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History of Breast Thermography

Evaluation of three thermal cameras

Skin temperature changes using an elastic thigh bandage

Abstracts of the Annual AAT Meeting October 2012

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(1)International Committee of Medical Journal Editors. Uniform requirements for manuscripts submitted to biomedical journals. Can. Med Assoc J 1997;156;270-7.

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Chapter in a book

Gautherie M, HaehnelP, Walter JM, Keith L. Long-Term assessment of Breast Cancer Risk by Liquid Crystal Thermal Imaging. In: Gautherie M, Albert E, editors. Biomedical Thermology. New York Alan R.Liss Publ; 1982. p. 279-301.

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A Review of the History of Thermography in Breast Cancer Detection-Part I: Thermography Facts and Statistics

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SUMMARY

Thermography is currently used as a means of detecting breast cancer, predominantly in small private clinics and usually as an early screening modality prior to mammograms. In spite of the cost-saving nature and safety of thermography, there is little reliable, publically available evidence on thermography's effectiveness in detecting breast cancer. The purpose of this review is to provide a review of the relevantresearch literature in order to assist the medical professional in making informed choices about the role of thermography in the detection of breast cancer..

Peer-reviewed journal articles were consulted to elucidate the relative strengths and weakness of the use of thermography in breast cancer detection. This is not a systematic review; however, this review has been compiled using the best available evidence for a topic of limited scope. Great care has been taken to gather and accurately appraise data from reviews and evidence-based clinical studies. Part I of this review summarizes the results of 20 trials published between 1961 and 2004. These studies were highly heterogeneous in study design, evaluation criteria applied, populations investigated and results obtained. Some commonly asked questions about the use of thermography in breast cancer detection and the answers suggested by the available literature will follow in the second part of this review.

KEY WORDS: Breast thermography, history, diagnostic study, narrative review

EINE ÜBERSICHT ZUR GESCHICHTE DES EINSATZES VON THERMOGRAPHY ZUR BRUSTKREBS-ERKENNUNG- TEIL 1: FAKTEN UND STATISTIK

Thermographie wird zur Zeit als Methode zur Brustkrebserkennung überwiegend in kleinen Privatkliniken und normalerweise als frühe Suchmodalität vor der Mammographie verwendet. Trotz ihrer kostensparenden Art und der relativen Sicherheit von Thermographie, gibt es wenig zuverlässige, öffentlich zugängliche Nachweise für die Wirksamkeit der Thermographie hinsichtlich der Erkennung von Brustkrebs. Das Ziel diese eine Übersicht ist es, relevante Forschungsergebnisse darzustellen, um medizinischem Fachpersonal eine informierte Entscheidung für den Einsatz von Thermographie zur Entdeckung von Brustkrebs zu ermöglichen.

Begutachtete Fachartikel wurden konsultiert, um die relativen Vor- und Nachteile der Thermographie bei der Brustkrebsentdeckung zu klären. Dieses ist keine systematische Übersicht; jedoch wurde dieser Bericht unter Verwendung der besten vorliegenden Daten zusammengestellt, die für ein Thema mit eingeschränktem Umfang vorliegen. Große Sorgfalt ist bei der Datensammlung angewendet worden und die Fakten aus Übersichten und evidenzbasierten klinischen Studien wurden umfassend bewertet. Der Teil I dieses Berichts fasst die Ergebnisse von 20 Untersuchungen zusammen, die zwischen 1961 und 2004 veröffentlicht wurden. Diese Studien waren im Studiendesign, in den angewendeten Bewertungskriterien, in den untersuchten Personengruppen und in den erzielten Ergebnissen im hohen Grad heterogen. Einige üblicher Weise gestellte Fragen über den Gebrauch von Thermographie in der Brustkrebsentdeckung und die Antworten, die durch die verfügbare Literatur vorgeschlagen werden, folgen im zweiten Teil dieser Übersicht.

