Reliability and Reproducibility of Skin Temperature of Overweight Subjects by an Infrared Thermography Software Designed for Human Beings

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SUMMARY

Introduction: The technical improvement and new applications of Infrared Thermography (IRT) with healthy subjects should be accompanied by results about the reproducibility of IRT measurements in different popula-tion groups. In addition, there is a remarkable necessity of a larger supply on software to analyze IRT images of human beings.
Therefore, the objectives of this study were: firstly, to investigate the reproducibility of skin temperature (Tsk) on overweight and obese subjects using IRT in different Regions of Interest (ROI), moments and side-to-side differences (ΔT); and secondly, to check the reliability of a new software called Termotracker®, specialized on the analysis of IRT images of human beings.
Methods: 22 overweight and obese males (11) and females (11) (age: 41,51±7,76 years; height: 1,65±0,09 m; weight: 82,41±11,81 Kg; BMI: 30,17±2,58 kg/m²) were assessed in two consecutive thermograms (5 seconds in-between) by the same observer, using an infrared camera (FLIR T335, Sweden) to get 4 IRT images from the whole body. 11 ROI were selected using Termotracker® to analyze its reproducibility and reliability through Intra-class Correlation Coefficient (ICC) and Coefficient of Variation (CV) values.
Results: The reproducibility of the side-to-side differences (ΔT) between two consecutive thermograms was very high in all ROIs (Mean ICC = 0,989), and excellent between two computers (Mean ICC = 0,998). The re-liability of the software was very high in all the ROIs (Mean ICC = 0,999). Intra-examiner reliability analysing the same subjects in two consecutive thermograms was also very high (Mean ICC = 0,997). CV values of the different ROIs were around 2%.
Conclusions: Skin temperature on overweight subjects had an excellent reproducibility for consecutive ther-mograms. The reproducibility of thermal asymmetries (ΔT) was also good but it had the influence of several factors that should be further investigated. Termotracker® reached excellent reliability results and it is a relia-ble and objective software to analyse IRT images of humans beings.

1. INTRODUCTION

Infrared Thermography (IRT) is a technique, which allows us to get rapidly and non-invasive thermal images from objects or human beings. Since the first applications of IRT on humans in the medical sector in 1950's and early 1960's (3, 25), this technique has underwent different and fluctuant stages, from the increasing interest in the 1970's and 1980's, to the rejection during the 1990's due to the lack of methodological standards and poor quality of the imaging systems (11). Nowadays, IRT is facing a new revival due to the technical improvements, which are paving the way for new applications (13, 14, 24).

Even if IRT has been widely used in pathological conditions, there are much less data available from healthy subjects (35). Moreover, the increase of interest on the application of IRT, not only in the medical sector but also in other fields as the physical activity with healthy subjects, makes more necessary to increase the knowledge concern-ing the factors affecting the application of IRT on humans (5, 24, 35), as well as the reproducibility of IRT measurements in different potential groups of application as children, elderly, overweight, disabled, or physically active subjects.

Overweight people represent a growing population group worldwide, mainly in occidental countries (5). Although IRT has been used on overweight and obese people –from the detection of some pathologies as diabetes (10, 29) to cellulite assessment (19)- few is known about the reproducibility of IRT measurements in overweight and obese subjects.
Ring has recently defended and described the new features of IRT technology and the improvement on standardization protocols (24). Nevertheless, most of research groups keep on analyzing IRT images using the software packages provide by the camera manufacturers, which are mainly created for industrial or architectural purposes, rarely adapted to human analysis (17). Therefore, there is a remarkable necessity of a larger supply on software to analyze IRT images of human beings.
The aims of the present study were: firstly, to investigate the reproducibility of skin temperature on overweight and obese subjects through IRT in different body regions, moments and thermal asymmetries (ΔT); and secondly, to check the reliability of the new software called Termotracker®, specialized on the analysis of IRT images of human beings and created by the research group of the Faculty of Phys-ical Activity and Sport Sciences-INEF from the Technical University of Madrid with the collabora-tion of several institutions.

