An investigation of the relationship between thermal imaging and digital thermometer testing at the knee

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Abstract

BACKGROUND: A number of research papers and theoretically clinical models summarising how temperature of the skin over the knee may be altered according to different pathological processes have been published. Thermal imaging (TI) is generally regarded as the ‘Gold’ or ‘reference’ standard for measuring skin temperature, however this technology is not widely accessible to most musculoskeletal physiotherapists working in clinical environments. This is largely due to the time required for analysis of the thermal images and the high cost of the equipment. A digital thermometer (DT) is portable with a convenient display of results which could offer an inexpensive substitute.

PURPOSE: The aim of this study was to determine the interchangeability between thermal imaging and a digital thermometer, using Bland-Altman limits of agreement, to determine skin temperature differences between right and left knees.

METHODS: Seventy-one healthy participants in the age group of 8 to 40 participated in the study. Data were collected in two phases. The first phase was as part of a public engagement event at the Lancashire Science Festival where school children were invited to learn about science. The second phase of data collection took place as part of a PhD study where staff and students at the university were recruited via electronic adverts and posters displayed around the campus. All subjects were free from lower back or lower limb problems and had not had any previous lower limb surgery.

RESULTS: Matched paired t tests showed no significant difference between temperature difference between right and left using DT and TI (t = 1.41, df = 69, P = 0.08). The DT and TI were interchangeable to measure knee skin temperature difference with a limit of agreement of −0.64 and 0.75; this limit of agreement is acceptable based on previous literature where skin temperature differences between affected and non-affected knees are equal to or greater than 1 °C.

CONCLUSION: This study concludes that an inexpensive handheld digital thermometer shows acceptable agreement with a thermal imaging camera. Clinically a handheld digital thermometer has the potential to play an important role in the localized assessment of skin temperature in physiotherapy and can offer an inexpensive substitute to thermal imaging; due to the massive difference in cost it is worth considering the adoption of digital thermometry in routine musculoskeletal physiotherapy practice.

Keywords: Knee skin temperature, Infrared Thermal Imaging, digital thermometer, relationship, agreement

1. Introduction

Physiotherapists have traditionally manually assessed raised skin temperature to evaluate the presence of inflammation in underlying tissues. Within podiatry instrumented skin temperature monitoring has become established as a valuable technique...
quality thermal imaging cameras have a significant
clinical practice are the financial implications, as high
cost, and the time required for analysis of the thermal
image. A digital skin temperature thermistor is
portable, fitting into a pocket, and could offer an
inexpensive substitute to thermal imaging. Digital
skin thermometers also have the advantage that they
are capable of producing instant objective data useful
for ‘real time’ clinical decision making.

This study compared the agreement in skin temper-
ature readings at the knee as measured by a thermal
imaging camera and a hand held, low cost digital
thermometer. Both thermal imaging cameras and dig-
tal skin thermometers use thermal detectors which
have a sensitivity in a similar wave band to mea-
sure naturally emitted infrared radiation from the skin
surface. As the same sensing principle is employed,
the results of a comparison between these two instru-
ments should be similar. The objective was therefore
to determine whether sufficient agreement exists between
the two types of temperature measurement equipment to
allow the inexpensive digital thermistor to be
used clinically as a replacement for the thermal imag-
ing camera to determine skin temperature difference
between knees. Thermal imaging was used as a ref-
erence standard as it has been shown to distinguish
temperature changes as subtle as 0.02°C [11]. In the
introduction, stress the rationale is that PFP knees may
be different temp so you want to be able to investigate
if skin temp is different between knees, as far as clini-
cally and research is concerned just knowing the temp
is not enough it is a comparative/relative measure you
are interested in – and then stress the clinically impor-
tant differences (BUT write better than this) However
we acknowledge the limitation in this approach as there
have been few clinical thermal imaging studies inves-
tigating the value for minimum clinically important
differences in skin temperature asymmetries of the
anterior knee [12]. For this study, given that a differ-
ce of 1.0°C or more between knees is considered by
some as clinically meaningful [13], we considered that
limits of agreement of less than ±1°C would suggest
that thermal imaging could be replaced by a digital
thermometer for detecting meaningful differences in
skin temperature in clinical practice.

2. Methods

Data were collected in two phases. The first phase
was as part of a public engagement event at the Lan-
cashire Science Festival where school children were
invited to learn about science. We had a stand demonstrating the use of thermal imaging in musculoskeletal conditions. Children who came to interact with our stand were asked if they would like to take part in a ‘real’ experiment, and where participants were under 16 years of age verbal assent was additionally taken from their accompanying guardian. If they agreed a thermal image and digital temperature measurement were recorded and they were shown their own knee thermal image. The second phase of data collection took place as part of a PhD study where staff and students at the university were recruited via electronic advert and posters displayed around the campus. After written consent was obtained, participants underwent a number of tests of the knee including those reported here. All participants enrolled in both phase 1 and phase 2 were free from lower back or lower limb problems and had not had any previous lower limb surgery. Prior to data collection in either phase, appropriate institutional ethical approval by the University of Central Lancashire was obtained and studies were performed in accordance with the Declaration of Helsinki [14].

