ISSN-1560-604X
Thermology international

Thermology International

Volume 31 (2021)
Number 2 (May)

What is the difference between resolution, accuracy, and uncertainty?

Using iOS Smartphone-attached infrared camera for detecting regional skin temperature symmetry

A Systematic Study to Evaluate the Benefit of using a Visualization Tool for Breast Thermography

This journal is indexed in
EMBASE/Scopus

Published by the
European Association of Thermology

THERMOLOGY INTERNATIONAL

Volume 31(2021) **Number 1 (May)**

Published by the
European Association of Thermology

Indexed in
Embase/Scopus

Organ of the American Academy of Thermology

Organ of the Brazilian Society of Thermology

Organ of the European Association of Thermology

Organ of the Polish Society of Thermology

Contents

What is the difference between resolution, accuracy, and uncertainty?

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Background

Temperature measurement devices such as thermal imagers routinely have claimed temperature resolutions of 0.1 °C, in fact many high-end devices claim a temperature resolution of 0.02 °C. Yet in the same data sheet, device accuracy is often ten times or even a hundred times higher, often at 2 °C. This apparent discrepancy has been a source of confusion to users of such devices so here we discuss the difference between resolution, accuracy and uncertainty. Note that although the discussion is given in the context of thermal imagers the arguments can be applied quite generally to a wide range of any measurement devices.

Definition of terms

To understand the difference between these three concepts it is important to understand what these terms mean. They are defined in the International Vocabulary of Metrology (VIM3) which can be found at the weblink given in [1].

To understand these formal definitions two background terms need to be understood first, these are:

- **Quantity:** property of a phenomenon, body, or substance, where the property has a magnitude that can be expressed as a number and a reference.

So *temperature* is a quantity that can be expressed in terms of a number "X" and a reference (e.g. a unit) "°C".

- **Measurand**: quantity intended to be measured.

When using a thermal imager, you are intending to measure *temperature of a person's skin in a defined body region* (as an example) so that is the measurand. The result we obtain from the measurement process is called the quantity value.

So, we now come to the terms that are the subject of this note, the VIM defines these three terms as follows:

- **Resolution:** smallest change in a quantity being measured that causes a perceptible change in the corresponding indication.
- **Measurement accuracy, accuracy of measurement, accuracy** (for conciseness referred to as "accuracy" in the subsequent text): Closeness of agreement between a measured quantity value and a true quantity value of a measurand.
- **Measurement uncertainty, uncertainty of measurement, uncertainty:** (for conciseness referred to as "uncertainty" or "measurement uncertainty" in the subsequent text) Non-negative parameter characterizing the dispersion of the quantity values being attributed to a measurand, based on the information used.

In context of a thermal imager these can be recast to read:

- **Resolution**: smallest change in a temperature being measured that causes a perceptible change in the corresponding indication.
- **Measurement accuracy, accuracy of measurement, accuracy:** Closeness of agreement between a measured *temperature* value and a true *temperature* value of the *temperature* you were intending to measure.
- **Measurement uncertainty, uncertainty of measurement, uncertainty:** Non-negative parameter characterizing the dispersion of the *temperature* values being attributed to a *temperature,* based on the information used.

The implications of the definitions

Here we discuss the implications of the definitions of resolution, accuracy, and uncertainty.

Resolution: This is generally much smaller than the measurement uncertainty and makes up only one component of the overall uncertainty of measurement. So for example if the resolution of your thermal imager is 0.1 °C and the temperature of the object you were measuring was 40.0 °C, the object would need to increase in temperature only by more than 0.05 °C for the reading of the thermal imager to display to the next resolvable value i.e. 40.1 °C.

Accuracy: Determining how accurate your thermal imager is, requires calibration against known traceable temperature reference standards [2]. Such a measurement tells you how far the temperature your thermal imager indicates from the true temperature value as given by the traceable calibration standard. For example, you might view a traceable blackbody reference source at 40.0 °C and your thermal imager may read 36.9 °C, which means your thermal imager is inaccurate at 40.0 °C by -3.1 °C. You may then correct for this lack of accuracy when you use the device. (Note this correction is likely to be temperature dependent).

Calibration against traceable temperature reference standards is the only way to determine temperature measurement accuracy; it cannot be determined by repeated measurement - this only tells us about the repeatability of the measurement device.

Uncertainty: The uncertainty of measurement requires an evaluation of all the possible components of uncertainty that contribute to a particular measurement situation. The simplest measurement situation is when the device is calibrated. In essence a calibration tells you how accurate the thermal imager is in an ideal (laboratory) setting. The calibration value must be applied to the output of the device at the temperature being measured. This has an uncertainty associated with it; **"the uncertainty of calibration"**. Both the calibration value and the uncertainty of calibration are given on the calibration certificate of the device.

When using a thermal imager to measure temperature in a real-world measurement setting that is not under full control (as compared to a calibration in a laboratory for instance) a full uncertainty budget would need to be developed. This would include the uncertainty of calibration but would also include components arising from the measurement setting e.g. temperature resolution of the thermal imager, standard deviation of the measurement, components for unknown surface emissivity, reflected thermal radiation, etc. All these components recognise that one can't properly know the accuracy of the device once it is taken out of the calibration laboratory and exposure to uncontrolled, real-world conditions. In such a real-world setting the value of measurement uncertainty could be large, generally at least an order of magnitude larger than the resolution and certainty significantly more than the calibration uncertainty.

It is beyond the scope of this tutorial paper to describe the preparation of uncertainty budgets. The interested reader should consult the internationally accepted "Evaluation of measurement data - Guide to the expression of uncertainty in measurement" (or GUM for short) which can be downloaded for free from the weblink in [3]. In that document the process of how to construct uncertainty budgets is described in detail.

Summary

In this paper we have defined the terms resolution, accuracy, and uncertainty according to their internationally agreed definitions. We have then described the implications of those definitions in the context of using thermal imagers for temperature measurement. In general, thermal imager resolution is at least an order of magnitude smaller than the uncertainty of measurement whilst the accuracy of a thermal imager (or any other device) can only be determined through calibrating the device against known traceable (temperature) references. In general, when considering whether a measurement is fit for purpose, it is the uncertainty that is important, not the device resolution.

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(Received 15.04.2021, accepted after external review 26.04.2021)

Using iOS Smartphone-attached infrared camera for detecting regional skin temperature symmetry

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SUMMARY

BACKGROUND: Regardless of the widespread use of low-resolution smartphone-attached Infra-Red cameras, even in clinical settings, to date, there is little evidence of their reliability. Hence, the purpose of this study was to test the agreement between a FLIR ONE Pro camera and a high-resolution device in detecting thermal symmetry of regional skin.

MATERIALS AND METHODS: This is a test-retest reliability study with 25 healthy individuals. They were mostly female (68%), of 35.4 (9.9) years of age. Thermal images were simultaneously captured by FLIR T650sc camera and FLIR ONE Pro for iOS, a smartphone-compatible infrared (IR) imaging device. The subjects were placed at 4 meters distance to the FLIR T650sc camera and 1,5 meters away from the FLIR ONE Pro for iOS. Thermographic examinations were conducted, one week apart, each time in the morning. Thermal image recording and subjects' preparation were standardized according to specialized literature, except for acclimation time, room temperature, and humidity. Images were processed by the software FLIR Tools. The cutaneous temperature of lower limbs was assessed in ten different regions of interest: thigh, leg, knee in the anterior view and thigh and leg in the posterior view. Kappa statistics was used to test the agreement of detecting skin temperature symmetry by FLIR ONE pro for iOS compared to FLIR T650sc, and repeatability was assessed by test-retest analysis on two different days. As a secondary analysis, Lin's Concordance Correlation Coefficient (CCC, or ρc), followed by Bland & Altman Limits of Agreement (LOA), were calculated to test concordance of absolute temperatures between both cameras.

RESULTS: Both cameras (FLIR T650sc and FLIR ONE Pro) were able to identify the presence of symmetry in both days of evaluations. Kappa statistics evidenced an agreement of 88% and 90% for the first (test) and the second (re-test) day of temperature collection, respectively ($p< 0.0001$). Lin's CCC test did not detect satisfactory agreement between both cameras regarding absolute temperature values, regardless of the day. Rho was 0.46 and 0.31 ($p<0.001$) in the first and second days of data collection, respectively.

CONCLUSIONS: The FLIR ONE Pro for iOS appears reliable to detect qualitative symmetry of skin temperature. However, the absolute temperature values provided by this device should be considered with caution.

KEYWORDS: infrared thermography, mobile thermography, FLIR ONE, reliability, reproducibility

DIE VERWENDUNG EINER AN EIN IOS SMARTPHONE-ANGESCHLOSSENEN INFRAROTKAMERA ZUR ERKENNUNG DER SYMMETRIE REGIONALER HAUTTEMPERATUREN

HINTERGRUND: Ungeachtet des auch im klinischen Umfeld weitverbreiteten Einsatzes von an ein Smartphone angesetzten Infrarot-Kameras mit niedriger Auflösung, gibt es bisher wenig Hinweise auf ihre Zuverlässigkeit. Daher bestand der Zweck dieser Studie darin, die Übereinstimmung zwischen einer FLIR ONE Pro-Kamera und einem hochauflösenden Gerät bei der Erkennung der thermischen Symmetrie regionaler Hauttemperaturen zu testen.

MATERIALIEN UND METHODS: Dies ist eine Test-Retest-Zuverlässigkeitsstudie mit 25 gesunden Personen, die überwiegend weiblich (68%) und im Alter von 35,4 (±9,9) Jahren waren. Mit einer FLIR T650sc Kamera und eine FLIR ONE Pro für iOS, einer Smartphone-kompatibles Infrarot (IR) Kamera, wurden gleichzeitig Wärmebilder aufgenommen. Die Probanden wurden in 4 Metern Entfernung zur FLIR T650sc Kamera und 1,5 Meter Abstand zur FLIR ONE Pro für iOS platziert. Thermografische Untersuchungen wurden im Abstand einer Woche, jeweils am Morgen durchgeführt. Die Aufzeichnung der Wärmebilder und die Vorbereitung der Probanden wurden nach Fachliteratur standardisiert, mit Ausnahme von Akklimatisierungszeit, Raumtemperatur und Luftfeuchtigkeit. Die Wärmebilder wurden mit der Software FLIR Tools verarbeitet. Die Hauttemperatur an den unteren Gliedmaßen wurde in zehn verschiedenen Messarealen bewertet: Oberschenkel, und Unterschenkel in der Ansicht von vorne und hinten, das Knie in der Ansicht von vorne. Kappa-Statistiken wurden verwendet, um die Übereinstimmung des Nachweises der Hauttemperatur-Symmetrie durch FLIR ONE pro für iOS im Vergleich zu FLIR T650sc zu testen, und die Wiederholbarkeit wurde durch Test-Retest-Analyse an zwei verschiedenen Tagen bewertet. Als sekundäre Analyse wurden Lin's Konkordanz-Korrelationskoeffizient (CCC, oder ρc), gefolgt von Bland & Altman Limits of Agreement (LOA), berechnet, um die Übereinstimmung der absoluten Temperaturen zwischen beiden Kameras zu testen.

ERGEBNISSE: Beide Kameras (FLIR T650sc und FLIR ONE Pro) konnten das Vorhandensein von qualitativer Symmetrie an beiden Untersuchungstagen nachweisen. Die Kappa-Statistiken zeigten eine Übereinstimmung von 88 % bzw. am ersten (Test) bzw. von 90 % am zweiten (Wiederholungs-Test) Tag der Temperaturerhebung ($p< 0,0001$). Lin's CCC-Test fand unabhängig vom Tag keine ausreichende Übereinstimmung der absoluten Temperaturwerte zwischen beiden Kameras. Rho lag im ersten und zweiten Tag der Datenerhebung bei 0,46 bzw. 0,31 ($p<0,001$).

SCHLUSSFOLGERUNGEN: Die FLIR ONE Pro für iOS erscheint zuverlässig, um die Qualität einer Symmetrie der Hauttemperatur zu erkennen. Die von diesem Gerät zur Verfügung gestellten absoluten Temperaturwerte, sollten jedoch mit Vorsicht betrachtet werden.

SCHLÜSSELWÖRTER: Infrarotthermografie, Mobiltelefon gestützte Thermografie, FLIR ONE, Reliabilität Reproduzierbarkeit

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Introduction

The application of thermography in medicine has become frequent and useful. It is known that thermography is non-evasive, safe, and harmless if appropriately used for health applications, either as a diagnostic adjunct or as outcomes from clinical trials [1].

Thermography may recognize abnormal cutaneous temperature patterns with infrared (IR) cameras [2]; moreover, recent studies evidenced that IR imaging may be obtained with low-cost devices, such as FLIR ONE Pro, a smartphone attached IR camera. Several studies report its use in different clinical applications, as diagnosis aid to ophthalmologic diseases [3], stress [4], arterial mapping [5], diabetic foot ulcer [6], lower extremity ischemia [7,8], burn wound assessment [9,10], and hand and upper extremity surgeries [11]. There are even reports of such devices achieving high concordance with gold standard evaluation methods [9,12].

Recent studies compared smartphone-attached IR devices with high-resolution devices. One specific study [11] compared the FLIR ONE Pro with an IR spot measurement sensor (Exergen DermaTemp 01001RS) by analyzing the hand temperature of healthy individuals. The authors found that FLIR ONE Pro can be helpful for immediate evaluation allowing identification of injuries, nonetheless the authors state that these devices are not interchangeable for absolute temperature [11]. Recently, our group published a study [13] with a similar methodology for testing the agreement between a FLIR ONE Pro and a high-resolution camera. The data in this study showed that even though both cameras managed to identify thermal symmetry, little to no agreement was established between FLIR ONE Pro and FLIR T650sc if they are tested under the same methodological rigor. For this reason, in this study [13], we suggested that reliability studies for such low-cost devices should consider the proper distance from the sensor to the subject. It was also stated by Oliver et al. [14], who studied the reliability of FLIR ONE and FLIR E8 devices by analyisng Achilles tendon temperature and reported the suitable distance should be with 0.5m to 1.0m from the low- cost device to the subject.