2. METHODS

2.1 Subjects

A total of twenty-two overweight and obese right-handed males (11) and females (11) (age: 41.51±7.76 years; height: 1.65±0.09 m; weight: 82.41±11.81 Kg; BMI: 30.17±2.58 kg/m²) exercising at least 2 times per week, took part of the study. They did not report any orthopedic limitation or diseases, consumption of medicaments or drugs.
Subjects were previously asked to avoid a list of factors affecting skin temperature on their daily activity (i.e. alcohol or tobacco consumption, applica-tion of creams or ointments, or physical activity) in the 24 hours before the test an signed a writing con-sent for participating in the study. During the accli-matization period, they were asked to answer a ques-tionnaire to know the existence of any possible influence factor affecting IRT results. The project was previously approved by the Ethics Committee of the Technical University of Madrid, following the principles outlined by the World Medical Assembly Declaration of Helsinki.

2.2 IRT evaluation

The evaluation took place in a laboratory with stand-ardized conditions (Temperature = 23.55±1.19ºC; Humidity = 46.59±4.08%; and Atmospheric Pressure = 942.69±3.03 mb/hPa) following guidelines of the European Association of Thermology (EAT) (2).
Whole body skin temperatures (Tsk) of each subject were recorded in four IRT images (Anterior and Posterior of Upper and Lower body) – as it is shown in figure 1- in two consecutive thermograms (5 seconds in-between) by the same observer. We decided to separate both thermograms just with 5 seconds in order to minimize the influence of factors that could affect the skin temperature records, as others authors have described in their studies (35).

2.3 Equipment

All thermal images were taken by an infrared camera (FLIR T335®, FLIR Systems, Danderyd, Sweden) with thermal sensitivity of 50mK, a wide range of temperature from -20 °C to +120 °C, spectrum range of 7.5-13 µm, resolution of 320 x 240 pixels, emis-sivity set at 0.98 (Steketee et al. 1973) and an accu-racy of ± 2%. The environmental conditions were controlled by a BAR-908-HG portable weather sta-tion (Oregon® Scientific, USA). Moreover, we use a tripod Hama Omega Premium II (semiprofessional Tripod 62.5-148 cm) and a “Roll-up" 125 x 206 cm to obtain a homogeneous background behind the subjects. We used also a "step" with marks for fixing the standing protocol position and raising slightly the subject from the floor surface. IRT images were transferred to a laptop Sony® VAIO Y11S1E/S (Sony, Japan). The IRT images were analyzed using the IRT software Termotracker® (pemaGROUP, Madrid, Spain) and statistic analyses were made through SPSS version 20.0 for Mac (IBM® Corpo-ration, Armonk, NY, USA).

2.4 Software

Termotracker® (pemaGROUP, Madrid, Spain) is a software for analysing IRT images of human beings, which was created by the Thermography research group of the Faculty of Physical Activity and Sport Sciences-INEF from the Technical University of Madrid with the collaboration of several institutions, as TS Company (Madrid, Spain), Spanish National Research Council (CSIC, Spain) or Alava Ingenieros (Madrid, Spain). The software is able to analyse the 4 IRT images of a subject (Anterior and Posterior, Upper and Lower body) dividing automatically each IRT image in Regions of

Interest (ROI) based on ar-ticular and muscular areas of the human anatomical structure (as it is shown in fig. 1) Termotracker® recognises a total of 78 ROI by a feature called "artificial vision" and based on an algorithm that identi-fies the subject shape and anatomical key points to automatically trace the ROIs, without requiring any external marker, which are often used by other authors in literature (6, 28). Termotracker® extracts from the total of pixels of each ROI the maximum, minimum and mean temperature with standard deviation (SD). The images can be organised in folders, ROI can be handily modified and the results can be transferred to an excel file. For this study, we decide to use 11 ROI: abdominal, right and left thigh union of several ROI, right and left anterior knee, right and left chest, right and left calf, back and lumbar ROI marked on the fig. 2. We decided to select only these ROIs because of their relevance and size, and to reduce the amount of information. All images were assessed in two different laptops with the same software.