2.1. Materials

Knee skin temperature was assessed using a FLIR A325 thermal imaging camera (TI) (ThermoVision A325 Flir Systems, Danderyd, Sweden) and an IR 21 B digital thermometer (RDSM nv, Hasselt, Belgium). The thermal imaging camera used in this study has a thermal sensitivity of c.0.07 at +30 °C [11]. The digital thermometer met the accuracy requirement in ASTM E1965-98 [15] and the EC directive 93/42/EEC. The type of temperature assessment (TI or DT) was standardized such that thermal imaging was always carried out first followed by the digital thermometer. This was to prevent the influence of DT probe contact on knee skin temperature. The digital thermometer was designed for use in foot temperature measurement. The temperature sensing element does not touch the skin however the rim of the thermometer is in contact with the skin. Participants were given 15 minutes to acclimatise to the room temperature, allowing their skin temperature to stabilise [16]. Both tests were performed on each knee. In addition both tests were carried out by the same researcher who was a qualified physiotherapist trained appropriately in using the 2 tools.

2.2. Thermal imaging

Participants were seated with hips flexed to 90°. The thermal imaging camera was mounted on a tripod, the height of which was determined by the camera angle, standardized to 90°. Thermally inert markers were placed at specific anatomic locations, defining an area over the anterior knee referred to as the region of interest (ROI) [17]. The four markers were placed on the widest medial and lateral points; longest upper and lower border of patella which were then identified on the computer screen and later manually joined together using the polysoft tool (Thermacam Researcher 2.8 software, Flir systems, Sweden) to define the region of interest. Mean surface skin temperature of the ROI was calculated for each image.

2.3. Digital thermometer

Knee skin surface temperature was recorded using a digital thermometer at the centre of patella. An average of 3 readings was taken at the centre of patella on both knees.

2.4. Statistical methods

All data from the thermal imaging and digital thermometry of each knee was entered into SPSS 17.0.1 for Windows (SPSS Inc., Chicago, IL) and Microsoft Office Excel 2007 (Microsoft Corporation, Redmond, WA) for analyses. Paired t tests were conducted (a) between the temperature at right and left knee using digital thermometer (b) between the temperature at right and left knee using thermal imaging (c) and on side to side temperature differences using thermal imaging and digital thermometer to determine if there was a significant difference. Pearson product-moment correlation coefficients were used to assess the strength of the relationships between the TI and DT. The alpha level for statistical significance was set at P<0.05. Bland and Altman plots with 95% limits of agreement [18] were used to assess the agreement between the skin temperatures measured using thermal imaging and digital thermometer.

3. Results

71 healthy participants in total (34 females, 37 males; mean age 19.17 years ± SD 10.04) participated...
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in this study. Mean room temperature was 22.7°C (SD 0.5°C, range 22.0°C – 23.6°C). The mean knee skin temperature using thermal imaging was 31.48°C (SD 1.80°C) for the right knee and 31.48°C (SD 1.83°C) for the left knee. The mean knee skin temperature using the digital thermometer was 30.22°C (SD 1.89°C) for the right knee and 30.15°C (SD 1.88°C) for the left knee. The mean skin temperature difference between right and left knee using thermal imaging was 0.06°C (SD 0.69°C). A paired t test showed no significant difference between the skin temperature of the right and left knee using thermal imaging ($t = 0.02, df = 69, P = 0.49$) or with the digital thermometer ($t = 0.74, df = 69, P = 0.23$). A paired t test conducted on differences between right and left knee temperature measurements using thermal imaging and the digital thermometer showed no significant difference ($t = 1.41, df = 69, P = 0.08$). There was a significant correlation between side to side temperature difference measured using the 2 instruments ($R = 0.86, P = 0.09$).

A box-and-whisker plot showing the distribution of temperature at right and left knee using TI and DT is shown in Fig. 1. The plot shows higher medians for thermal imaging readings at right and left knee demonstrating higher temperature readings as compared to the digital thermometer readings at both knees.

To determine the interchangeability of the 2 temperature measuring instruments, Bland and Altman (BA) limits of agreement methodology were applied to data. The Bland and Altman results are plotted in Figs. 2 and 3. The mean bias was 0.06. The 95% limits of agreement were –0.64 to 0.75. The 95% confidence interval for the lower limits of agreement was –0.78 to –0.49 and for the upper limits of agreement was 0.61 to 0.89.