Even though high-resolution IR devices were considered reliable in different studies [15-17], apart from those using a FLIR ONE [18-20], the reliability of thermo- graphy techniques is still an important matter [21]. Nonetheless, as the use of low-cost IR devices is relatively recent, concordance or reliability studies are still desirable [13]. Moreover, the application of thermography in clinical settings may not meet the standardization proposed by the literature [1, 2,17], especially regarding room temperature and acclimation time, variables that require proper consideration. This issue justifies the need to understand the repro- ducibility of findings obtained by low-cost cameras, which are commonly used in settings with uncontrolled" environmental conditions, as well as the need to monitor the technological advance of such devices [22]. Therefore, the primary objective of this study was to test the agreement between a FLIR ONE Pro camera and a high-resolution device in detecting the quality of thermal symmetry of regional skin. A secondary objective was to investigate the agreement of absolute temperatures recorded by either devices.

Method

This cross-sectional observational study was performed in line with the principles of the Declaration of Helsinki. The study was approved by the Ethics Committee of the University of São Paulo under protocol number 837.421, and all the participants were included after consenting to participate in. Healthy adult male and female staff of a rehabilitation facility were invited to participate. The individuals must not had fever at the moment of the evaluation, nor using anti-inflammatory medication.

Subjects were instructed to stand upright on a marker on the floor, 0.4m away from the wall and 4m away from the camera in the evaluation with FLIR T650sc camera. When imaging was performed with the smartphone attached FLIR ONE Pro (for iOS), the distance between participant and camera was 1.5m and 0.4m, respectively, between participant and wall.

Volunteers remained standing in the same position during image capture, and the camera was perpendicularly positioned in relation to the participant. The subjects were instructed not to perform movements with arms or legs or scratch their skin before and during the procedure. Before the exam (about 2 hours), the participants did not take hot baths or showers, use ointments or powder, or perform physical exercises. They were instructed not to take in stimulants, beverages containing alcohol or caffeine, not to use nasal decongestants, and not to smoke [13, 16, 23, 24]. Once all requirements were met, volunteers were not asked to keep their lower limbs areas exposed to room temperature for 15 minutes to achieve thermal equilibrium with the temperature of the examination room, i.e., there was no acclimation. Evaluations were always carried out in the morning.

A FLIR T650sc infrared device is equipped with a focal plane array (FPA) of 640x480 elements and captures thermal images at 30Hz. The sensor can capture infrared radiation within a spectral band of 7,4 - 14 μm, has a NETD (Noise Equivalent Temperature Difference) <20mK , and am accuracy of 1% within a temperature range from -40°C to 70°C. The images were collected considering the skin emissivity to be 0.98. The images were simultaneously collected with the FLIR ONE Pro for iOS device, equipped with a FPA of 160x120 elements, sensor pixel size of 12μm, a spectral bandwidth of 8 to 14μm, an accuracy of 3°C or ±5%, a thermal sensitivity of 150 mK and image recording frequency of 8.7Hz. The smartphone-based IR camera was attached to an iPhone 7 A1778 (iPhone, Apple Inc. USA).

Both devices were switched on fifteen minutes before data collection to allow image and temperature stabilization. Then, two evaluators simultaneously captured images to minimize bias of time gap between pairs of images of the

Figure 1
Regions of Interest (ROIs) of lower limbs. On the left, anterior view; on the right, posterior view captured by FLIR T650sc

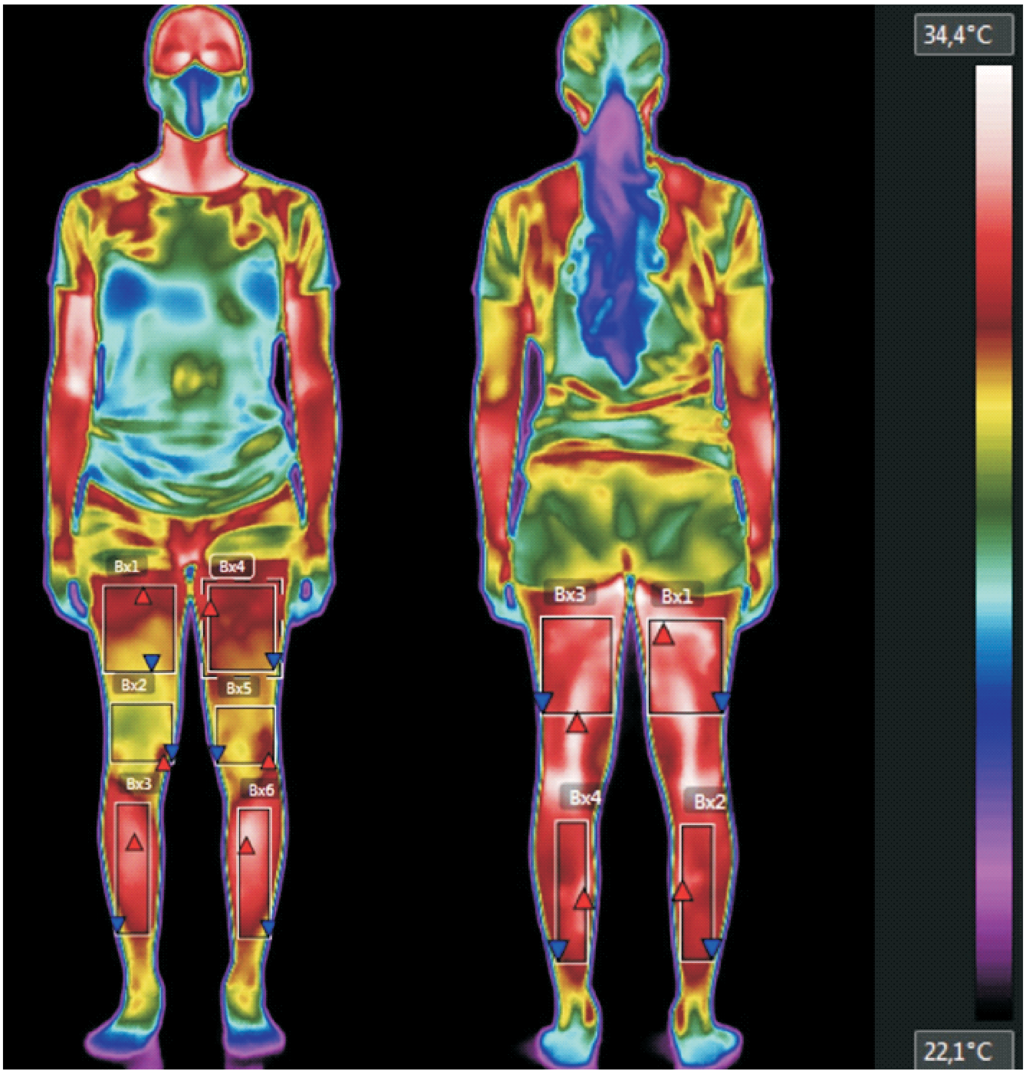
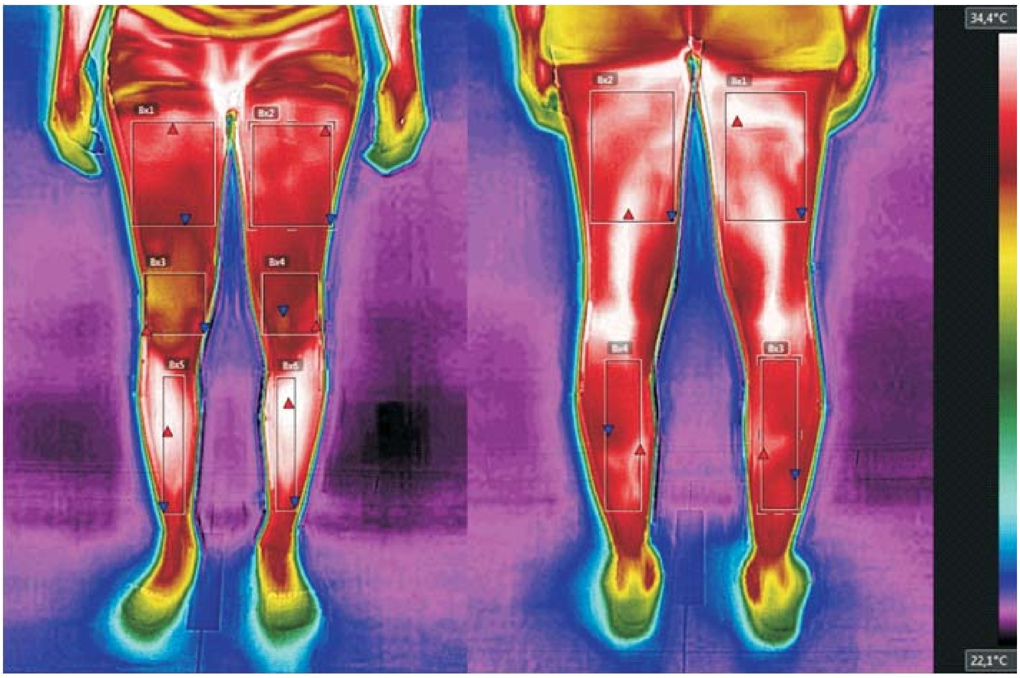


Figure 2
Regions of Interest (ROIs) of lower limbs. On the left, anterior view; on the right, posterior view captured by FLIR ONE pro.



same Region of Interest (ROI). The IR images were captured in both anterior and posterior view of the volunteers. Thermographic evaluations were carried out on two different days, separated by one week, and always in the morning. The images were analysed by the software FLIR Tools. The average temperature was evaluated for each ROI. ROIs were rectangles determined by anatomical references previously described in the literature [13,16,24]. The following anatomical landmarks were used for ROI definition: 1-thigh: 5 cm above the superior border of the patella and the inguinal line, 2- leg: 5 cm below the inferior border of the patella, and 10 cm above the malleolus and the entire anterior region of the 3-knee (about 2 centimetres above and below the upper and lower edges of the patella respectively) as can be seen in figures 1 (for FLIR T650sc) and 2 (for FLIR ONE Pro).

Data analysis

Data were analyzed with Stata14® for Windows. Mean, standard deviation (SD), and frequency were used to describe demographic and clinical data of participants and environmental variables. The mean temperature of each ROI on the right side of the body was subtracted from the values obtained on the left side. The resulting difference was transformed into 2 classes, where absolute values equal or less than 0.3°C were considered as symmetric or, if otherwise, non-symmetric. The threshold for symmetry was based on the observation of small temperature differences between both sides of the body [16].

Thus, dichotomic data were generated for both variables, the device (FLIR ONE or FLIR T650sc) and symmetry (presence or absence). The analysis of the primary objective, the agreement of the presence of body symmetry as detected by either type camera was based on Kappa statistics [25] at the first (test) and second day (retest) of temperature collection. A 95% Confidence Interval (95%CI) was generated to the obtained Kappa agreement by bootstrapping the analysis with 1000 repetitions.

Reproducibility of FLIR ONE pro was considered if the lower bound of the 95%CI agreement with FLIR T650sc was above the expected agreement for the test and the re-test analysis. As described by Cohen [26], a certain amount of agreement is expected by chance; in our results, the achieved and the expected agreements are described.

The agreement between both devices was assessed by pair-wise comparison of the mean temperatures of each ROI. Data collected by FLIR ONE and FLIR T650sc was tested with Lin's Concordance Correlation Coefficient (CCC,or ρc), and concordance would be considered satisfactory if $\rho c > 0.90$.The Bland & Altman Limits of Agreement (LOA) would also be calculated if $\rho c > 0.90$ [27,28].

Results

Twenty-five subjects signed the Informed Consent Form and were included in the study. They were mostly female (68%), with 35.4 (9.9) years of age and body mass index (BMI) of 25.06kg/m² (4.68 kg/m²). Among the participants, four subjects had either musculoskeletal or peripheral nervous system diseases. Regarding environmental variables, in the first and second days of data collection, the room temperatures were 22.4°C (±0.8°C) and 21.7°C (±0.5°C), respectively, and room humidity was 73.6% (±2.3%) and 70.34% (±2.7%) respectively.

The IR camera FLIR T650sc was able to identify 214 (85%) occurrences of temperature symmetry, whereas FLIR ONE pro for iOS identified 212 (84.4%) in the first day (test) of data collection. As for the second day of data collection, FLIR T650sc identified 202 (84%) symmetric areas and FLIR ONE pro for iOS 194 (80.8%). Kappa statistics evidenced an agreement of 88% and 90% for the first (test) and the second (re-test) days of temperature collection, respectively, which was considered above the expected values and statistically significant, as $p < 0.001$ regardless of the day. Table 1 presents the results of Kappa statistics for the test and re-test assessments of both cameras.