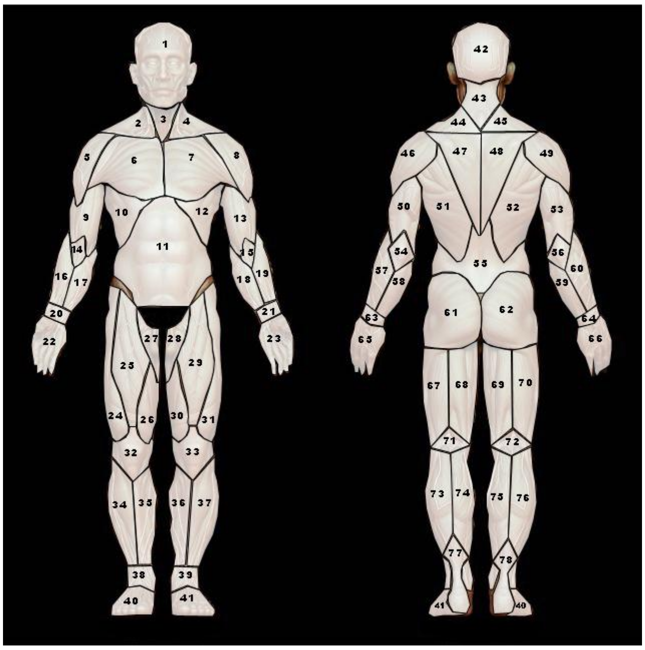

Fig. 1 - Distribution of the 78 Regions of Interest (ROI) made by Termotracker® software by analysing IRT images.

2.5 Statistics

Kolmogorov-Smirnov tests were used in order to verify the normality of the dependent variables and to determine the use of parametric or nonparametric statistics. The results indicated a normal frequency distribution, therefore parametric statistics were applied.

A two-way mixed model was used to determine: the Intra-class Correlations Coefficient (ICC) consider-ing the obtained data from two different computers (reliability of the software); the intra-examiner relia-bility (two thermograms of all subjects by the same researcher); and the reproducibility of thermal asymmetries between bilateral ROIs (ΔT) (obtained by two computers from two different thermograms). Coefficient of Variation (CV) (SD/mean * 100) was also used to analyze the dispersion of the data. In addition, Bland-Altman plots were calculated to show the intra-examiner agreement and the disper-sion of all readings with 95% agreement limits. Pearson Correlation Coefficient was calculated in order to describe the correlation of ΔT results be-tween 1st and 2nd thermogram. The level of signifi-cance was set at α=0.05.