SCHLÜSSELWÖRTER:: Brust Thermographie, Geschichte, diagnostische Untersuchung, narrative Übersicht

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A Brief History and Description of Thermography

Thermography has been successfully utilized to detect breast tissue abnormalities since the mid 1950's [1-3]. In 1973, the National Cancer Institute and American Cancer Society began the Breast Cancer Detection Demonstration Project (BCDDP) to examine the feasibility of mass-screening for breast cancer in women of various ages. This project used clinical examinations, mammography and, for a time, thermography, in breast cancer screening. However, in 1978, the National Cancer Institute recommended that the use of thermography be discontinued and this modality was removed from the BCDDP study before much meaningful data about thermography could be collected (Figure 1).The recommendation to discontinue thermography was in large part due to inconsistent results from poor image quality and temperature resolution and high

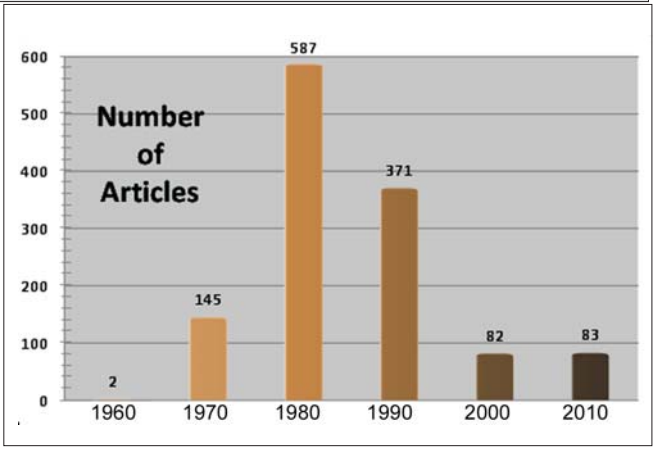

Figure 1.
A rudimentary search of the terms "thermography AND breast cancer" in PubMed shows the rise and fall of published reports of thermography within 10 year blocks from 1950-2010.

false-positive rates [4,5]. Additional set-backs in the use of thermography are thought to be due to clinical expectations that it could be used as a diagnostic tool rather than a method of early detection of breast tissue abnormalities. Recent emerging technological improvements in thermography as well as the desire to better address concerns over mammography (radiation exposure, patient discomfort, cost, etc.) has revived interest in this modality.

The use of thermography as a means of identifying possible abnormalities in breast tissue relies on the principle that all objects with a temperature above absolute zero emit infrared energy. The ability to measure the temperature of a body using infrared radiation emitted at wavelengths between 3-12mm creates a visual representation using either colors or grey scale for visualization and quantification [6]. The temperature reading is compared to the same area on the contralateral breast by an infrared camera, and converted to an image through a computerized processing system. In this way, any asymmetrical heat patterns can be discerned. Modern equipment can discriminate a temperature change as small as 0.05°C or better [7,8].

While other screening techniques such as mammogram and ultrasound depend on anatomical changes to detect abnormalities in breast tissue, thermography recognizes physiological changes that are read as asymmetric heat patterns. These asymmetric profiles, in and of themselves, are not indicators of any particular state of the breast tissues. They could be due to a variety of factors, such as taking oral contraceptives, estrogen-related vasodilatation, menstrual cycle, pregnancy, trauma, infection, benign lesions, inflam- mation and other non-malignant vascular changes, etc. [9,10]

An asymmetric heat pattern may also be caused by angiogenesis (the growth of new blood vessels), which is detected by thermography because of unregulated hyperemia of body core-temperature blood perfusion to the tissue. Part of this process is thought to be due to the production of nitric oxide by a lesion, be it benign or malignant. Nitric oxide can act as a potent vasodilator, resulting in increased trafficking of nutrients and oxygen to the site, which in turn may encourage the growth of new blood vessels (Figure 2). Angiogenesis may be an early indicator