The agreement analysis by Lin's CCC evidenced that, regardless of the day, there was no satisfactory concordance between the temperature means of each ROI collected by both devices, as rho was 0.43 (p<0.001) (figure 3). As no

Figure 3-
Lin's concordance correlation coefficient between FLIR ONE PRO and FLIR T650sc

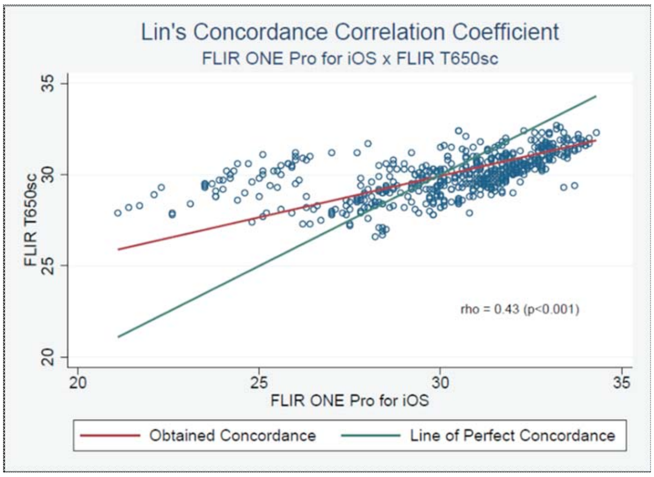


Table 1 Kappa statistics for test and re-test of symmetry for both devices

	Rate of Symmetry°		Obtained Agreement between FLIR T650sc and FLIR ONE	Expected Agreementbetween FLIRT650sc and FLIR ONE	Kappa	p-value
	FLIR T650sc	FLIR ONE				
Test	85%	84.4%	88% (82.5% - 93.5%)†	74.78%	0.52	<0.0001
Re-test	84%	80.8%	90% (85.0% - 95.0%)†	71.07%	0.65	<0.0001

° Rate of symmetry presented as a percentage; † 95%CI bootstrapped with 1000 repetitions satisfactory concordance was found, the test of Limits of Agreement was not conducted.

Discussion

In the introduction, we emphasized that this study was conducted because increasing the understanding of low-cost thermography devices is essential and desirable[22]. Therefore, this research's objective was to verify the ability of FLIR ONE Pro to reproduce regional skin temperature symmetry as dected by the FLIR T650sc. We also assessed the concordance of raw temperature readings of FLIR ONE compared to a high-resolution InfraRed device in an uncontrolled environment.

Our data showed that absolute temperature readings registered by the FLIR ONE Pro did not have a satisfactory level of agreement when compared to FLIR T650sc temperatures in the CCC analysis. Nonetheless, the Kappa analysis evidenced a significant result, which is that the symmetry of regional skin temperature can be detected by both of the studied cameras and that the FLIR ONE Pro can reproduce the thermal symmetry findings obtained with a high resolutions device. Thermal symmetry is an important criterium for thermographic evaluation, since disturbance of symmetry may be a sign of pathology.

In our study, even with the inclusion of four subjects of both sexes with physical disorders, without environmental control over temperature and humidity, both devices manage to detect body symmetry during both days of data collection. Also, both devices reached higher agreement than the expected values indicating reliability and interchangeability of thermal symmetry classification between devices.

Some studies reported that temperature differences more significant than 0.5°C between both sides of the body may be considered lack of symmetry, indicating functional changes [24]. Our study chose 0.3°C as the threshold, an even more conservative when compared to a study that reported a suitable difference of 0.4°C between both sides of the body of healthy individuals [29].

Therefore, our study assures the reproducibility of temperature differences obtained with the FLIR ONE Pro , which is valuable information for clinicians and therapists who plan to use such devices to evaluate their patients, given its low cost and potential for clinical use and. Regarding the uncontrolled environmental conditions, i.e., room temperature and humidity and time for acclimation of participants, important variables for thermographic evaluations [17], we chose not to control such factors since we aimed to simulate possible natural conditions of a clinical setting or even home use, which may not manage to control such environmental variables properly..

Even though a previous study conducted by our group [13] reported body symmetry of healthy males after being analyzed by both devices and, as found in the present study, there was no agreement of absolute temperature values regardless of the day of evaluation, we emphasize that, in that study, the distance of both cameras to the subjects were four meters [13], regardless of the device. For this reason, the results of the present study evidenced that absolute values obtained by low-cost devices should be interpreted with discretion when assessing body temperature [30]. The shorter distance set for FLIR ONE Pro for iOS, as suggested by a previous study [13] and indicated by other authors [14], was also chosen to assess the lower limbs in a single image.

The lack of manipulation of variables such as room temperature and humidity and the climatization of the participants may have hindered the results. This was done by design of our methodology to simulate a natural condition of use. Also, the proper calibration of both devices with tools as blackbody could have yielded different results regarding the agreement of absolute temperature values. However, this was a secondary objective once this issue had been addressed by a previous study [13]. We also understand that the variation in environmental conditions might been a consequence of the study design. For this reason, future studies should consider to include a mechanism for controlling ambient conditions such as temperature and humidity.

We suggest both devices may be used in future studies for evaluating the thermal symmetry of patients that demand continuous monitoring, such as those with rheumatic diseases. Nonetheless, we recommend that the new low-cost infra-red devices are further tested to explore their potential when used in clinical settings in a scientific and reliable way. In particular, the value of qualitative and quantified assessment of thermal symmetry as an study outcome warrants further research.

Conclusion

FLIR ONE Pro for iOS has reliability and reproducibility for the qualitative assessment of thermal symmetry in individuals of both sexes, even in an uncontrolled environment. However, our study evidenced that there is no agreement of absolute temperature values of FLIR ONE Pro when compared to FLIR T650sc.

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(Received 01.02.2021, revision accepted 05.05.2021)

A Systematic Study to Evaluate the Benefit of using a Visualization Tool for Breast Thermography

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SUMMARY

Breast thermography is a non-contact, non-invasive, and irradiation free imaging modality that is found to be applicable for detection of breast cancers. One of the main challenges with breast thermography is the subjectivity and the accuracy of visual interpretation of thermal images. In this paper, we present a systematic retrospective study that measures the performance of manual interpretation of breast thermal images and also evaluates the benefit of using a software visualization tool to aid this interpretation. The thermal analysis and visualization tool considered for this study was SMILE-100, which automatically transforms the temperature values into contrast-enhanced colour images and annotates elevated temperature regions to help thermologists in detection of signs of malignancy. The study was conducted in 258 symptomatic women and the reference used was the standard recommendation for diagnosing breast cancer involving a combination of mammography, ultrasound, and biopsy. The sensitivity and specificity of the thermologist's assessment without tool support was found to be 60.3% (95%CI: 48.2% to 72.4%) and 81.5% (95%CI: 76.1% to 87.0%), respectively. When the same thermologist was aided with SMILE-100 tool after a washout period of two months, a sensitivity and specificity of 81.0% (95% CI: 71.2% to 90.6%) and 75.9% (95% CI: 69.9% to 81.9%), respectively, was observed. Furthermore, the sensitivity and specificity of tool generated Hotspot annotations was found to be 85.7% (95%CI: 77.1% to 94.4%) and 70.3% (95%CI: 63.8% to 76.7%), respectively. These results show that SMILE-100 can be a good tool to improve the interpretation accuracy of thermal images and reduce the subjectivity in interpretation.

KEYWORDS: Visualization tool, computer aided thermography, annotated thermal images, quantitative thermal parameters.

EINE SYSTEMATISCHE STUDIE ZUM NUTZEN EINES VISUALISIERUNGSTOOLS FÜR DIE BEWERTUNG DER BRUSTTHERMOGRAPHIE

Die Brustthermographie ist eine berührungslose, nicht-invasive und bestrahlungsfreie bildgebende Modalität, die für den Nachweis von Brustkrebs anwendbar ist. Eine der größten Herausforderungen bei der Brustthermographie ist die Subjektivität und Genauigkeit der visuellen Interpretation von Wärmebildern. In diesem Beitrag stellen wir eine systematische retrospektive Studie vor, die die Leistung der manuellen Interpretation von Brustwärmebildern misst und auch den Nutzen eines Software-Visualisierungstools zur Unterstützung dieser Interpretation bewertet. Das für diese Studie in Betracht gezogene thermische Analyse- und Visualisierungstool heißt SMILE-100, das die Temperaturwerte automatisch in kontrastverstärkte Farbbilder umwandelt und erhöhte Temperaturbereiche kennzeichnet, um den Thermologen bei der Erkennung von Malignitätszeichen zu helfen. Die Studie wurde in 258 symptomatische Frauen durchgeführt und als Referenz wurde die Standard-Empfehlung für die Diagnose von Brustkrebs mit einer Kombination von Mammographie, Ultraschall, und Biopsie verwendet. Die Auswertung des Thermologen ohne Werkzeugunterstützung erzielt eine Sensitivität von 60,3% (95%CI: 48,2% bis 72,4%) und eine Spezifität von 81,5 % (95 %CI: 76,1 % bis 87,0 %). Wenn derselbe Thermologe zwei Monaten später bei einer wiederholten Auswertung mit dem SMILE-100-Werkzeug unterstützt wurde, veränderte sich die Sensitivität auf 81,0% (95% CI: 71,2% bis 90,6%) und die Spezifität auf 75,9 % (95 % CI: 69,9 % bis 81,9 %). Darüber hinaus wurde festgestellt, dass die vom Visualisierungstool vorgenommene Hotspot-Kennzeichnung eine Sensitivität von 85,7 % (95 %CI: 77,1 % bis 94,4 %) und eine Spezifität von 70,3 % (95 %CI: 63,8 % bis 76,7 %) zeigte. Diese Ergebnisse zeigen, dass SMILE-100 ein gutes Werkzeug sein kann, um die Interpretationsgenauigkeit von Wärmebildern zu verbessern und die Subjektivität bei der Interpretation zu reduzieren.

SCHLÜSSELWÖRTER: Visualisierungtool, computergestützte Thermografie, gekennzeichnete Wärmebilder, quantitative thermische Parameter.

Thermology international 2021, 31(2) 53-61

Introduction

Breast thermography is a non-contact, non-invasive, and irradiation-free imaging modality that is found to be applicable in breast cancer diagnosis, breast cancer prognosis, treatment monitoring of breast cancers and lymph node metastasis detection [1-4]. Thermography uses infrared thermal cameras for capturing and converting the Long Wave InfraRed (LWIR) radiation emitted from a human body into temperature values. In particular, breast thermography involves the measurement of temperature values emitted from a breast surface and converts into heat maps or colour images (thermal images). These thermal images are interpreted by trained physicians (thermologists) to identify suspicious thermal patterns and detect if there are any abnormalities in the breast.

Malignant breast lesions have been found to be associated with high skin temperatures (localized hyperthermia) in computational and experimental studies [4-6]. This localized hyperthermia corresponds to the high metabolic activity of the cancerous growth and increased vascular activity.

There have been different hypotheses to understand the mode of heat transfer from the cancer site to the skin [4-6]. While the actual mechanism of the heat transfer is still unproven, breast thermography is reported to show promising results for detection of breast cancers in different studies [1, 4].

There are several advantages of using infrared thermal cameras for breast imaging. By controlling the infrared camera remotely [7], breast imaging can be made privacy aware where technicians can capture the images from outside the room or a screen partition. Thermal imaging can also cut down the infrastructure cost by one tenth when compared to conventional radiation-based imaging modalities [1]. As there is no contact, no radiation exposure or compression of breasts during the test, breast thermography is safe from side-effects. However, one of the main challenges with breast thermography is the accuracy of visual interpretation of thermal images. The temperature values obtained from thermal cameras are usually rendered using pseudo color palettes such as Rainbow [8] and this visual representation may change significantly depending on the choice of lower and upper temperature limits of the colour palette. Furthermore, breast thermography interpretation requires analysis of over 400,000 colour pixels per image and is a huge cognitive task. Therefore, it requires high expertise for manual interpretation of thermal images. We have developed a new visualization software called SMILE-100, which automatically transforms the temperature values into contrast enhanced colour images and annotates elevated temperature regions to help thermologists in detection of malignancy. In this paper, we discuss the results of the first validation study of SMILE-100 on a multi-site clinical trial data.

Literature review

There have been studies ever since the 1960's that showed the effectiveness of infrared thermography in detecting breast cancer. In 1965, in a study by Gershon-Cohen et al., [9] on 4,000 women, thermography showed a sensitivity and specificity of 95% for detecting breast cancers. In another study, Hoffman et al. [10] observed a sensitivity and a specificity of 91.6% and 92.6%, respectively, on 1924 women. In a population of 4,621 women with 35% of women under 35 years of age, Stark and Way [11] noted a sensitivity and a specificity of 98.3% and 93.5%, respectively. Haberman et al.[12] studied 39,802 women for a 3-year period and found that thermography reported initial signs of malignancy even before they were seen on conventional imaging modalities. Gautherie et al.[13] observed that out of the 1,245 women who had an equivocal thermogram but were normal on other tests, 400 women developed cancer within 5 years. Similar results showing the potential of thermography for detecting breast cancers early was also shown in studies conducted by Spitalier et al [14] and Hobbins et al. [15]. Spitalier et al. [14] also reported that thermography was able to diagnose 91% of small lesions (T0 cancers with size<1 cm) that were non-palpable. However, the above studies are over 40 years ago when breast cancer research was still in its nascent stage.

In 2003, Parisky et al. [16], found that thermography identified 97% of breast cancers on 769 women who were recommended biopsy based on suspicious mammographic findings. On 1,008 Indian women, a study by Rassiwala et al., [17] in 2014 reported a sensitivity of 97.6% and a specificity of 99.2%. However, the above studies had biased participant cohorts or used a comparator that was not a standard imaging test. Summarizing the drawbacks of different breast thermography studies, Ammer [18] concluded that there is insufficient evidence to show the benefit of breast thermo- graphy for screening as most available studies are not randomized and not conducted in a systematic way.

