seem to be respected, we could not use these two methods of measuring SST interchangeably.

**Limitations of Study**

In our effort to be precise and scientific, we advise the readers that the use of two kinds of measuring instruments may have some limits and/or other influences on the results. In our case, we feel that the thermistors may seem to be colder than the IRCs because of the heat transfer effect from the metal disk being exposed on one side to the room temperature (69°F to 74°F) and the other side being trapped and insulated on the skin by a piece of skin tape. We feel that it is possible that some thermal transfer could have happened and have affected the temperature measurement of the thermistors by cooling it inadvertently via conduction. In addition, we feel that the tape may have insulated part of the disk on the skin, thus limiting the humidity evaporation from that area and acting as a cooling barrier, affecting thus...
again the measurements from the direct skin temperature contact by the thermistors.

CONCLUSION

We found the IRC to be a valid tool using the protocols of this study. However, we also found that the technical application for the measurements of the cervical spine should be modified to accommodate the smaller surface area of the cervical region. Normative data for digitized infrared segmental thermometry should be established to validate the clinical usefulness of this instrument in a segmental manipulation setting.

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REFERENCES