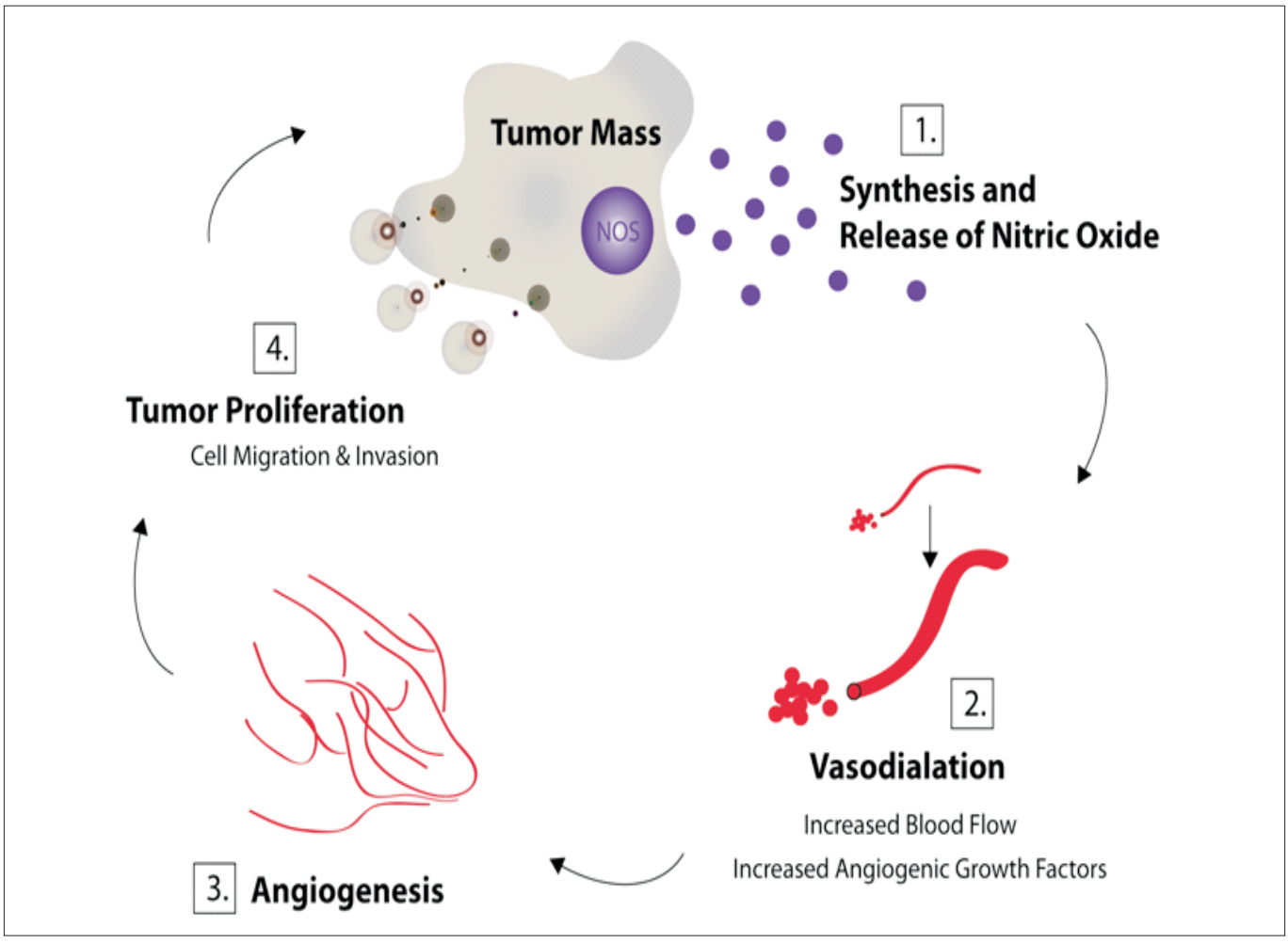

Figure 2.
Nitric oxide is a signaling molecule found in nanomolar quantities throughout the body and is involved in a variety of biological functions, including the inflammatory and immune responses, neuronal signaling, and cardiovascular health.
1. Tumors express nitric oxide synthetase (NOS), the synthesizing molecule of nitric oxide.
2. Nitric oxide diffuses across membranes and can act as a vasodilator (relaxer) on near-by blood vessels.
3. This increases local blood flow, bringing angiogenic growth factors that stimulate the growth of new blood vessels (angiogenesis).
4. This increased vascularization results in augmented blood and nutrient flow to the tumor, which in turn, stimulates growth, migration and invasion.

of future invasive breast cancer and may be a marker for ductal or lobular carcinoma *in situ* (DCIS or LCIS).