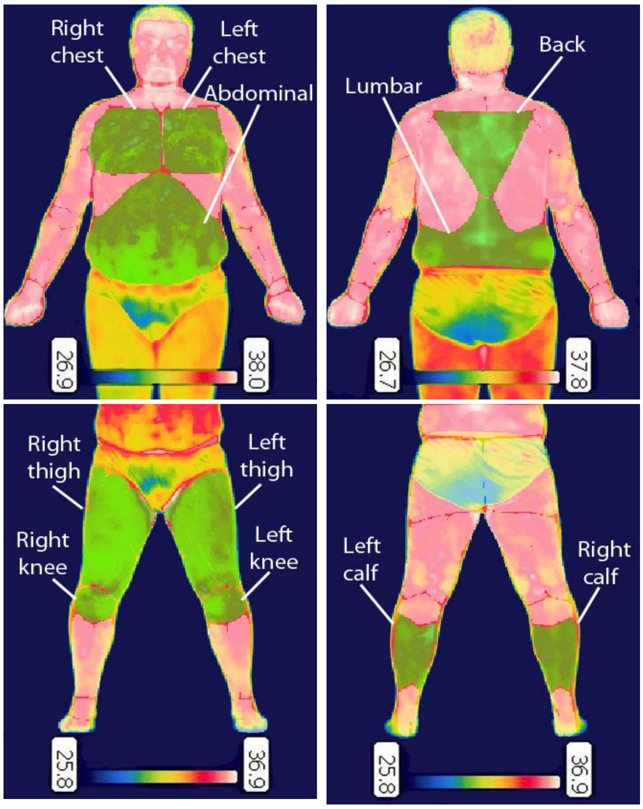

Fig. 2 - Anterior and Posterior IRT iamges of Upper and Lower body with the ROI selected by Termotracker® and analysed in this study (n=22).

3. RESULTS

Coefficients of Variation (CV) were calculated (see table 1) showing higher CV on the upper body ROIs (i.e. right and left chest, lumbar and ab-dominal) and lower CV on the lower body (i.e. right and left calf). Nevertheless, the CV results were ranged between 1.20% and 3.10% in both thermo-grams, with a CV mean value of 2.08% for the Thermogram 1, and 2.13% for Thermogram 2.

Concerning the side-to-side differences (ΔT) between bilateral ROI (see table 2), the bigger asymmetry was found on the knee, with a result of (ΔT = 0.13±0.38). Despite the fact of all subjects

Table 1. Mean temperatures with minimal and maximal values, standard deviations (SD) and coefficient of variation (CV) of each Region of Interest (ROI) on Thermogram 1 and Thermogram 2 (n=22)

	Skin temperature Thermogram 1			Skin temperature Thermogram 2		
ROI	Mean±SD	(min-max)	CV (%)	Mean±SD	(min-max)	CV (%)
Abdominal	31.05±1.33	(27.55-33.38)	2.45	31.00±1.37	(27.00-33.29)	2.83
Right Thigh	30.27±1.34	(26.59-31.78)	1.68	30.26±1.34	(26.59-31.84)	1.66
Left Thigh	30.35±1.38	(26.69-32.32)	1.79	30.34±1.40	(26.71-32.34)	1.83
Right Knee	30.11±1.18	(27.77-32.38)	1.83	30.13±1.21	(27.75-32.40)	1.88
Left Knee	30.25±1.30	(27.06-32.64)	1.89	30.26±1.32	(27.04-32.72)	1.92
Right Chest	31.49±1.16	(28.69-33.66)	3.09	31.54±1.13	(28.89-33.57)	3.10
Left Chest	31.42±1.16	(28.39-33.55)	2.96	31.46±1.13	(28.54-33.49)	2.96
Right Calf	30.79±1.08	(28.68-32.50)	1.20	30.79±1.06	(28.69-32.40)	1.20
Left Calf	30.88±1.12	(28.44-32.61)	1.25	30.87±1.11	(28.53-32.53)	1.24
Back	31.62±1.17	(28.82-33.65)	1.77	31.65±1.14	(29.03-33.66)	1.73
Lumbar	30.83±1.42	(27.79-33.08)	2.95	30.84±1.40	(27.95-33.08)	3.04
Mean±ST			2.08±0.68			2.13±0.72

were right handed, the results of ΔT show warmer skin temperatures in the left ROIs excepting the chest, were the right side was hotter than the left (ΔT = 0.08±0.22). Pearson Correlation Coefficient of ΔT results between thermogram 1 and thermogram 2 were very high ($r > 0.98$ in all bilateral ROIs; $p < .001$)

Intra-class Correlation Coefficients (ICC) analysis is summarized in table 3. On the one hand, the Intra-class Correlation Coefficients (ICC) from the analy-sis of the IRT images in two different computers was very high in all the ROIs (mean ICC = 0.999); on the other hand, the intra-examiner reliability using the software to analyse two consecutive thermograms of the same subjects was also very high (mean ICC = 0. 997). The lowest ICC value was found on the Abdominal ROI (ICC = 0.987). More-over, Figs. 3 and 4 show the Bland-Altman mean difference plots, which can be used to visualize the overall degree of agreement. In this case, they corre-spond to intra-examiner agreement between both thermograms (fig. 3) and both computers (fig. 4), with only 4.13% and 3.30% of all readings falling outside the 95% agreement limits respectively.