Recently in 2020, a multi-site observational study performed on 470 women [19] showed that an artificial intelligence-led software achieved a high sensitivity of 91% and a specificity of 82.4% for automated interpretation of thermal images. In this paper, we present another such systematic retrospective study that measures the performance of manual interpretation of breast thermal images and also evaluates the benefit of using a software visualization tool to aid this interpretation.

Methods

Study Design

The goal of this study was to evaluate whether a thermal annotation and visualization tool (SMILE-100) can aid in better interpretation of breast thermal images. The primary objective of the study was to compare sensitivity and specificity of thermal image interpretation with and without the use of the software.

Study Protocol

A retrospective analysis of thermal images captured in an ethics committee-approved multi-site clinical study was performed to evaluate the sensitivity and specificity of the thermal image interpretation. An informed consent form was signed by each participant before obtaining their thermal images. The study included symptomatic women aged above 18 years and those who had symptoms such as lump, nipple discharge, nipple inversion, pain, skin changes etc. Pregnant women, lactating women, and women with prior diagnosis of breast cancer were excluded from the study. The ground truth of malignancy was provided by the principal investigators (senior radiologists) using standard- of-care tests as per clinical practice at the study sites. These standard-of-care tests involved one or more combinations of mammography, ultrasound, MRI, and biopsy. Figure 1 describes the study protocol that was used to compare the performance of manual interpretation of thermal images with that of semi-automated interpretation of thermal images where a thermologist was supported by SMILE-100 software tool.

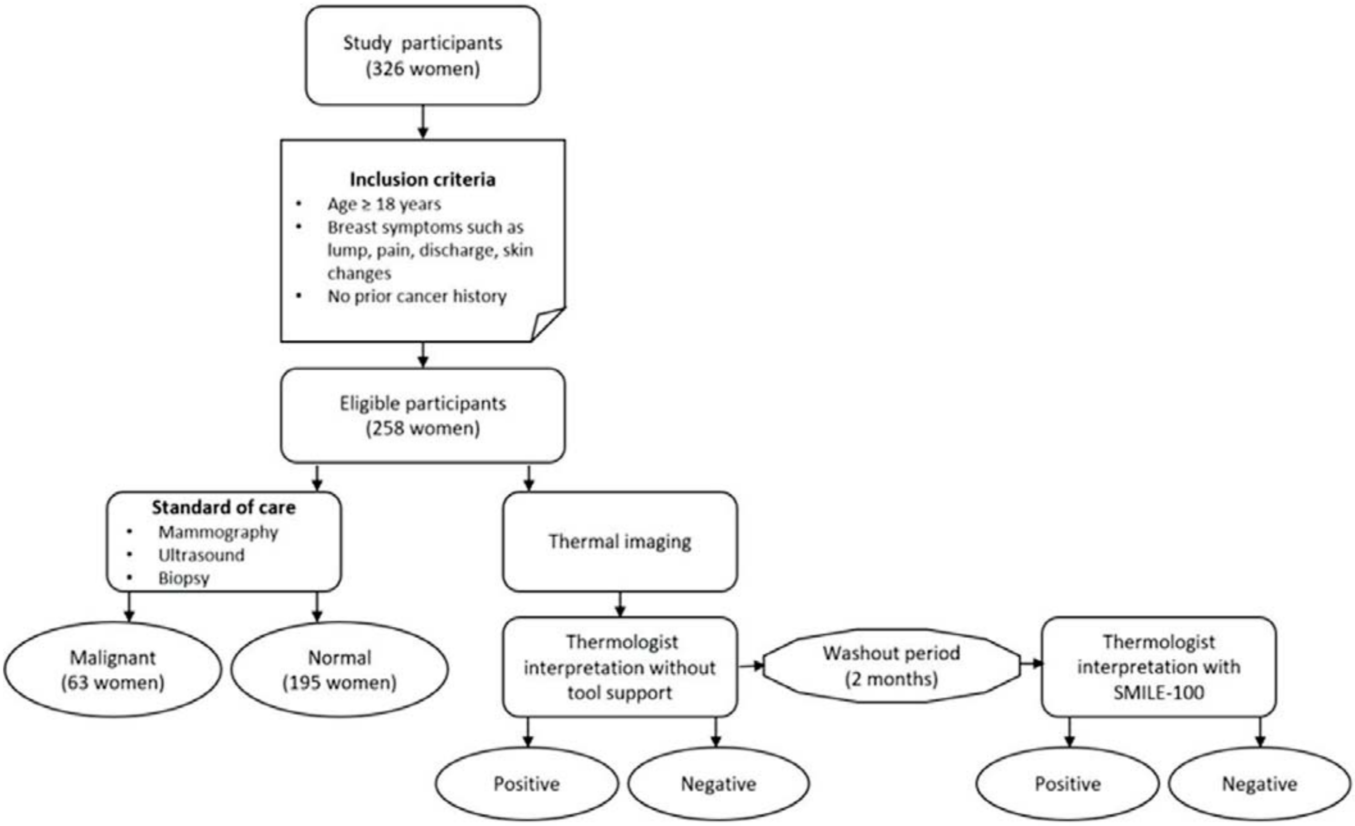
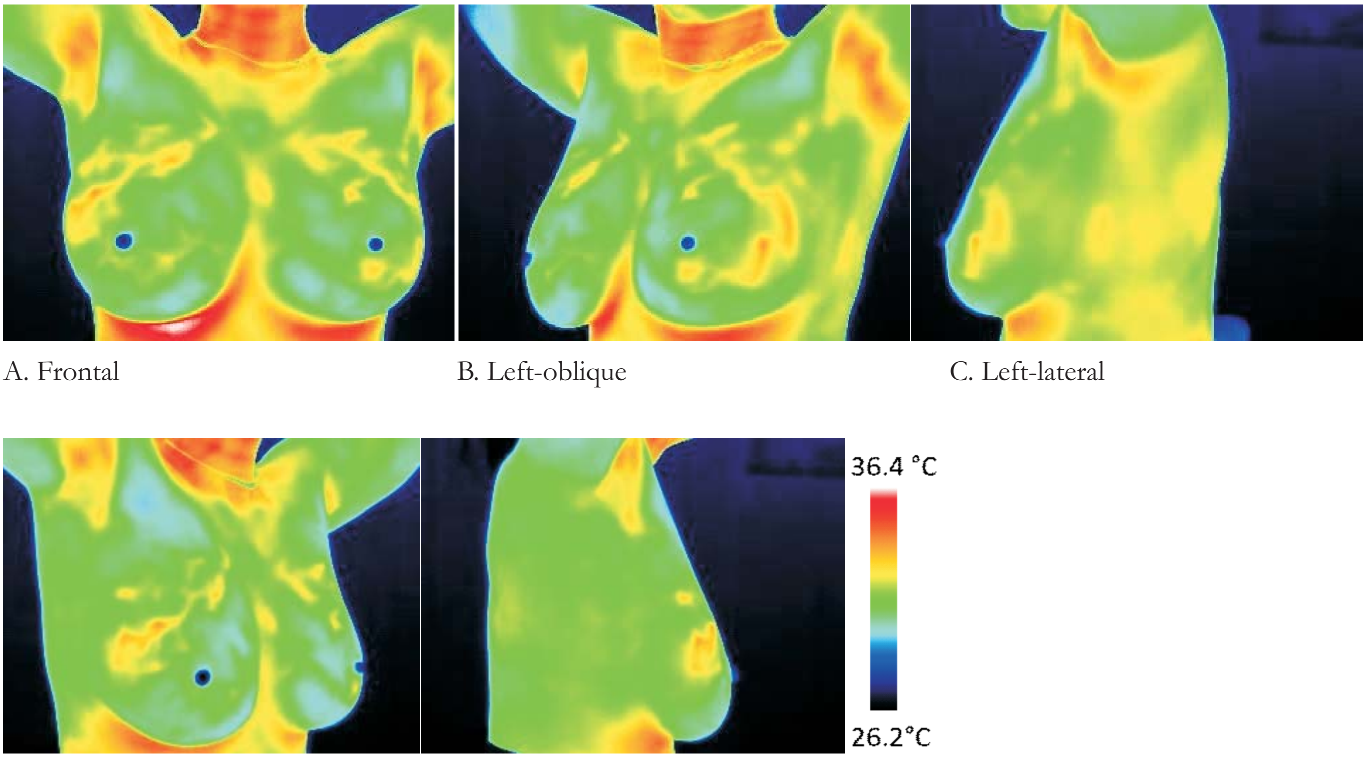


Figure 1.
Schematic drawing of the clinical study protocol.



A. Frontal B. Left-oblique C. Left-lateral

D. Right-oblique E. right-lateral

Figure 2
Thermal images of a participant taken at five different view angles.

All the participating women were sent for breast thermal imaging followed by the standard-of-care procedures. It was important to perform thermal imaging before mammogram or breast ultrasound in order to avoid any thermal disturbances created due to compression of breast during mammography or effect of gel applied during ultrasound, respectively. The results of thermal imaging were blinded to the standard-of-care procedures and vice versa.

Thermal Imaging Protocol

A standard thermal imaging protocol was followed for capturing thermal images in five views [1]. The five thermal images included: frontal, left-lateral, right-lateral, left-oblique, and right-oblique, as shown in Figure 2. Each participant was acclimated for 10 minutes without their upper clothing in a room with ambient temperature between 21-26°C and relative humidity between 40% and 70%. In one clinical site, air-conditioned room was used for cooling and in the other clinical site, air cooler was used due to the unavailability of airconditioned room. Participants were asked to sit on a rotatable chair with hands lifted up behind their head. The height of the thermal camera and distance between the chair and the camera were adjusted for each participant before capturing the skin temperature distribution in the region from neck to abdomen. The woman was verbally instructed by the technician to turn left or right to enable image capture in different views. Additional markings on the floor were used to guide the participant to the aforementioned views. FLIR A315 thermal camera (FLIR Systems, Wilsonville, OR) with a spatial infrared image resolution of 320x240 pixels and thermal sensitivity of 50 mK (< 0.05°C @ +30°C) was used for capturing thermal images in both the clinical sites.

Thermal Imaging Interpretation

For the first round of interpretation, the five thermal images per participant were made available to the thermologist, who classified each participant as suspicious for malignancy or not. After a washout period of two months, the same thermal images of the participants were uploaded to the SMILE-100 by an imaging technician. On upload, the tool created new thermal images in a contrast enhanced color palette and highlighted the areas of hot and warm thermal regions in the images with quantitative metrics. These annotated images were presented to the same thermologist who interpreted the images in the first round, for a repeat interpretation. The thermologist did not have access to any report or images of participants during the washout period to ensure that the thermologist makes an unbiased independent re-assessment of the thermal images in the second round of interpretation.

SMILE-100 Tool

The device under evaluation is our cloud-based visualization software tool called SMILE-100 that is intended to assist thermologists to perform a quantitative analysis of breast thermograms.

The software supports the following two user roles whose functions are described in figure 3.
(i) a thermographer or imaging technician role, and
(ii) thermologist or the expert interpreter role.

Thermographer View

In the thermographer view, SMILE-100 is intended to help imaging technicians or thermographers to capture good quality thermal images. The tool checks for focus and labeling errors during the image capture process and guides the thermographer if re-imaging is needed [20-22]. SMILE-100 also performs pre-processing of the thermal images to aid better visualization of the images for thermologist´s interpretation. Specifically, the thermographer view supports five main functionalities:

a) Data entry of paient's clinical, familial, and medical history so that the thermologist can consider cancer risk factors during interpretation for personalized care management.

b) Image quality checks to verify if the uploaded thermal images are focused and captured in the correct position as per the thermal imaging protocol. These quality checks

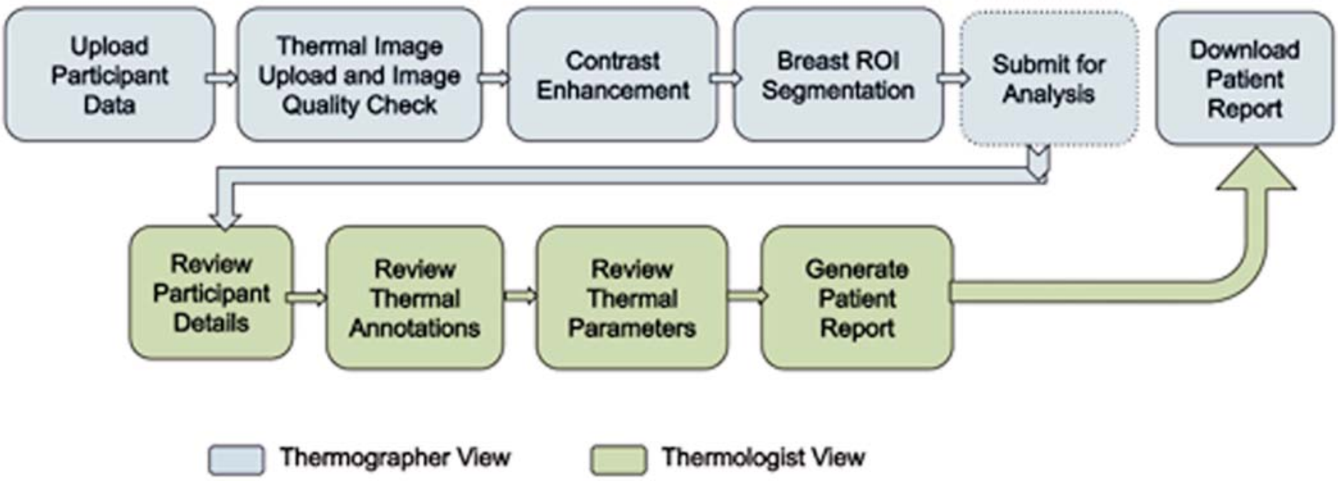


Figure 3
Schematic drawing showing the functionality of SMILE-100 for a Thermographer and a Thermologist.