Thermography alone does not give information about the inner cellular composition of a lesion; nor does it see depth or define the physical size of a lesion. It merely provides information on temperature differences compared to a reference area. There are no homogeneous phenotypes or manifestations of breast cancer; therefore, thermal asymmetry between breasts should be taken as an indication for a follow-up examination (Figure 3A-B).

The following table 3 "Thermography Facts " outlines information from 20 clinical studies on the use of thermography in breast cancer detection. Of these studies, 12 were more heavily weighted than others based on several factors, including: whether the study cohort was sufficient for meaningful analysis, whether methodology was reported and whether statistical analysis could be performed by the amount of data disclosed in the report. There are several caveats to keep in mind when interpreting any of the clinical thermography studies.

Results

The 20 papers selected have been published between 1961 and 2004. 3 papers had their focus on methods for detecting breast cancer by thermography [13,14,15], 10 papers reported prospective investigations [3,5,10,11,12,16,20,21, 22, 24,25], 3 publications obtained data from retrospective studies [8,18,19]. The remaining 3 studies have been designed in both ways, in retrospective and prospective manners [17,23,27].

Populations investigated

The size of cohorts reported varied between 23 [12] and 11240 [5] subjects. In 6 clinical studies [18, 20, 21, 22, 25, 27] samples representative for the general female population have been investigated, the remaining 11 clinical studies have been conducted in women with various breast diseases. Mean age of investigated subjects was in the range between 43 [13] and 53.9 years [24], the age of the youngest woman studied was 20 years [19], the oldest was 80 years of age [11].

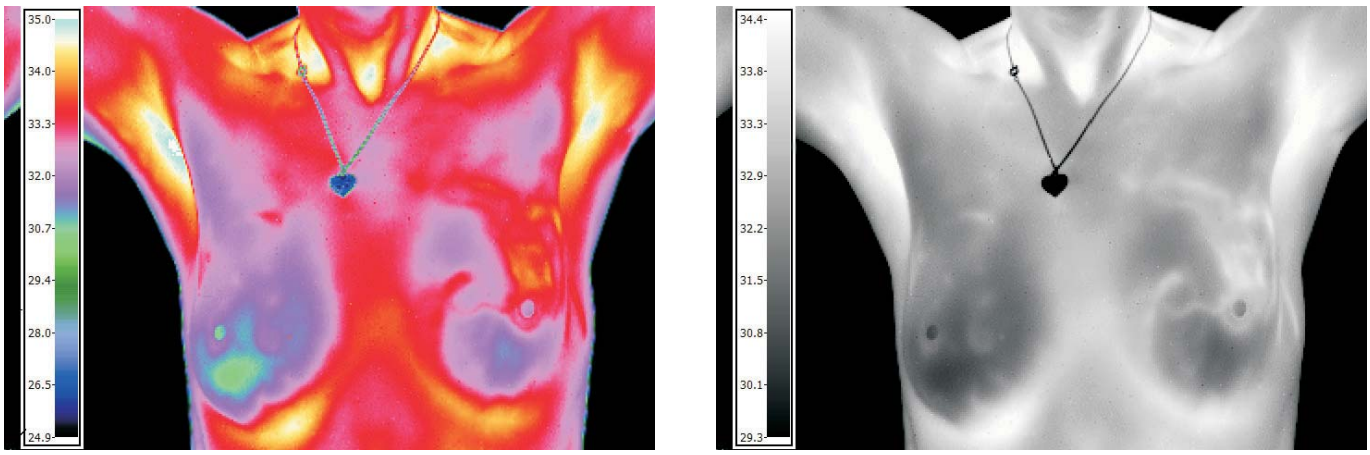

Figure 3A.
A patient who had a normal mammogram and breast MRI shows an asymmetric heat pattern (left image) and signs of angiogenesis (right image) in the left breast.