In table 4 the side-to-side differences (ΔT) results are summarized considering bilateral ROIs. The outcomes point out the high level of agreement between both computers (mean ICC = 0.998). Likewise, the reproducibility of ΔT between two consecutive themograms was also very high in all ROIs (mean ICC = 0.989), despite they were the lowest values compared with other reliability and reproducibility results (see table 5).

Table 2. Mean temperatures and standard deviations (SD) of thermal asymmetries (*ΔT*) –side to side temperature differences- of the Thermogram 1 and Thermogram 2. Pearson Correlation Coefficient between both Thermograms and p value **p < .001 (n=22)

	ΔT of ROI			
	Thermogram 1	Thermogram 2		
ROI	Mean±SD	Mean±SD	Pearson	P value
Thigh	-0.09±0.23	-0.08±0.23	0.998**	0.000
Knee	-0.13±0.39	-0.13±0.38	0.994**	0.000
Chest	0.07±0.23	0.08±0.22	0.986**	0.000
Calf	-0.09±0.33	-0.08±0.31	0.997**	0.000

4. DISCUSSION

Even if skin temperature is supposed to be constant along the time (9), or symmet-rical on both sides of the body in terms of skin temperature (18, 33), the list of factors affecting the skin temperature is so large (23), that a lack of feasibility on Tsk records could be considered one of the weakest points of IRT.

Therefore, working on the improvement of IRT for a wider application consists not only on making better cameras with advanced features, but also on deepen our knowledge about skin temperature, and how it behaves depending on the interaction with extrinsic and intrinsic factors. Among the enormous quantity of further work left to do, this study pre-tends to take two small steps forward: firstly, to analyse the reliability and reproducibility of IRT in a special population group, as overweight and obese people; and secondly, examining the reliability of a specific software created to analyse IRT images of human beings.

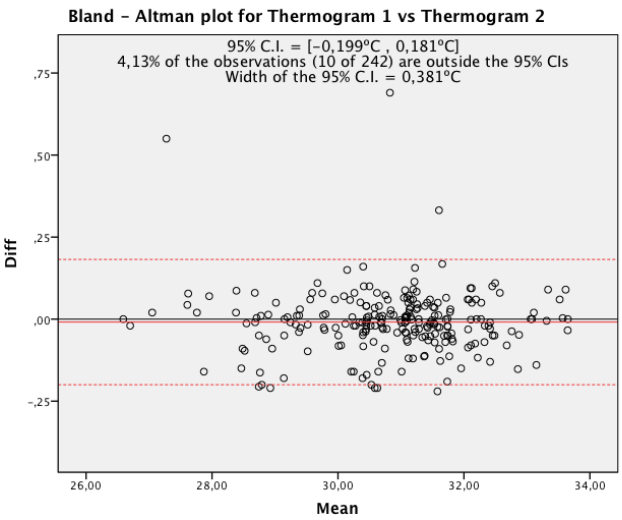

Fig. 3 - Bland – Altman plots for intra-examiner agreement between the same observed in two thermograms, 4.13% of all readings done fell outside the 95% agreement limits.