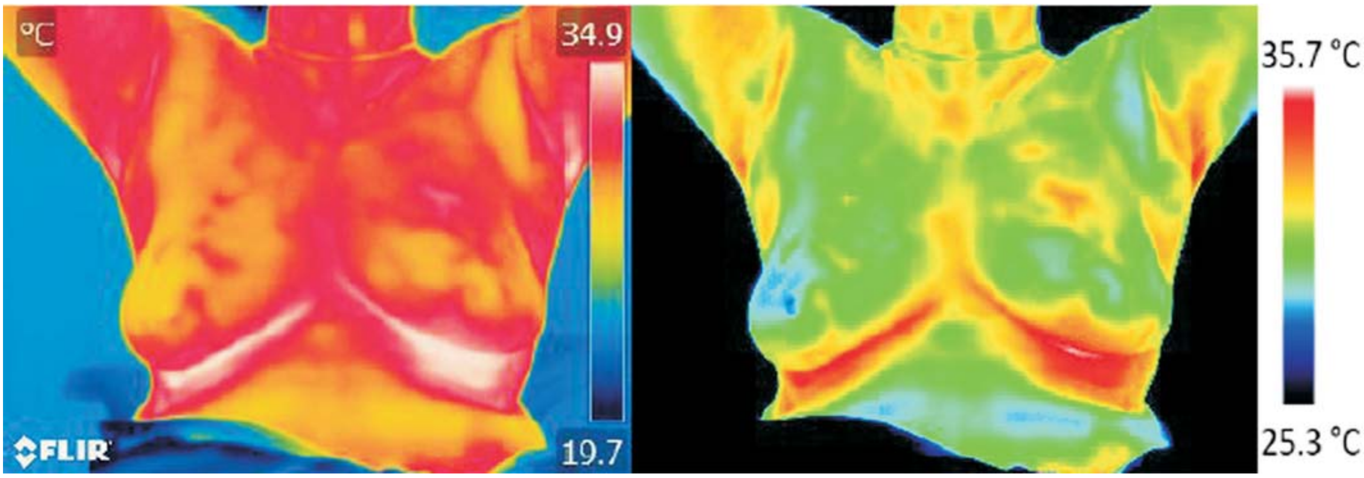


Figure 4 (a) (b)

a) Image generated by thermal camera with default upper and lower temperature limits for the colour bar.
b) Contrast enhanced image generated by SMILE-100 with auto-slected upper and lower temperature limits

(focus and view labeling) are implemented using pretrained machine learning models and are described in [20-22]. In case of any errors detected, thermographer can either recapture the image or skip the warning message predicted by the algorithm.

c) Preprocessing of thermal images that include foreground-background separation using Otsu segmentation [23] and contrast enhancement in the breast area by automatically selecting the maximum and minimum temperature limits for the color palette such that more than 70% of body pixels are above green color in the Rainbow color palette. Figure 4 shows an example of a thermal image before and after processing.

d) Segmentation of breast regions in the thermal images. To ease the segmentation process, an initial moldable polygon structure predicted using a pretrained deep learning model [20] is displayed to the thermographer. Thermographer can either accept the predicted segmentation or modify it by adjusting the polygon vertices. After segmentation, thermographer submits the data to thermologist for review and certification.

e) Download of final certified report which has the final impression of the thermologist and email to the participant.

Thermologist View

In thermologist view, the expert can visualize and explore the tool-generated thermal images with annotations of high temperature regions and quantified parameters that describe these high temperature regions. SMILE-100 expert view also allows thermologists to enter the final impression of thermal interpretation to be included in the patient report.

Broadly, the annotations generated by the SMILE-100 tool corresponding to high thermal activities are divided into three bands - 'Hotspots', 'Warmspots', and 'Normal' based on two temperature thresholds (T_h and T_w) that are derived for every image. We refer to regions consisting of pixels with temperature values above T_h as Hotspots, and regions consisting of pixels with temperature values in between T_h and T_w as Warmspots.

Let 't' be the temperature of the pixel 'p' in the thermal image.

- if $t > T_h$, then $p \in$ Hotspot region
- if $T_h \geq t > T_w$, then $p \in$ Warmspot region
- if $t \leq T_w$, then $p \in$ Normal region

The initial estimate for temperature thresholds, T_h and T_w, for distinguishing elevated temperature regions are derived using a fusion of adaptive histogram thresholding technique as discussed in our prior work [24] per the below equations.

$$T_{1h} = \mu + \rho_h * (T_{max} - \mu) \quad (1)$$

$$T_{2h} = T_{max} - \tau_h \quad (2)$$

$$\mathbf{T_h = max(T_{1h}, T_{2h})} \quad (3)$$

$$T_{1w} = \mu + \rho_w * (T_{max} - \mu) \quad (4)$$

$$T_{2w} = T_{max} - \tau_w \quad (5)$$

$$\mathbf{T_w = max(T_{1w}, T_{2w})} \quad (6)$$

Where, μ represents the mean of the modes of the temperatures in the breast region of the five thermal images, which conceptually represent the baseline breast surface temperature of the person. T_{max} represents the maximum temperature across all the five captured thermal images. (ρ_h, τ_h) and (ρ_w, τ_w) are configurable parameters that are chosen to maximize the detection of elevated temperature regions corresponding to high thermal activities.

Hotspots are demarcated in blue boundary and Warmspots are shown with pink boundary as shown in Figures 5 and 6.

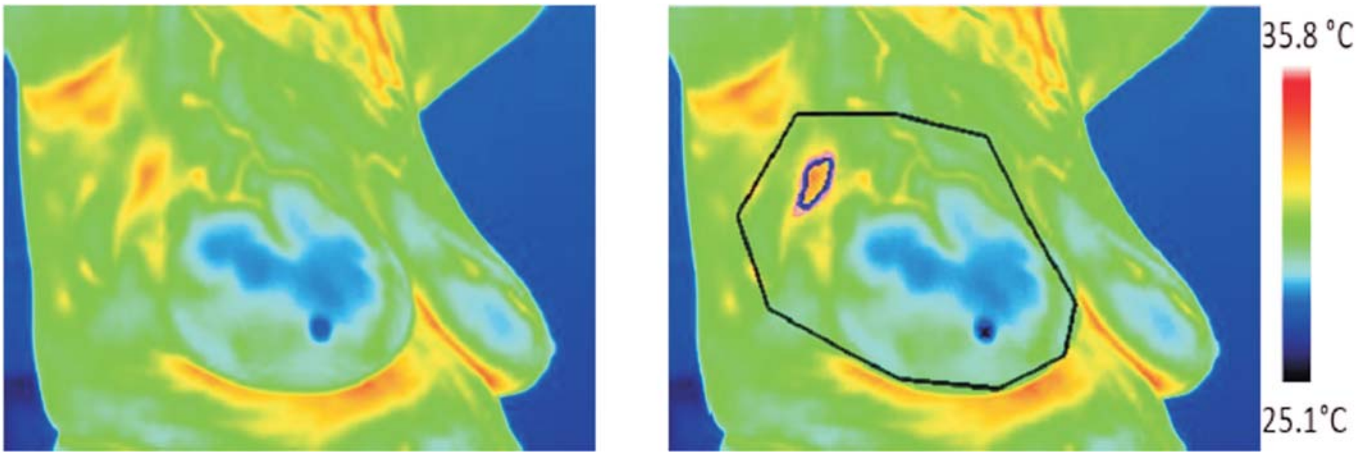


Figure 5 (a) (b)
Participant 01027: (a) Image without annotation (b) Image with Hotspot marking (blue border).

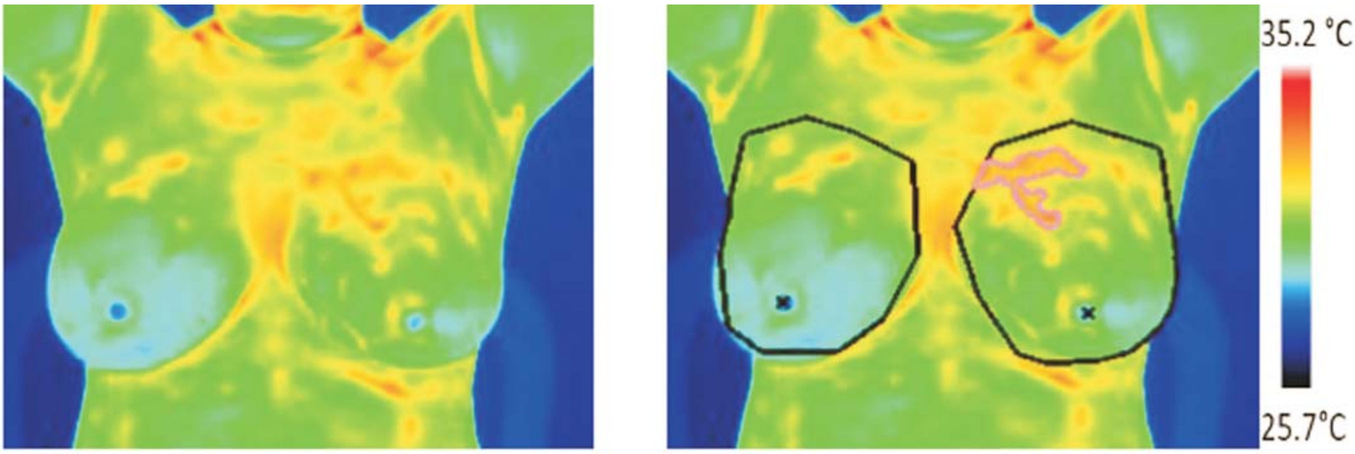


Figure 6 (a) (b)
Participant 02077: (a) Image without annotation (b) Image with Warmspot marking (pink border).

Though the thermologist had an option of changing the temperature thresholds, the automatically computed temperature thresholds were used in this study.

Since these Hotspots and Warmspots are marked explicitly, thermologists can study the characteristics of these thermal patterns for interpretation. To further aid this, the SMILE-100 tool generates quantifiable thermal parameters computed from the detected Hotspot regions. The thermal quantifiable parameters are: number of Hotspots/ Warm- spots, extent of Hotspots, Hotspot shape with irregularity metrics, temperature increase with respect to the surrounding region, maximum Hotspot temperature and a computation of the symmetry of the detected Hotspots in left and right breasts [24]. The generated annotations and quantified parameters can aid thermologists in visual and quantitative assessment of elevated temperature regions in the thermal images. In addition to SMILE-100 annotated images, thermologist can also access original thermal images (as captured by thermal camera with default color palette) and raw temperature values per pixel.

Results

In total, 326 women were recruited for the study between September 2017 and July 2018. Of the 326 women, 258 women who met the inclusion criteria were eligible to be included in the study. Sixty-eight women who were excluded from the study included 47 women who did not provide consent to participate, 7 women who did not obtain a biopsy for a suspected lesion and 14 women for whom correct thermal images were not obtained. Out of 258 women who participated in the complete study, 63 women had a final diagnosis of a malignant breast based on the reports of the standard imaging tests (n=18, 29%) and biopsy (n=45, 71%). The remaining 195 cases were negative for malignancy as per standard-of-care.

A senior radiologist who is also a trained and certified thermologist with over 14 years of experience in interpreting thermal images through visual analysis was requested to assess the thermal images. The interpreting radiologist/ thermologist did not have access to the images or reports of mammography or ultrasound. In the first round of thermal image interpretation, each participant was graded using 1 to 5 thermo-biological grading system where thermo-biological grades 3, 4 and 5 were considered as positive for malignancy. When the thermologist interpretation results were compared with the final diagnosis obtained from standard-of-care tests, the sensitivity and specificity was found to be 60.3% (95%CI: 48.2% to 72.4%) and 81.5%

Table 1.
Performance metrics of interpretation of thermal images with and without the software tool under evaluation.
NPV = negative predictive value, PPV = positive predictive value.

	Manual interpretation of raw thermal images (95% CI)	Manual interpretation of SMILE-100 annotated thermal images (95% CI)
Sensitivity	60.3% (48.2%, 72.4%)	81.0% (71.2%, 90.6%)
Specificity	81.5% (76.1%, 87.0%)	75.9% (69.9%, 81.9%)
PPV	51.3% (40.0%, 62.7%)	52.0% (42.1%, 61.9%)
NPV	86.4% (81.5%, 91.4%)	92.5% (88.4%, 96.6%)

(95%CI: 76.1% to 87.0%), respectively, as shown in Table 1. The corresponding positive predictive value (PPV) was 51.3% (95% CI: 40.0% to 62.7%) and negative predictive value (NPV) was 86.4% (95% CI: 81.5% to 91.4%).

After two months of washout period, the same thermal images were presented to the same senior radiologist/thermologist, but now with the annotations from SMILE-100 visualization software. Using the generated annotation and thermal parameters, the expert thermologist classified the thermal images into those suspicious for malignancy and those who were not. This resulted in a sensitivity and specificity of 81.0% (95% CI: 71.2% to 90.6%) and 75.9% (95% CI: 69.9% to 81.9%), respectively. The corresponding PPV was 52.0% (95% CI: 42.1% to 61.9%) and NPV was 92.5% (95% CI: 88.4% to 96.6%).

In order to evaluate the effectiveness of the automated annotations generated by the tool, the sensitivity and specificity were recalculated naively assuming that an elevated temperature region (Hotspot/Warmspot) always corresponds to a suspicious malignant lesion. Table 2 shows the sensitivity and specificity of SMILE-100 by considering the automatically detected Hotspots and Warmspots as positive for malignancy. The Hotspots and Warmspots were detected as described in Section 2 and were not influenced by the expert thermologist.