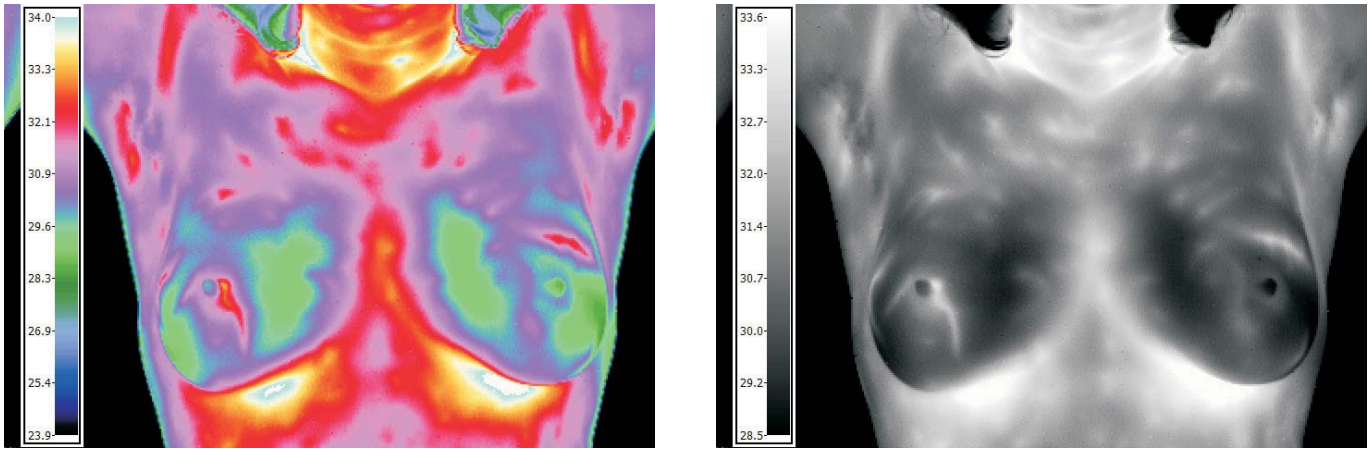

Figure 3B.
This patient presented with a palpable lump in the right breast. The thermogram reveals hyperthermic vascular asymmetry. Biopsy confirmed extensive ductal carcinoma.

