Temperature Measurement Reliability and Validity With Thermocouple Extension Leads or Changing Lead Temperature

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Context: Thermocouples' leads are often too short, necessitating the use of an extension lead.

Objective: To determine if temperature measures were influenced by extension-lead use or lead temperature changes.

Design: Descriptive laboratory study.

Setting: Laboratory.

Other Participants: Experiment 1: 10 IT-21 thermocouples and 5 extension leads. Experiment 2: 5 IT-21 and PT-6 thermocouples.

Methods: In experiment 1, temperature data were collected on 10 IT-21 thermocouples in a stable water bath with and without extension leads. In experiment 2, temperature data were

collected on 5 IT-21 and PT-6 thermocouples in a stable water bath before, during, and after ice-pack application to extension leads.

Results: In experiment 1, extension leads did not influence IT-21 validity ($P = .45$) or reliability ($P = .10$). In experiment 2, postapplication IT-21 temperatures were greater than preapplication and application measures ($P < .05$).

Conclusions: Extension leads had no influence on temperature measures. Ice application to leads may increase measurement error.

Key Words: uncertainty, therapeutic modalities, cryotherapy, thermotherapy

Key Points

- The use of extension leads did not affect thermocouple measurement reliability and validity.
- Researchers should report the reliability and validity of thermocouple measurements.

Thermocouples are interfaced with electrothermometers to measure temperature. Some thermocouple models, such as the implantable IT-21 (Physitemp Instruments, Inc, Clifton, NJ), have leads that are too short to reach from an electrothermometer to the tissue or substance being measured, necessitating the use of a thermocouple extension lead. When studying superficial modalities, such as ice and heat packs, researchers must place most modalities on at least part of the leads during data collection. In previous work,^{1,2} we reported that an electrothermometer influenced uncertainty (validity $\pm$ reliability), otherwise referred to as *accuracy* by manufacturers.³ The only thermocouple model to influence uncertainty more than the electrothermometer manufacturer's claims was the IT-212; thermocouple manufacturers provide only range values for their equipment.⁴ This finding caused us to question whether extension leads influence temperature measurement uncertainty. Because thermocouples are composed of 2 dissimilar metal wires and metal is typically a good conductor of heat energy, we also asked if altering the temperature around the thermocouple leads could influence the reported temperature. Therefore, the purpose of our study was to determine if the

use of extension leads or the temperature of the thermocouple lead alters the validity and reliability of temperature measurements.

METHODS

Study Design

Two experiments were performed. Experiment 1 was a 2×2 repeated-measures factorial design with extension lead (with, without) and trial (1, 2) as the independent variables. Experiment 2 was a 1×3 repeated-measures factorial design with phase (preapplication, ice application, postapplication) as the independent variable. The dependent variables for both experiments were temperatures measured with an electrothermometer and with a National Institute of Standards and Technology (NIST)-calibrated mercury thermometer.

Instruments

Ten IT-21 thermocouples, 5 PT-6 thermocouples (Physitemp Instruments, Inc), and 5 EXT-6 probe extension

Figure. The distal ends of 10 IT-21 thermocouples were inserted through a polystyrene cooler, secured with a silicone-based polymer, and connected to the Iso-Thermex.

leads (Physitemp Instruments, Inc) were studied. A 16-channel Iso-Thermex electrothermometer (Columbus Instruments, Columbus, OH), with a temperature range of -50°C to 50°C and a NIST-certified mercury thermometer (model 15-059-18; Fisher Scientific, Pittsburgh, PA) graded at 0.1°C were used to measure water-bath temperature. A stirrer (model PC 103; Corning Inc, Corning, NY) and magnetic stir bar circulated the water bath.

Procedures

Experiment 1. The distal ends of 10 IT-21 thermocouples were inserted through a polystyrene cooler, secured with a silicone-based polymer, and connected to the Iso-Thermex (Figure). The polystyrene cooler was then placed on a stir plate and filled with tap water (17.2°C), which had been in the 18.1°C room for at least 24 hours. A magnetic stir bar was centered in the bottom of the cooler to circulate the water bath. The mercury thermometer was connected to a ring stand and positioned in the water bath so that its bulb was approximately 3 cm from the bottom of the cooler. During the first trial, 5 of 10 thermocouples were interfaced directly to the Iso-Thermex, and the remaining 5 were connected via extension leads. For the second trial, the extension leads were switched to the thermocouples not connected with an extension lead during the first trial. We collected data for each trial every 20 seconds for 5 minutes.^{1,2,5}

Experiment 2. For Experiment 2, 5 IT-21 and 5 PT-6 thermocouples were set up in our polystyrene cooler similarly to the setup used in experiment 1 but without the use of extension leads. After confirming a stable water-bath temperature of 18.2°C , we began our data collection. Data were collected every 10 seconds for 10 minutes during preapplication (2.5 minutes), application (5 minutes), and postapplication (2.5 minutes) phases.^{1,2,5} During the application phase, we placed a 2-kg ice bag on the thermocouple leads.