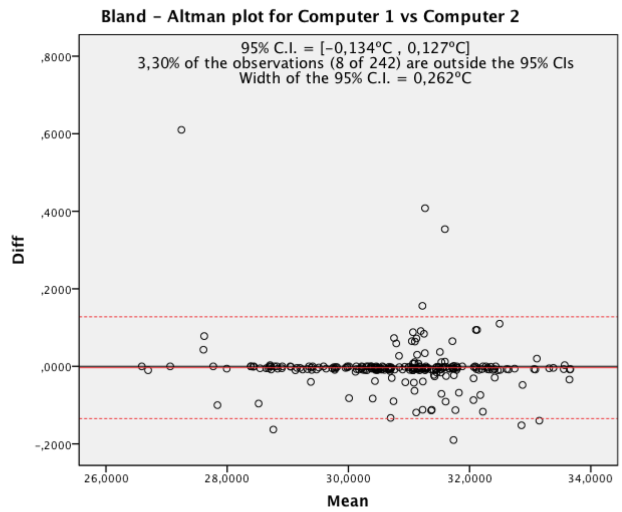

Fig. 4 - Bland – Altman plots for intra-examiner agreement between the same software in two computers. 3.30% of all readings done fell outside the 95% agreement limits.

Concerning the first objective, IRT reliability has been studied in several works, both with patients (6, 12, 28, 31) and healthy subjects (16, 21, 35). So far, most of the studies cited above reached ICC results ranged between 0.4 and 0.9. However, some of them reported the influence of factors as technical errors, the physiological variability from one day to other (35), or the existence of anterior injuries (12).
Consequently, we decided to use only one examiner, following a standardised protocol based on the guidelines of the EAT (2) with healthy subjects in two consecutive thermo-grams, separated by just 5 seconds in order to avoid the potential influence of those factors. According to the Littlejohn (16) classification of ICC values (poor: 0 – 0.39, Fair: 0.40 – 0.59, Good: 0.60 – 0.79 and Excellent: 0.80 – 1.0), our results showed excellent ICC values between the two consecutive thermograms (mean ICC = 0.997), what is almost perfect.

Table 4. Intra-class Correlation Coefficients (ICC) and their mean with Standard Deviation (SD) in two different computers with the same software Termotracker® and in two different thermograms for each Region of Interest (ROI) (n=22)

ROI	Software reliability (two computers)	Intra-examiner reliability (two thermograms)
Abdominal	0.997	0.987
Right Thigh	1	0.998
Left Thigh	1	0.999
Right Knee	0.999	0.998
Left Knee	0.999	0.999
Right Chest	0.999	0.997
Left Chest	0.999	0.998
Right Calf	0.999	0.998
Left Calf	0.999	0.999
Back	1	0.998
Lumbar	0.999	0.998
Mean±SD	0.999±0.001	0.997±0.003

Table 5. Intra-class Correlation Coefficients (ICC) and their mean with Standard Deviation (SD) for the reproducibility of thermal asymmetries (ΔT) of the bilateral Regions of Interest (ROI) in two different computers with the same software Termotracker® and in two different thermograms (n=22)

	Reproducibility of ΔT	
ΔT of ROI	Software	Thermogram
Thigh	0.998	0.980
Knee	0.998	0.994
Chest	0.996	0.985
Calf	0.999	0.996
Mean±SD	0.998±0.001	0.989±0.008

In addition, we took into account the growing use of thermal asymmetries in the application of IRT on humans (7, 18, 33, 34) to calculate the side-to-side differences (ΔT) in the selected bilateral ROIs. In that case, our reproducibility results of bilateral ΔT for two consecutive thermograms, if somehow

Table 6. Mean, minimal, maximal values of Intra-class Correlation Coefficients (ICC) with Standard Deviation (SD) for the reliability of the software and the examiner and the reproducibility of thermal asymmetries (ΔT) in two different computers with the same software Termotracker® and in two different thermograms (n=22)

	Min	Max	Mean	SD
Intra-examiner reliability (between two computers)	0.997	1.000	0.999	0.001
Intra-examiner reliability (between two thermograms)	0.987	0.999	0.997	0.003
Intra-examiner reliability (between two days) (Zaproudina et al. 2008) (n=16)	**0.080**	**0.780**	**0.880**	**0.210**
Reproducibility of ΔT (between two computers)	0.996	0.999	0.998	0.001
Reproducibility of ΔT (between two thermograms)	0.980	0.996	0.989	0.008
Reproducibility of ΔT (between two days) (Zaproudina et al. 2008) (n=16)	**-0.010**	**0.830**	**0.400**	**0.220**

slightly lower compared with the absolute Tsk values, were still excellent, with an ICC mean of 0.989. The highest results correspond to the calf and knee, reaching chest and thigh lower values. This difference could be related to the ROI size, but fur-ther investigations with more time between thermo-grams are required to check this tendency.