Table 3 Thermography facts

Author	Referenz	Affiliation	Publish date	**Study date**	**Type of study**	**Study topic**	**Study size at onset (n)**	**Study reports on (n)**
Arena et al.	11	Arena Oncology Associates, NY	2003	-	prospective	The benfit of IR in detecting small, early-stage cancer	351	238, 67, 46
Head et al.	12	Mastology Research Institute, Baton Rouge, LA	2001	-	prospective	Determining the temperature parameters of normal breast tissue	23	23
Ng et al.	13	Nanyang Tech University, Singapore	2004	-	technical	Computer modeling for early detection	3	3
Qi et al.	14	University of Tennesee, Knoxville, TN	2001	-	technical	Examines a pattern classification approach to help automate anaysis of asymmetrical temperature patterns	-	-
Qi et al.	15	Univesity of Tennesee, Knoxville, TN	2000	-	technical	Examines a pattern classification approach to help automate analysis of asymmetrical temperature patterns	-	-
Yahara et al.	16	Kurume University School of Medicine, Japan	2003	1997-1999	prospective	Evaluate the validity of thermography for breast lesions	48	48
Gamagami et al.	17	The Breast Center, Van Nuys, CA	1997	1982-1995	Prospective, retrospective	Examines whether retro evidence of angiogenesis could be seen in mammography as predictor or early cancer; Thermography to improve early detection	530; 168	530; 168
Head et al.	18	Medical Thermal Diagnostics, Baton Rouge, LA	2000	1973-1981, >1989	Retrospective	Examining new generation technology for improved risk assessmnt, detection, diagnosis, and prognosis; report on a subset of 2nd generation patients in context of 1993 study	546	220 (patients scanned w/ 2nd generation technology)
Geser et al.	19	University of Zurich, Switzerland	1987	-	retrospective	Comparing 2 methods for quantitative parameters for thermography (dynamic vs. steady state), analyzed in terms of diagnostic relevance	213	162, 51, 29
Amalric et al.	20	Cancer Institute and Associated Clinics in Marseilles France	1982	1970-1980	prospective	role of thermography in 10 years history of breast cancer management	61.000	6822
Davey et al.	21	Royal Marsden Hospital, London	1970	1968-1969	prospective	thermology as mass screeninng tool	1768	1717
Dodd et al.	22	Department of Radiology at Jefferson Medical College Hospital, University of TX MD Anderson Hospital and Tumor Institute	1969	1964-1969	prospective	thermography to detect breast cancer and as a mass screening tool	4726	597
Head et al.	23	Elliot Mastology Center, LA in conjunction w/ BCDDP	1993	1973-1981, >1989	Prospective, retrospective	thermography as a prognostic tool and predictor of tumor growth rate	326	126, 100, 100
Isard et al.	10	Albert Einstein Medical Center	1972	1967-1970	prospective	thermography in breast cancer detection	10.055	5662, 4393
Jones et al.	24	Royal Marsden Hospital, London	1975	1967-1972	prospective	thermography to detect and prognosis breast cancer	>12,000	1464
Keyserlingk et al.	8	Ville Marie Breast and Oncology Center, Montreal, Quebec, Canada	1998	-	retrospective	compares thermography, mammography & clinical exam for breast cancer detection	100	100
Parisky et al.	25	USC/Norris Cancer Center, Los Angeles, CA; St. Agnes Healthcare, Baltimore, MD; Providence Hospital, Washington, D.C.; Lahey Clinic Northshore, Peabody, MA; Mt Sinai Medical Center, Miami, FL	2003	4 year study	BLIND prospective	efficacy of dynamic computer InfraRed image system for cancer vs. benign	2.400	1231
Stark	5	Queen Elizabeth Hospital, Gateshead, Co. Durham, England	1985	1968-1974, 1974-1984	prospective	thermography for early detection and risk factors	11.240	5825, 3881, 1534
van Dam et al.	26	Department. of Gynecology, Antwerp University Hospital., Belgium	1988	1982-1986	BLIND retrospective	assessing multi modality testing of palpable masses	1340	201
Lloyd-Williams et al.	3	Middlesex Hospital, London	1961	1960-1961	prospective	thermography to diagnose breast abnormalities	100	100
Lloyd-Williams et al.	27	Royal United Hospital, Bath, UK	1990	5 years	Prospective, retrospective	thermography to detect breast cancer, detect at risk groups	10.238	9819