Discussion

Interpretation of thermal images involves visual analysis of temperature values represented in color pixels. Without any tool support, this is a huge cognitive task for a thermologist as there are about 400,000 color pixels that need to be reviewed per person. SMILE-100 is a computer-aided analysis and visualization software that generates annotated thermal images with markings for active thermal regions (Hotspots and Warmspots) along with quantitative parameters. The visualization of contrast-enhanced images with annotations can potentially reduce errors due to oversight. The quantified thermal parameters alleviate the need for manual computation of aggregate thermal parameters such as maximum temperature, relative increase in temperature and so on.

Overall, our hypothesis for this study was that automated annotations of thermograms corresponding to high thermal activities can aid a thermologist to make more accurate interpretation. As seen in the Table 1, use of SMILE-100 visualization tool helped in increasing the sensitivity by 20.7% as compared to the thermal image interpretation without the tool. However, specificity reduced by 5.5% when the thermologist was influenced by the tool. To understand the benefit of the tool, we discuss two case studies where the tool helped the thermologist in the correct interpretation.

Case Study 1

A 32-year-old woman with participant ID 01027 visited the clinical site with breast pain. Figure 5 shows thermal images of the patient with and without SMILE-100 annotations. The thermologist initially graded this participant as normal overlooking the thermal increase near the axillary tail. However, when the same images were presented along with SMILE-100 annotations which clearly showed the thermal increase as a Hotspot (after the washout period), the thermo- logist suspected malignancy and suggested a diagnostic workup for the participant. The participant was later diagnosed as positive for malignancy with histopathological confirmation and the lesion location coincided with the identified Hotspot in the right breast at 10 o'clock position.

Case Study 2

A 50-year-old woman with participant ID 02077 visited the clinical site with breast pain. Figure 6 shows thermal images of the participant with and without tool annotations. The expert thermologist suggested for a follow-up after looking at the asymmetry in the thermal images in the first round of interpretation. However, in the second round after washout, when the SMILE-100 annotation for the same participant showed only a Warmspot (shown with a pink border), the thermologist graded the heat pattern to be of low level of concern. The corresponding mammography report also showed negative for malignancy.

In order to measure the effectiveness of detected Hotspots and Warmspots, we computed the sensitivity and specificity by assuming their presence to be indicative of malignancy (Table 2). The sensitivity when Hotspot alone was considered as positive was 85.7% while specificity was 70.3%. This indicates that even if a naive thermographer was going to use the Hotspot annotation as a means of in-

Table 2
Sensitivity, specificity, Positive Predictive Value (PPV) and Negative Predictive Value (NPV) with Hotspot and Warmspot

	Sensitivity (95% CI)	Specificity (95% CI)	PPV (95% CI)	NPV (95% CI)
Hotspot	85.7% (77.1%, 94.4%)	70.3% (63.8%, 76.7%)	48.2% (39.0%, 57.5%)	93.8% (90.0%, 97.7%)
Warmspot	90.5% (83.2%, 97.7%)	48.2% (41.2%, 55.2%)	36.1% (28.6%, 43.6%)	94.0% (89.3%, 98.7%)

terpretation, it would have a reasonable accuracy. This can enable trained health workers to conduct the screening in remote places, when high-skilled radiologists or thermologists are not available for interpretation of thermal images. This is particularly useful in low- and middle-income countries (LMICs) where the current screening guidelines recommends only clinical breast examination [25] which can be enhanced to include thermal imaging.

Furthermore, in order to measure the usefulness of Warmspots towards detecting malignancy, sensitivity was calculated assuming a Warmspot alone as indicative of the result. From Table 2, it can be seen that the sensitivity increased to 90.5%. However, the specificity dropped to 48.2% when presence of Warmspots was considered as positive, instead of Hotspots. So, use of Warmspots alone for interpretation is not recommended, unless it is for a woman with a high-risk of breast cancer.

Clinical interaction plays a major role in adoptability of any new solution [26]. For that reason, SMILE-100 is developed as an interactive tool that allows the thermologist to adjust the temperature limits, modify the Hotspot and Warmspot thresholds (Th and Tw) and select different color palettes. Having said that, to bring objectivity in the clinical study protocol, the thermologist was not allowed to modify the parameters in the second round of interpretation.

Currently, there is no single imaging modality that can detect breast cancer in early stages with high levels of accuracy in women of all age groups. Therefore, there has been increased emphasis on use of multiple imaging modalities for breast cancer detection. Though the US Food and Drug Administration (FDA) has approved use of breast thermography as an adjunct modality to standard imaging tests, it is rarely being used in clinical practice. Subjectivity in interpretation and non-existence of systematic studies of thermography could be few of the reasons for the same. The results of this study show that SMILE-100 can be a good tool to improve the interpretation accuracy of thermal images and reduce the subjectivity in interpretation. This opens up the possibility of using SMILE-100 in clinical practice as an adjunct modality to standard imaging tests.

To summarize, interpretation of breast thermograms by thermologist aided by SMILE-100 has helped to achieve better accuracy in detecting breast cancers. The annotated markings help thermologists to focus on significant findings or high thermal activity regions, thereby saving the time of the expert and also reducing errors due to oversight. The use of automatically detected Hotspots alone to identify likely malignant lesions resulted in a sensitivity of 85.7% for detecting breast cancers showing the potential of the technique for large scale screening by low-skilled health workers. Overall, this study has unfolded the promise of computer-aided thermography to potentially be a part of the breast cancer care pathway.

As future enhancement to the SMILE-100 tool, we intend to provide additional quantitative parameters of Hotspots using machine learning to help reduce false positives. Looking for thermal patterns beyond Hotspots and Warmspots may increase the sensitivity as well. One such pattern that we would like to evaluate further is the vascularity pattern based on cylindrical thermal signatures [3, 27]. This might help the expert in quantitative analysis of both vascular and thermal patterns in the breast region [1, 28]. One of the limitations of the study was that it included only symptomatic patients from the two cancer sites. A large-scale study on diverse asymptomatic women is needed to further evaluate the clinical performance of the tool compared to standard imaging test for breast cancer detection. Further, a health technology assessment of the tool needs to be conducted to assess if there is a cost benefit over other modes of screening for adoption in LMICs.

Smile-100 tool is evailable for evaluation and can be accessed at https://www.niramaismile100.com

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(Received 07.01.2021, revision accepted 29.04.2021)

Preliminary report on the evaluation of submissions to the EAT2021 Online Conference

Kurt Ammer

Editor in Chief, Thermology international, European Association of Thermology, Vienna, Austria

Abstracts submitted to the tri-annual Conference of the European Association of Thermology are object to a peer review since 2012 [1,2,3]. The first round of the review process of submissions to the XV. EAT Congress was completed on May 17th, and the results of this quality assurance exercise are reported in the following.

In total. 35 submissions were received, 28 for oral presentations and 7 for posters. The abstracts originated from the following 13 countries (number of submissions in brackets): Poland (7) Russia (4), Czech Republic (3) Slovakia (1), Slovenia (2), Norway (1), Denmark (1), United Kingdom (5), Portugal (3,) Spain (3), India (1), USA (1) and Brazil (3).

The most submissions, 6 for oral presentations and 2 for posters were received for the topic "temperature measurement in animal welfare, veterinary applications and equine physiology".

In the first round of evaluation, review reports from 2 referees were available for 33 papers. Evaluation of the 2 remaining abstracts was based on the opinion of a single reviewer, 2 papers were read by 3 peers. All referees completed an evaluation form, in which they assessed the submission using a 5-point scale (5 = outstanding, 4 = strong, 3=somewhat or mixed, 2=limited, 1=unclear or not at all) in the following 7 statements:

- Relevance of the abstract theme to the event.
- Novelty of the subject introduced with this abstract.
- Study aim, objectives, research questions and/or hypotheses are clearly stated.
- Clarity of the methodology followed in the study.
- Results are reported for the aim, objectives, or research question.
- Conclusions are appropriately stated based on results.
- Implications of findings for further research or implementation are clearly stated.

Referees were also asked to recommend to "accept" (at 3 levels of priority) or "reject" the paper. Another request was to provide comments and constructive criticisms to the authors, particularly in recommendations of "accept with low priority" or "reject", but critical comments were also welcomed in case of top priority papers. Referees were informed beforehand that authors will be invited to revise abstracts classified as medium or low priority or rejected.

The mean value of the score in the statements mentioned above was the result of assessment of one referee; the final score was built from the average score of both reviewers.

The mean score of the first reviewer was 3.51 ± 0. 73, and the second referee scored 3.59 ± 0.89 points. Thus, the mean score of the first round was 3.54 ± 0.66 points. Figure 1 shows box and whisker plots representing median value, 25-75 percentile and minimum and maximum value of scores obtained by the first, second reviewer and the mean score of both referees. The dots show the distribution of all score values.

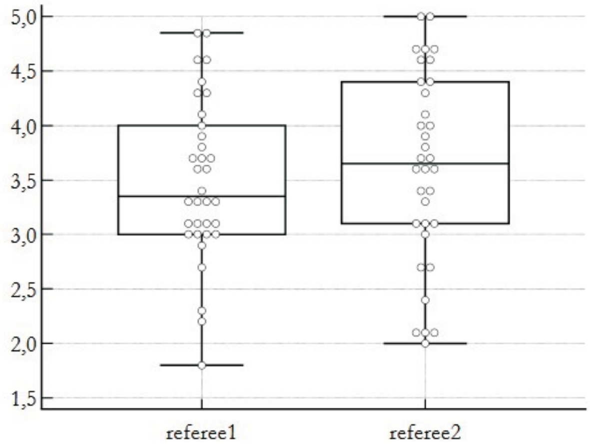

Figure 1
Box and whisker plots representing median value, 25-75 percentile and minimum and maximum value of scores obtained by the first and the second reviewer. The dots show the distri-

The agreement of scores was only fair to moderate with a mean value of the absolute difference of 0.74 ± 0.55 (median: 0.6, minimum 0.1, maximum 2.3) points. The box and whisker plot of score difference show that 75th percentile is 1.1 with 95% confidence interval between 0.9 and 1.58 points (figure 2)

The recommendation "accept at high priority without requiring revision"appeared 3-times in 68 review reports, resulting in only three abstract being accepted after the first round of evaluation. 5 times, the reviewer did not provide a comment, 21 review reports asked for optional revision and mandatory revision was required 34-times. The recommendation "reject" was given in 5 reports. Figure 3 shows the percentage of provided recommendations.

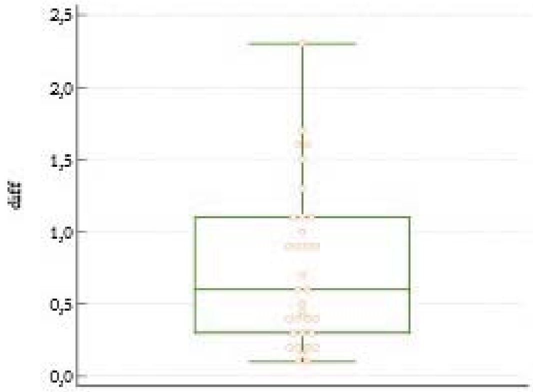

Figure 2
Box and whisker plots representing median value, 25-75 percentile and minimum and maximum value of the absolute difference between scores obtained by the first and the second reviewer. The dots show the distribution of all difference values.

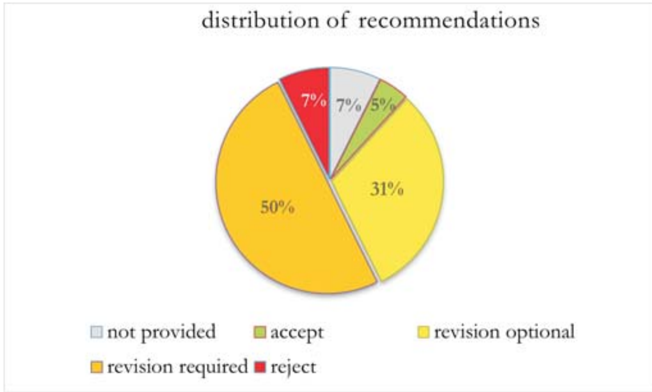

Figure3
Recommendations provided in 68 review reports

34 invitations for revision were distributed to the authors and 20 authors returned a revised manuscript by date 23.05.2021. Following a review by the editor, 18 submission were formally accepted, and other 2 abstracts were accepted after a second revision.

Abstracts scoring at the final evaluation 4 or more points were accepted with high priority, while scores equal or greater than 3 points led to the decision of "accept" with medium priority. No abstracts were accepted with low priority defined by scores less than 3 points. Since the deadline for re-submissions is May 31th, the final number of accepted presentations can yet not be determined. However, the following presentations will be included in the conference prgramme.