Fig. 1. Box and whisker plot showing the distribution of temperature in Celcius at right and left knee using Digital Thermometer (DT) and Thermal Imaging (TI).

Fig. 2. Comparison of differences in temperature differences in Celcius between right and left knee using Thermal Imaging (reference standard) and Digital Thermometer. X Axis: Mean of temperature difference between right and left knee measured using Thermal Imaging and Digital Thermometer Difference. Y Axis: Difference of temperature difference between right and left knee measured using Thermal Imaging and Digital Thermometer.
4. Discussion

The aim of this study was to determine if agreement exists between the two temperature measuring instruments to determine any temperature difference between left and right knee. The mean difference of side-to-side temperature difference using TI and DT was 0.06. The mean difference between right and left knee using digital thermometer (0.063) was higher than thermal imaging (0.007). Despite this, the limits of agreement (-0.64 and 0.75) are small enough (i.e. within ±0.1 based on the criterion for a clinically important difference for this study), for us to be confident that the digital thermometer can be used in place of thermal imaging to determine knee temperature differences for clinical purposes.

All skin temperature measurements recorded in this study fall within the range of knee skin temperature reported in a recently published large scale review of knee temperature measurements [19]. Interestingly in contrast to this review we consistently found slightly lower digital thermometer readings compared to thermal imaging. This may be due to the nature of our experiment using the same individuals where it is possible that participants had not acclimatised fully to the ambient temperature and so their knees cooled slightly between the measurements even though both measurements were performed within a short time frame (<1 minute) of each other. The results from this study show that the digital thermometer consistently measures skin temperature at the anterior knee lower than thermal imaging by an average of 1.3°C. There was a significant difference between the absolute temperatures of thermal imaging and digital thermometer and so the absolute temperature readings between the tools are not interchangeable.

It is important to view these results in light of potential clinical applications of objective temperature measurements within musculoskeletal physiotherapy; temperature difference comparisons between different anatomical sites or on the same site over a period of time could be important indicators for initial diagnosis and in the evaluation of treatment outcomes in clinical and research settings.

4.1. Diagnostic aid

It is key to interpreting potentially clinically important data to know that the skin temperature of a healthy knee is normally lower than that of contiguous skin. Menard and Paquette (1980) demonstrated that skin temperature at the knee was 1.23°C less than the temperature at the tibia in normal participants [20]. If the difference is exaggerated, so that the knee becomes excessively cold, this may be an indication that there is a sympathetic component to the patient’s condition. Sympathetically maintained pain is characterised by low temperature over the knee with a hot patella [19]. Patellar skin temperature has been found to demonstrate an interesting interrelationship with structural knee OA damage as measured by the Kellgren-Lawrence scale, where higher temperatures were found in knees with greater structural damage [21]. In PFP a clinical model summarising how temperature may be altered according to different pathological processes has previously been published [22].

4.2. Outcome monitoring

Regular monitoring of temperature and identifying temperature differences overtime could help in moni-
toring appropriate treatment strategies related to either
the ischaemic causes of pain or inflammatory causes
of pain. In patients with chronic knee pain with cold
knees, a return to normal limb temperature symmetry
was demonstrated in patients whose pain completely
or almost resolved [6], unfortunately no details of the
successful therapeutic procedures that restored tem-
perature and function to normal are given. It has
been reported that patients with patellofemoral pain
with cold knees had worse outcomes and showed less
improvement in response to an exercise based approach
to physiotherapy than PFP patients with normal tem-
perature knees [7]. Therefore using skin temperature
measurement may assist musculoskeletal clinicians in
formulating alternative treatment strategies [23]. For
example in an ABA design single case experiment
using acupuncture in a PFP patient with an exces-
sively cold knee it was demonstrated that during the
course of treatment as skin temperature increased, pain
decreased and function improved [24].

A limitation of this study is the generalizability of
the results to other body parts as the data were collected
only at the knee. Also data in this study was collected
in healthy participants and the experiment should
be repeated in disease groups as these display differing
thermal profiles [18].

5. Conclusion

This study concludes that an inexpensive handheld
digital thermometer shows good agreement with a
thermal imaging camera in measuring skin to skin tem-
perature difference. The absolute temperature readings
measured by the two tools are not interchangeable.
Clinically a digital thermometer has the potential to
play an important role in the localized assessment of
skin temperature and can offer an inexpensive substi-
tute to thermal imaging. Due to the massive difference
in the cost between the 2 instruments it is worth con-
sidering the adoption of digital thermometry in routine
musculoskeletal physiotherapy practice.

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Conflict of interest

None of the authors have any professional or finan-
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