Table 3 continued

Author	Sub-groups	General population	Groups Compared	Study findings	Technology
Arena et al.	prior cancer group had lumpectomy 1-10yrs prior	NO- A priori knowledge of cancer	cancer free vs. newly diagnosed vs. prior cancer	Thermography useful for early detection	-
Head et al.	-	Yes-screening	all healthy	Objective temperature cutoffs can improve sensitivity & specificity; Differences >0.05°C are consistent with high risk of breast cancer and poorer prognosis	Prism 200 IR Imaging System
Ng et al.	-	NOused 3 test cases	3 test cases	Could help eliminate false findings	-
Qi et al.	-	-	-	-	Inframetrics 600M camera (thermal sensitivity 0.05°K)
Qi et al.	-	-	-	-	Inframetrics 600M camera (thermal sensitivity 0.05°K)
Yahara et al.	-	NO-known primary invasive ductal carcinoma	cancer	Findings suggest relationship between core temperature and high-risk group and core temperature and size of abnorml spot on thermogram	Liquid crystal contact thermography
Gamagami et al.	cancer with prior mammography; cancer before and during chemotherapy	NO-some screening, some 2nd opinion on cancer diagnosis	confirmed cancer	Thermography is a better indicator than a prognostic tool for breast cancer, Thermography combined with mammography is a more powerful screening tool for early dedection	-
Head et al.	types of abnormal pattern	YES (2nd gen)-screening	1st gen vs. 2nd gen findings	2nd gen focal-plane system had increased sensitivity (better detected vascular asymmetry)	Inframetrics scanning mercury-cadmuim-telluride detector system and Amber focal-plane system for comparison
Geser et al.	Symptomatic cancer, cancer w/ both methods	NO-all had breast diseases	cancer vs. no cancer	Methods had similar findings diagnostically, in one case dynamic method prevented a false positive	-
Amalric et al.	confirmed cancer	YES	confirmed cancer vs. benign	despite high false+, when combo w/ other modalities it improves or gives information on diagnosis, detection, prognosis, follow-up, risks	-
Davey et al.	patients who had thermograms	YES (wellness screening)	cancer vs. no cancer	useful as adjunct to clinical exam & mammography	Pyroscan infrared detector
Dodd et al.	first half of study reported	YES	cancer vs. normal + benign	may find at risk groups	Pyroscan thermographic unit
Head et al.	deceased, living w/ cancer, living screened	NO	living and dead cancer vs. benign w/ mastopathies	tumor size and indicators of tumor growth rate (ex. Ferritin) were related to abnormal thermogram)	Inframetrics scanning mercury-cadmium-telluride detector system (North Billerica, MA), Amber focal-plane, indium-antimonide, staring array system (Raytheon, INC., Dallas, TX)
Isard et al.	symptomatic, asymptomatic	NO -special group (all referred for mammography)	cancer vs. benign + normal	improves accuracy of diagnosis in symptomatic group w/ mammography and exam, finds high risk in asymptomatic group	AGA Thermovision Unit
Jones et al.	biopsy or histology performed	NO -special group (all had biopsy)	cancer vs. benign in biopsy group	stage of disease affects thermographic assessment, thermography should be used as adjunct to mammography	Smith's Pyroscan (Mark IIb) infrared scanner, or Rank Thermographic System (after 1971)
Keyserlingk et al.	clinical exam, mammography, thermography	NO -special group (all have cancer)	determined cancer vs. suspicious benign	combo of modalities increases detection rates	Scanning mirror optical system w/ mercury-cadmium-telluride detector (Bales Scientific, CA)
Parisky et al.	biopsies, microcalcifications excluded	NO -special group (all referred for biopsy)	cancer vs. benign in biopsy group	valuable as adjunct to mammography and ultrasound	BCS2100 dynamic computerized infrared imaging system (Computerized Thermal Imaging, Ogden, UT)
Stark	no risk, 1 risk factor, >1 risk factor	YES	cancer vs. no cancer	Thermography is not diagnostic, but valuable as risk factor	AGA Thermovision Unit
van Dam et al.	lump in breast	NO -special group (all had lump)	cancer vs. benign	limitations of individual modalities were compensated by others, but authors conclude thermography is not a necessary part of combo	-
Lloyd-Williams et al.	all had lump in 1 breast	NO -special group (all had lump in 1 breast)	cancer vs. benign in group w/ lumps	may differentiate cyst from cancer by temperature	Schwarz thermopile with calcium flow window
Lloyd-Williams et al.	follow-up after 5 years via clinical records	YES	cancer vs. no cancer	not sensitive as screen tool, not good risk indicator	AWRE, Aldermaston & Barr and Stroud; Rank Precision Industries