According to the second objective, we examined the reliability of a software created to analyse IRT images. Some authors reported inter-examiner variations (22, 35), due in some cases to the difficulty of selecting man-ually the areas of the ROIs (2). Therefore, in addition to the efforts done on creating standardised protocols and guidelines (2, 23, 27), it should be suitable to develop specific and automatic software able to manage with this difficult task. Termotracker® is a new software with a computer vision algorithm, which automatically identifies the body shape and the regions of interest from the IRT images, providing a database with the main data of the con-sidered ROIs. The results of reliability and reproduc-ibility reached in this study by the software Termotracker are almost perfect (between 0.998 and 0.999) –table 5-. By comparing the results with those ob-tained by Zaproudina et al. (35) (see table 6), the higher reliability even in ICC intra-examiner results could be due to this automatic process to identify ROI, task done in other studies by the observer (6, 12, 28). This automation of determining the areas of each ROI improves the IRT reliability, making possible a faster and more efficient IRT analysis of the thermograms from human beings. These results should be expected to be perfect (ICC = 1.0), but the few imperfections showed in figure 4 should be improved by removing some random parameters from the computer vision algorithms implemented in Thermotracker®.

In addition, the use of coefficients of variation (CV) showed a small dispersion of the Tsk in all ROIs. Our results are better than those reported by Zaproudina et al. (35), which indicated CV lower than 10%. Our CV mean values of 2.08% and 2.13% -Thermograms 1 and 2 respectively- reinforce the good data obtained on the reproducibility results. Likewise, Bland-Altman plots showed good results of intra-examiner agreement, with only 4.13% of the readings out of the 95% agreement limits between Thermograms 1 and 2, and 3.30% in the case of intra-examiner agreement between computer 1 and 2.

The distribution of skin temperatures showed warmer temperatures in the upper body ROIs, as back and right and left chest. The abdominal ROI will be supposed to be among or close to these values; but it reached lower Tsk values, which could be justify by the remarkable isolating effect of the sub-cutaneous fat in this body area (26). Colder temperatures are show on distal ROI as thighs or knees –table 1.

In general terms, the results of this study are coin-cident with those of Owens et al. (20) and Burnham et al. (4) with ICC over 0.9, but both au-thors did not used IRT cameras, but a handheld thermographic scanner and Infrared Skin Ther-mometer respectively. Other studies examining inter and intra-examiner reliability of IRT cameras reached good results (6, 12, 16, 21, 28, 31, 35), but none took as sample of overweight subjects, and reached so excellent ICC results like the ones showed in our study. Moreover, among the new technological features (15, 30, 31) and similar softwares (Murawski et al. 2003), Termotracker® seems to be one of the firsts IRT software created to analyse IRT images of human beings, which reported excellent reliability results. Nonethe-less, it should be improved until reaching ICC values of 1, to ensure an automatically perfect analysis of the considered ROIs in IRT images.

5. CONCLUSIONS

Skin temperature on overweight subjects has an excellent reproducibility for consecutive thermograms. The reproducibility of thermal asymmetries (ΔT) is also good but could be influenced by several factors that should be further investigated. The high reliability results of the software suggest the im-portance of using specific software to analyses IRT images on humans, eliminating the likely human error of drawing each ROI and improving the efficiency and objectivity of a technique with a high potential of application on humans. So that, we conclude that Termotracker® is a reliable and objective software to analyse IRT images of humans beings.

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