Oral presentations

- PROGRESS IN IMPROVING BODY TEMPERATURE MEASUREMENT ON A GLOBAL BASIS (UK)
- UNCERTAINTY OF THERMAL IMAGERS FOR BODY CORE TEMPERATURE SCREENING (Slovenia)
- DYNAMICS OF THE LOCAL TEMPERATURE OF BLOOD, PUS, MUCUS AND CATALASE SOLUTION WHEN THEY INTERACT WITH HYDROGEN PEROXIDE IN VITRO (Russia)
- IRT IMAGE EVALUATION VARIABILITY - EFFECT OF SUBJECTIVE PLACEMENT OF THE REGION OF INTEREST (Czech Republic)
- THERMAL IMAGING IN RHEUMATOID ARTHRITIS KNEES JOINTS AND ITS CORRELATION WITH POWER DOPPLER ULTRASOUND (India)
- SYSTEMATIC REVIEWS AND META-ANALYSIS ABOUT INFRARED THERMOGRAPHY IN MUSCULOSKELETAL RESEARCH - TRENDS AND CRITICAL APPRAISAL (Portugal)
- TEMPERATURE DYNAMICS OF THE MUSICIAN'S FINGERS WHEN PLAYING THE SAXOPHONE IN COLD CONDITIONS (Russia)
- INFRARED THERMOGRAPHY TO CONFIRM THE CORRECT PLACEMENT OF THE NEEDLE IN THE PERFORMANCE OF LUMBAR SYMPATHETIC BLOCKS FOR COMPLEX REGIONAL PAIN SYNDROME (Spain)
- SELECTING DOMINANT PERFORATING BLOOD VESSELS FOR AUTOLOGOUS BREAST RECONSTRUCTION: A COMPARATIVE STUDY USING DYNAMIC INFRARED THERMOGRAPHY, LASER FLUORESCENCE ANGIOGRAPHY OF INDOCYANINE GREEN, ULTRASOUND DOPPLER AND CT ANGIOGRAPHY (Norway)
- PLANTAR FOOT ASSESSMENT USING LIQUID CRYSTAL THERMOGRAPHY (UK)
- BODY TEMPERATURE MEASURED BY A FOREHEAD THERMOMETER IN AFEBRILE SUBJECTS ATTENDING A HOSPITAL CLINIC DURING THE COVID-19 PANDEMIC (UK)
- MACHINE LEARNING TECHNIQUES ON PANDEMIC FEVER SCREENING (Portugal)
- IMAGE ANALYSIS AND MACHINE LEARNING CLASSIFICATION FOR SKIN CANCER THERMAL IMAGES USING OPEN SOUCE TOOLS (Portugal)
- THERMORECOVERY PROJECT: EFFECT OF A 10KM RUN ON SKIN TEMPERATURE AND THERMAL PARAMETERS AFTER A COLD-STRESS TEST IN THE SUBSEQUENT 24H (Spain)
- APPLICATION OF DYNAMIC THERMOGRAPHY AFTER A FATIGUING STRENGTH EXERCISE (Spain)

- INFLUENCE OF TWO DIFFERENT MILITARY COMBAT JACKETS ON FACE TEMPERATURE (Brazil)
- THE USE OF INFRARED THERMOGRAPHY TO EVALUATE THE EFFECT OF HIGH INTENSITY LASER THERAPY ON THE SURFACE TEMPERATURE OF THE HINDLIMB'S FLEXOR TENDON AREA IN CLINICALLY HEALTHY RACEHORSES (Poland)
- APPLICATION OF THERAPEUTIC MUD IN EQUESTRIAN PHYSIOTHERAPY (Poland)

Posters

- EXPLORATIONS IN SKIN TEMPERATURE AND OBJECTIVE SKIN COLOUR MEASUREMENTS IN RAYNAUD'S PHENOMENON: A PILOT STUDY (UK)
- ATHLETES TEMPERATURE RESPONSE DURING AN ENDURANCE TRIATHLON RACE (Brazil)
- THERMOGRAPHIC MEASUREMENTS IN THE TOPIC OF THESES OF STUDENTS OF HEALTH CARE STUDY PROGRAMS (Czech Republic)
- CONVENTIONAL AND NOVEL APPROACH FOR THE ASSESSMENT OF FLANK TEMPERATURE OF POLISH NATIVE BREED MARES DURING PREGNANCY (Poland)

Acknowledgment

This review process was only possible by the assistance of EAT members and their expertise and willingness to evaluate the submitted papers. I like to thank the following colleagues for their help:

John Allen, UK

Kevin Howell, UK

George Havenith, UK

Peter Plassmann, UK

Aderito Seixas, Portugal

Danilo Gomes Moreira, Brazil

Manuel Sillero-Quintana Spain

James Mercer, Norway

Anna Jung, Poland

Jozef Gabrhel, Slovakia

Maria Soroko, Poland

Sebastian Opalinski, Poland

Mari Tienhaara (nee Vainionpää), Finland

Laszlo Talas, Hungary

Marjolein Beemsterboer, Netherlands

Irma Wensink, Netherlands

Ram Purohit, USA

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2021

25^{th} – 28^{th} July 2021

15^{th} International Conference on Heat Transfer, Fluid Mechanics and Thermodynamics HEFAT2021

The Organizing Committee of the International Conference on Heat Transfer, Fluid Mechanics and Thermodynamics (HEFAT) and the Editorial Board of Applied Thermal Engineering (ATE) are delighted to announce that we have established a partnership, starting in 2021. HEFAT will form the main forum for the board, authors, reviewers, and guests of ATE from all over the world, to meet and exchange ideas in overlapping research, innovation, and development areas. The HEFAT-ATE conference will form a regular opportunity for the Editorial Board of ATE to have its board meetings and allow authors and presenters theopportunity to meet both the board and representatives of the publisher, Elsevier.

The conference will be hosted **VIRTUALLY (online only**) instead of in Amsterdam, Netherlands. Oral and poster presentations will take place in real-time without sacrificing audience participation or networking, thanks to leading virtual conferencing technology.

The conference is co-sponsored by the International Centre for Heat and Mass Transfer (ICHMT) and the American Society of Thermal and Fluids Engineering (ASTFE).

Beyond inclusion in the proceedings of the conference, papers from the conference will be recommended for publication in dedicated special issues of ATE, best papers from ATE along with outstanding reviewers contributing to ATE will be announced and awarded at the conference.

Conference website: https://hefat2021.org

Journal website:https://www.journals.elsevier.com/applied-thermal-engineering

1^{st} September 2021.

Short Course on Medical Thermography

Online

Registration is possible via the EAT-website at https// www.eurothermology.org/education

2^{nd} - 3^{rd} September 2021

XV Congress of the European Association of Thermology → **Online** ←

For further information on both events go to page 71

28^{th}-30^{th} September 2021

XIV International Conference THERMOGRAPHY AND THERMOMETRY IN INFRARED in Kazimierz Dolny, Poland

Conference "Thermography and Thermometry in Infrared" is the main conference on thermal imaging in Poland. It takes place every two years. It is a scientific and technical forum, where experts in various fields dealing with thermography can exchange their experiences, present the results of their research and discuss the use of thermography and thermometry in infrared. The conference helps in integrating the scientific and research community with industry.

The first organizer of the conference was Dr. Piotr Prêgowski. Thanks to him, the conference gained a high scientific rank and contributed to the integration of scientists and technicians involved in thermography. The actual organizer of the TTP Conference is the Institute of Electronics (Lodz University of Technology). The ambition of the TTP Conference organizers is to maintain the current conference profile, i.e. to promote and develop thermographic techniques in various fields of science and technology, with particular emphasis on quantitative thermography. The TTP Conference is accompanied by an exhibition of thermal imaging equipment, where the manufacturers present their latest hardware and software achievements.

CONFERENCE TOPICS

- Infrared detectors, detection of infrared radiation and radiometric temperature measurement
- Thermal imaging systems and their software
- Modelling and measurement of temperature distribution, thermal processes
- Non-destructive testing using infrared techniques
- Biomedical applications of infrared thermal imaging
- Industrial applications of infrared thermal imaging
- Civil engineering applications of infrared thermal imaging
- Scientific and technological applications of infrared thermal imaging

THERMOGRAPHIC SCHOOL

On 28.09.2021 the organizers invite for lectures and demonstrations during the thermographic school. The lecturers are specialists from Poland and abroad. The organizers issue certificates of participation in the thermographic course.

EXHIBITORS SESSION

As in previous years, there will be an exhibition of thermal imaging equipment during the TTP 2021 Conference. Manufacturers of thermographic hardware and software will be presenting their offer and their latest achievements. We offer two pages (full color) in conference proceedings and the possibility of presentation during Sponsors' plenary session.

PAPERS AND PUBLICATIONS

The organizers grant the possibility of publication of selected papers (in English or Polish) in the PAR Journal (20p).

PAR Measurement Automation Robotics

The papers will undergo a review process according to the PAR Editorial Office requirements. The hardcopies of PAR, entirely dedicated to the TTP Conference, will be delivered at the registration desk. For papers published in PAR, it is necessary to provide abstracts according to the template, which will be included in the electronic version of the conference proceedings (pendrive).

The deadline for abstract submission is 30.05. 2021.

Due to the review process, we kindly ask for submission of the papers in electronic form until 20.05.2021. The detailed guidelines for authors will be presented on the website http://thermo.p.lodz.pl/ttp and will be send to you later on.

POSTER SESSION

There is a poster session during the TTP 2021 Conference. Every exhibitor gets 0.5 m2 space for presenting his work. All the required stationery will be delivered by the organizers.

IMPORTANT DATES

01.04.2021 – registration via the website

20.05.2021 – submission of the full paper in electronic form (PAR) via the website http://thermo.p.lodz.pl/ttp.

30.05.2021 – submission of the paper in electronic form for publication in the conference proceedings, via the website http://thermo.p.lodz.pl/ttp.

28.09.2021 - Kazimierz Dolny

Start of the TTP Conference.

FEES

The conference fee covers the participation in the conference, accommodation (4 days), board, conference proceedings and an excursion.

- 350 EUR (1500 PLN) – payment before 01.06.2021
- 450 EUR (1900 PLN) – payment after 01.06.2021
- 250 EUR (1000 PLN) – student fee
- 300 EUR (1200 PLN) – accompanying person fee

Bank account number will be given on the conference website.

TIME AND VENUE

The TTP 2021 Conference will take place on

28 - 30 September 2021

Przedsiêbiorstwo Turystyczne

"Zajazd Piastowski" Sp. z o.o.

ul. Sloneczna 4, 24-120 Kazimierz Dolny

tel. 81 88 90 900, kom. 609 628 999

e-mail: zajazd@zajazdpiastowski.pl

Detailed information on conference venue can be found at the website http://thermo.p.lodz.pl/ttp.

ACCOMPANYING EVENTS

The TTP 2021 Conference will be accompanied by meetings, the main purpose of which is to integrate conference participants, scientists, engineers, practitioners and enthusiasts of infrared thermography. A sightseeing trip is also planned.

ADDITIONAL INFORMATION

Please send all the inquiries and comments to the conference secretariat. The preferred contact method is an electronic correspondence.

All important information will be sent in subsequent communications and will be posted on the conference website http://www.thermo.p.lodz.pl/ttp.

website http://www.thermo.p.lodz.pl/ttp.

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1st-3rd October 2021

AAT 2021 Annual Scientific Session

Virtual and Live Streaming Presentations

About The Event

The 2021 Annual Scientific Session will be a Virtual Meeting consisting of both recorded presentations and live sessions. Those who register for the full meeting with next year's membership will be given 60 days post-meeting access to the recorded presentations.

Separate registration is required for the Pre-Meeting Physician's Thermography Interpretation Course. It will be held between 8:30am and 5:00pm (Eastern Time) on Friday, October 1st, 2021. This meeting will be a live virtual session

Further information at the AAT-website https://annualmeeting.aathermology.org/

Preliminary programme

Day 1 - Friday, October 1st, 2021

Pre-Meeting Physician Member Interpretation Course (separate registration required):

8:30 am - 4:00 pm
By Robert Schwartz, MD AAT COB, Greenville, SC

Day 2 - Saturday, October 2nd, 2021

General Sessions

7:30 am
Virtual Log In Open

Registration would be started by 8:00 am.

7:45 am - 9:30 am
From Artificial Intelligence to Fundamental Physics for Medical Thermology

7:45 am - 8:00 am
Welcoming Remarks

By Robert Schwartz, MD AAT COB, Greenville, SC

8:00 am - 8:20 am
The AAT Medical Thermography Artificial Intelligence Intiative

By Robert Schwartz, MD AAT COB, Greenville, SC

8:20 am - 9:00 am
Clinical Applications of PACS in Thermal Imaging

By Marcos Brioschi, MD, PhD Sao Paulo, Brazil

9:00 am - 9:30 am
Fundamentals of Infrared Imaging Systems

By Javier Gonzalez PhD AAT Member, Orlando Florida

9:30 am - 11:30 pm
Neuro-Musculoskeletal Thermology

9:30 am - 10:00 am
SSR Medical Thermography and Neuromodulation

By Behnum Habibi, MD AAT Board, Philadelphia, PA

10:00 am - 10:30 am
Medical Thermography Applications In a MSK Pain Practice

By Matthew Terzella, MD AAT Board, Greenville, SC

10:30 am - 10:45 am
Clinical Applications of Thermography in Complex Regional Pain Syndrome

By Jason Hamamoto, MD Resident, Dept of PMR, Temple University

10:45 am - 11:00 am
Clinical Applications of Thermography in Complex Regional Pain Syndrome (Continued)

By Jay Darji, DO Resident, Dept. of PMR, Temple University

11:00 am - 11:30 am
Use of Medical Thermography In Craniocervical Junction Disorders

By Robert Schwartz, MD AAT COB, Greenville, SC

11:30 am - 12:00 am
Virtual Exhibit Hall

12:00 pm - 1:00 pm
Lunch

1.00 pm - 3.00 pm
Clinicians Corner: Breast Thermography

1:00 pm - 1:20 pm
Defining Specific Applications of Breast Thermography
By Robert Kane, DC AAT Member, San Francisco, CA

1:00 pm - 3:00 pm

1:20 pm - 1:40 pm
Updates in Breast Guidelines, Thermal Signs Assessment, and A Case Report
By Robert Schwartz, MD AAT COB, Greenville, SC

1:40 pm - 2:10 pm
Thermography, Ultrasonography And Elastography In Breast Cancer
By Severino Tadeu de Menezes Lima, MD ABTHERM Member, Serra Telhada, Brazil