Statistical Analysis

The absolute difference between the thermocouple and mercury thermometer readings was computed for each measurement.^{1,5} The means of the absolute differences were

Table 1. Validity, Reliability, and Uncertainty (Validity + Reliability) With and Without Extension Leads During Experiment 1

Condition	Validity	Reliability	Uncertainty
Extension	± 0.08	± 0.03	± 0.11
No extension	± 0.07	± 0.03	± 0.10

our measure of validity for each thermocouple. Differences in thermocouple validity with or without extension leads and for each application phase were analyzed with repeated-measures analyses of variance. The Scheffé multiple-comparisons test was used to isolate significant differences between means for both experiments.

We computed the mean and SD for each thermocouple and used the SD as a measure of reliability. Differences in reliability between extension-lead use and for each application phase were analyzed with a modified Levene equal-variance test, followed by pairwise *F* tests when appropriate.⁶

Our *P* value was set at $< .05$, whereas differences of less than the manufacturer's claims ($\pm 0.1^{\circ}\text{C}$) were not considered practically different.^{1,5} In experiment 2, we identified 2 IT-21 outliers with box plots and removed them before data analysis.

RESULTS

For experiment 1, extension leads did not influence the validity ($F_{1,8} = 0.64$, $P = .45$; Table 1) or reliability (modified Levene test = 2.65, $P = .10$) of the IT-21 thermocouple measurements.

For experiment 2, after we removed the outlier data, ice application to the thermocouple leads influenced the validity of the temperature measures ($F_{2,12} = 14.82$, $P = .001$; Table 2). The IT-21 postapplication validity was less than the IT-21 preapplication and application validities, as indicated by the higher absolute differences. The IT-21 validity during postapplication was less than the PT-6 validity during any phase (Scheffé test: $P < .05$). Any other statistical differences were not practically different. Although statistical differences were calculated for reliability, these differences were also not practically different (modified Levene test = 9.185, $P = .001$).

DISCUSSION

The use of extension leads did not change the uncertainty of temperature measurements of IT-21 thermocouples. The uncertainty of Physitemp's IT-21 thermocouples during experiment 1 (Table 1) and Physitemp's IT-21s and PT-6s during the preapplication measures of experiment 2 (Table 2) was similar to the uncertainty observed in a previous study⁵ ($\pm 0.2^{\circ}\text{C}$). Validity of the IT-21 thermo-

Table 2. Validity + Reliability for the PT-6 and IT-21 Thermocouples During Experiment 2

Condition	PT-6	IT-21	IT-21 Including Outliers
Preapplication	0.12 ± 0.04	0.14 ± 0.02	0.15 ± 0.03
Ice application	0.13 ± 0.04	0.15 ± 0.03	0.20 ± 0.24
Postapplication	0.11 ± 0.04	$0.19^a \pm 0.02$	0.32 ± 0.35

^a IT-21 postapplication > IT-21 ice application > all PT-6 values (Scheffé, $P < .05$); IT-21 postapplication > IT-21 preapplication.

Table 3. Uncertainty (Validity + Reliability) for the PT-6 and IT-21 Thermocouples During Experiment 2

Condition	PT-6	IT-21	IT-21 Including Outliers
Preapplication	±0.16	±0.16	±0.18
Ice application	±0.17	±0.18	±0.44
Postapplication	±0.15	±0.21	±0.67

couples before ice application was consistent with previous research^{1,2,5} (Table 2). Once the ice bags were applied, however, both validity and reliability decreased. These changes in validity and reliability were due to 2 outlier thermocouples. Once these IT-21 thermocouples were removed, the overall validity and reliability data improved to levels consistent with those observed in a previous study.⁵

Apparently the small IT-21 thermocouple wires are much more fragile than those of other thermocouple models. From our experience, age and the amount of use influenced the IT-21 thermocouple uncertainty more than that of other Physitemp thermocouple models (Table 3). Other models use larger-gauge wire, which may explain why we have not observed rogue Physitemp IT-18 or PT-6 thermocouples.

Scientists should test, and report, the validity, reliability, and uncertainty of their thermocouples under the conditions used in data collection.^{1,5} In addition, we suggest that investigators use Physitemp's IT-21 thermocouples with caution.

CONCLUSION

The use of thermocouple extension leads appears to have no effect on uncertainty. We recommend authors use caution when collecting temperature data where a thermal modality is applied to Physitemp's IT-21 thermocouple leads. By reporting their thermocouple uncertainty, scientists allow others to understand the limitations of the data.

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