2:20 pm - 2:40 pm
Breast Thermography and the Practice of Gynecology
By Rita de Cassia Dantas Monteiro, MD ABTHERM Member, Ponta Verde, Brazil

2:40 pm - 3:00 pm
Addressing Challenges of Outsourced Thermography Services
By Nina Rea Atlanta, GA

3:00 pm - 3:30pm
Virtual Exhibit Hall

3:30 pm - 5:00 pm
Veterinary Session: Thermology Presentations

3:30 pm - 3:55 pm
Infrared Thermal Imaging For The Diagnosis/Assessment Of Back Pain In Horses

By Tracy Turner, DVM Past President, AAT, Elk River, MN

3:55 pm - 4:20 pm
Infrared Thermography As A Means Of Screening And Preventing Injury In Elite Equine Athletes

By Ken Marcella, DVM AAT Member, Canton, GA

4:20 pm - 4:40 pm
Combining Thermal Imaging and Musculoskeletal Ultrasound to Identify Sports Medicine Injuries in Working and Performance Dogs

By Kim Henneman, DVM Park City, Utah

4:40 pm - 5:00 pm
Use of Thermal Imaging in Equine Integrative Sports Medicine

By Sara s Le Jeune, DVM UCDavis, CA

5:00 pm
Saturday Session Ends

5:30 pm - 6:00 pm
Virtual Meet and Mingle Reception

Day 3 - Sunday, October 3rd, 2021

General Sessions and Annual Business Meeting

8:00 am - 10:30 am
Oral Systemic Session

8:00 am - 8:20 am
Thermographic Imaging of Gastroenterology Patients

By Richard Brownstein, MD AAT Member, Clarksdale, MS

8:20 am - 8:40 am
Medical Thermology in Family Practice

By Eric Ehle, DO AAT Member, Amarillo, TX

8:40 am - 9:00 am
Thermal Imaging to Monitor Laser Therapy Treatment Effects
By John Godbold, Jr., DVM AAT Member, Jackson, TN, Ronald Riegel, DVM Marysville, OH

9:00 am - 9:40 am
Virtual Exhibit Hall

9:40 am - 10:00 am
Software as a Medical Device (SaMD)
By Robert Schwartz, MD AAT COB, Greenville, SC

10:00 am - 10:20 am
Machine Learning Applied to the Korean Temperature Data Base for Oral Systemic Conditions

By Ho Yeol Zhang, MD, PhD NHIS Ilsan Hospital, Seoul, Korea

10:20 am - 10:30 am
Why The AAT Is Needed In The SaMD Space

By Barry Hix MBA, MPH Birmingham, AL

10:30 am - 10:45 am
Missed Breast Pathology: A Problem With The Test Or The Report?

By Rebecca Peden, B.C.N.D., D.A.Hom., L.E.H.P. AAT Member, Lawrenceville, GA

10:45 am - 11:00 am
Equine Thermography Versus Symptoms, PE, & Other Studies

By Irma Wensink, Paraveterinair AAT Member, Epe, The Netherlands

11:00 am
General Session Ends

11:00 am - 1:00 pm
Board of Directors Meeting (Board Members Only)

XV Congress of the European Association of Thermology 2nd - 3rd September 2021, Online

IMPORTANT ANNOUNCEMENT

The XV Congress switches to online only.

The EAT and Wroclaw University of Environmental and Life Sciences are delighted to invite you to participate in the XV EAT Congress, online from 2nd to 3rd September 2021. Due to the current pandemic situation in Europe, the EAT Board and Organising Committee have decided that the Congress will now take place online only, and the abstract deadline will be extended to 31st March 2021.
If you have already submitted an abstract, this will be considered for the online meeting, and you will be contacted by the Chair of the Scientific Committee once review of your abstract is complete.

Full details about the format of the online sessions, and how to register, will be posted on the EAT website at:

www.eurothermology.org/XVCongress.html

as soon as the information becomes available.
Please submit your abstract now, and check back regularly for the latest Congress news.

Dr. Kevin Howell,
President, European Association of Thermology

Dr. Maria Soroko,
Chair, XV Congress Organising Committee

The Congress is held under the honorary patronage of His Magnificence, Rector of the Wroclaw University of Environmental and Life Sciences.

Key dates

- 1st September 2021.
  Short Course on Medical Thermography Online

- 2nd - 3rd September 2021.
  XV Congress Scientific Sessions Online.

The XV Congress of the EAT is supported by:

Thermetrix Limited
Making Life Better

About the Congress

The XV Congress of the European Association of Thermology will be an influential conference for professionals in biomedical temperature science. It is a unique opportunity for industry and scientists to meet and acquire new knowledge, as well as to exchange experience of temperature measurement in medicine and biology during oral presentation and poster sessions.

Key Meeting Themes

Key topics for the Congress will include:

- Infrared thermography in biomedicine.
- Temperature measurement in animal welfare, veterinary applications and equine physiology.
- Contact temperature measurement.
- Hardware and software solutions for infrared imaging.
- Biomedical applications: surgery, neurology, vascular and pain syndromes.
- Thermometry in exercise physiology, rehabilitation, and human performance research.
- Calibration and traceability in biomedical thermometry.

All abstracts will be published as an appendix of the EAT journal "Thermology International", indexed in EMBASE/SCOPUS

Prizes for:

Best oral presentation (**The Francis Ring prize**),
and best poster (**The Kurt Ammer prize**)

Organising Committee

This committee is responsible for all operational aspects of the Congress, including delivery of the meeting at the local venue

- **Maria Soroko (POL), Chair**
- Kurt Ammer (AUT)
- Wanda Górniak (POL)
- Kevin Howell (GBR)
- Anna Jung (POL)
- Damian Knecht (POL)
- Alicja Kowalczyk (POL)
- Sebastian Opalinski (POL)
- Adam Roman (POL)
- Adérito Seixas (POR)
- Manuel Sillero-Quintana (ESP)
- Ricardo Vardasca (POR)
- Klaudia Wlazlak (POL)
- Anna Zielak-Steciwko (POL)

International Scientific Committee

This committee is responsible for reviewing all submitted abstracts to the Congress, and approving the final Congress programme.

- **Kurt Ammer (AUT), Chair**
- John Allen (GBR)
- Danilo Gomes Moreira (B
- Anna Jung (POL)
- Mariusz Korczynski (POL)RA)
- Kevin Howell (GBR)
-
- Robert Kupczynski (POL)
- James Mercer (NOR)
- Sebastian Opalinski (POL)
- David Pascoe (USA)
- Adérito Seixas (POR)
- Manuel Sillero-Quintana (ESP)
- Maria Soroko (POL)
- Hisashi Usuki (JPN)
- Mari Tienhaara (neeVainionpää) (FIN)
- Ricardo Vardasca (POR)
- Ho Yeol Zhang (KOR)

Registration fees

	Late registration (from 18th May 2021
EAT member	€ 130
Non-member	€ 150
Student	€ 100

Online registration for the XV Congress of the European Association of Thermology is now open , please click here.

Registration includes access to all congress live online sessions, our on-demand library of recorded presentations, and the online library of posters.

Attendance at the pre-congress Short Course on Medical Thermography requires a **separate registration and payment.**

More information on page 72.

The following presentations and posters are already confirmed for the Congress. Titles in RED LETTERS are related to the topic "Temperature measurement in animal welfare, veterinary applications and equine physiology".

Oral presentations

KEYNOTE: COMFORT, THERMAL STRESS, AND CLOTHING.
Prof George Havenith,
Professor of Environmental Physiology and Ergonomics, Loughborough University, UK

PROGRESS IN IMPROVING BODY TEMPERATURE MEASUREMENT ON A GLOBAL BASIS (UK)

UNCERTAINTY OF THERMAL IMAGERS FOR BODY CORE TEMPERATURE SCREENING (Slovenia)

DYNAMICS OF THE LOCAL TEMPERATURE OF BLOOD, PUS, MUCUS AND CATALASE SOLUTION WHEN THEY INTERACT WITH HYDROGEN PEROXIDE IN VITRO (Russia)

IRT IMAGE EVALUATION VARIABILITY – EFFECT OF SUBJECTIVE PLACEMENT OF THE REGION OF INTEREST (Czech Republic)

THERMAL IMAGING IN RHEUMATOID ARTHRITIS KNEES JOINTS AND ITS CORRELATION WITH POWER DOPPLER ULTRASOUND (India)

SYSTEMATIC REVIEWS AND META-ANALYSIS ABOUT INFRARED THERMOGRAPHY IN MUSCULO-SKELETAL RESEARCH - TRENDS AND CRITICAL APPRAISAL (Portugal)

TEMPERATURE DYNAMICS OF THE MUSICIAN'S FINGERS WHEN PLAYING THE SAXOPHONE IN COLD CONDITIONS (Russia)

INFRARED THERMOGRAPHY TO CONFIRM THE CORRECT PLACEMENT OF THE NEEDLE IN THE PERFORMANCE OF LUMBAR SYMPATHETIC BLOCKS FOR COMPLEX REGIONAL PAIN SYNDROME (Spain)

SELECTING DOMINANT PERFORATING BLOOD VESSELS FOR AUTOLOGOUS BREAST RECONSTRUCTION: A COMPARATIVE STUDY USING DYNAMIC INFRARED THERMOGRAPHY, LASER FLUORESCENCE ANGIOGRAPHY OF INDOCYANINE GREEN, ULTRASOUND DOPPLER AND CT ANGIOGRAPHY (Norway)

PLANTAR FOOT ASSESSMENT USING LIQUID CRYSTAL THERMOGRAPHY (UK)

BODY TEMPERATURE MEASURED BY A FOREHEAD THERMOMETER IN AFEBRILE SUBJECTS ATTENDING A HOSPITAL CLINIC DURING THE COVID-19 PANDEMIC (UK)

MACHINE LEARNING TECHNIQUES ON PANDEMIC FEVER SCREENING (Portugal)

IMAGE ANALYSIS AND MACHINE LEARNING CLASSIFICATION FOR SKIN CANCER THERMAL IMAGES USING OPEN SOURCE TOOLS (Portugal)

THERMORECOVERY PROJECT: EFFECT OF A 10KM RUN ON SKIN TEMPERATURE AND THERMAL PARAMETERS AFTER A COLD-STRESS TEST IN THE SUBSEQUENT 24H (Spain)

APPLICATION OF DYNAMIC THERMOGRAPHY AFTER A FATIGUING STRENGTH EXERCISE (Spain)

INFLUENCE OF TWO DIFFERENT MILITARY COMBAT JACKETS ON FACE TEMPERATURE (Brazil)

THE USE OF INFRARED THERMOGRAPHY TO EVALUATE THE EFFECT OF HIGH INTENSITY LASER THERAPY ON THE SURFACE TEMPERATURE OF THE HINDLIMB'S FLEXOR TENDON AREA IN CLINICALLY HEALTHY RACEHORSES (Poland)

APPLICATION OF THERAPEUTIC MUD IN EQUESTRIAN PHYSIOTHERAPY (Poland)

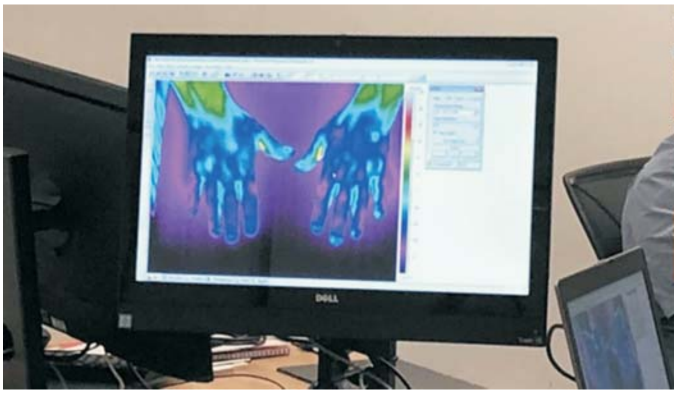
Posters

EXPLORATIONS IN SKIN TEMPERATURE AND OBJECTIVE SKIN COLOUR MEASUREMENTS IN RAYNAUD'S PHENOMENON: A PILOT STUDY (UK)

THERMOGRAPHIC MEASUREMENTS IN THE TOPIC OF THESES OF STUDENTS OF HEALTH CARE STUDY PROGRAMMES (Czech Republic)

ATHLETES' FACE TEMPERATURE RESPONSE DURING AN ENDURANCE TRIATHLON RACE (Brazil)

CONVENTIONAL AND NOVEL APPROACH FOR THE ASSESSMENT OF FLANK TEMPERATURE OF POLISH NATIVE BREED MARES DURING PREGNANCY (Poland)




Short Course in Medical Thermography

The European Association of Thermology has education as one of its key aims. To that end, we offer the EAT "Short Course in Medical Thermography," taught by an experienced faculty of thermology researchers.

The Course normally takes place every three years, along with the Congress of the EAT, at a European venue.

The next edition of the Course will take place online on 1st September 2021, immediately prior to the XV Congress of the EAT.

Registration for the course is now open by completing our online form: click here.

The course fee for the full day of teaching is 150 euros.

Upon completion of the application form, the EAT will provide payment details. Upon receipt of the course fee, your place on the course will be confirmed.

Main themes of the 2021 syllabus will include:

- Physical principles of heat transfer
- Principles of thermal physiology and skin blood perfusion
- Standardization of thermal imaging, recording and analysis
- Quality assurance for thermal imaging systems
- Producing a thermographic report
- Provocation tests
- Image analysis
- Hands-on supervised practice
- Educational resources

The full syllabus of the last Course in 2018 can be downloaded for Thermology International subscribers as a .pdf file