Tabelle 3 continued

Author	Methods	Mean age (years)	Abnormal thermogram (classification)	Abnormal thermogram (criteria)	Cancer type x thermography	Benign type x thermography
Arena et al.	thermography	35-80	% exceeding risk for threshold, nipple, areolar, global, aysmmetry, hot spot	Algoritm of quantifiable parameters	NO	NO
Head et al.	clinical exam, thermography, mammography, ultrasound	-	asymmetric heat patterns	temperature difference 0.5°C for whole breast, 1.0°C for breast quadrants	NO	NO
Ng et al.	thermography	43 (38, 43, 47)	-	-	-	-
Qi et al.	thermography	-	5 procedures for auto analysis of asymmetry	-	-	-
Qi et al.	thermography	-	5 procedures for auto analysis of asymmetry	-	-	-
Yahara et al.	thermography, needle-thermometer for core temperature of tumour	50 (27-76)	asymmetric heat patterns		Yes	NO
Gamagami et al.	thermography, mammography	-	-	-	NO	NO
Head et al.	thermography, mammography	-	asymmetric heat patterns	focal hot spots, areolar and/or periareolar heat, vessel discrepancy, diffuse global heat, or thermographic edge signs	NO	NO
Geser et al.	thermography	(20-75)	DTH 1-5 rating for thermograms (1-3 negative thermograms, 4-5 positive thermmograms)	1=normal, 2=inconspicuous, 3=inconspicuous w/ some evident signs, 4=conspicuous, 5=highly conspicuous	NO	NO
Amalric et al.	clinical exam, thermography, mammographyg	-	TH 1-5 rating for thermograms	1=normal, 2=benign, 3=one suspicious sign, 4=sign of malignancy or several suspicious signs, 5=several signs of malignancy	NO	NO
Davey et al.	clinical exam, thermography, mammographyg	-	asymmetric heat patterns	temperature change of >1.5°C	NO	NO
Dodd et al.	clinical exam, thermography, mammographyg	-	asymmetric heat patterns	criteria not given	NO	NO
Head et al.	clinical exam, thermography, mammography	-	asymmetric heat patterns	focal hot spots, areolar and/or periareolar heat, vessel discrepancy, diffuse global heat, or thermographic edge signs	NO	NO
Isard et al.	clinical exam, thermography, mammography	-	asymmetric heat patterns	avascular, vascular, mottled	NO	NO
Jones et al.	thermography	51.3 normals, 53.9 abnormals	normal, equivocal, abnormal	normal-symmetry between breasts, equivocal-some asymmetry with temperature increase of ~1°C, abnormal-prominent regions of temperature increase >1.5°C	NO	YES
Keyserlingk et al.	clinical exam, thermography, mammography	53	Ville Marie IR Grading scale	one or more abnormal signs	NO	NO
Parisky et al.	thermography, ultrasound	-	index of suspicion	numeric value that ranges from 0 to 100 (higher number=higher suspicion of malignancy)	NO	NO
Stark	clinical exam, thermography, mammographyg	-	asymmetric heat patterns	difference of > 1.5°C, localized, areolar, and/or focal heat difference, cold spot surrounded by heat	NO	NO
van Dam et al.	clinical exam, thermography, mammography, ultrasound	46,7	TH I-V rating for thermograms	THI and THII considered benign, > TIII considered cancer	NO	YES
Lloyd-Williams et al.	clinical exam, thermography	-	asymmetric heat patterns	temperature change of >1°C	NO	YES
Lloyd-Williams et al.	clinical exam, thermography, mammography	-	asymmetric heat patterns	difference of > 1.5°C, heat change in areola, generalized, localized, localized increased vascularity	NO	NO

Table 3 continued

Author	Tumor stage x thermography	Symptoms	Cancer confirmation	Follow-up	Worthwhile comparisons	Confounding factors
Arena et al.	NO	-	biopsy	NO	-	specialized group with known cancer made statistics of 98% sensitivity
Head et al.	NO	Asymptomatics	-	NO	Right breast temperature were all slightly higher than left, suggests heart may be an influence on right side	Not a comparison study
Ng et al.	-	-	-	-	-	-
Qi et al.	-	-	-	-	-	-
Qi et al.	-	-	-	-	-	-
Yahara et al.	Hot area x thermography	-	histology	NO	Comparison of Pathological and Thermographic Areas of the Tumor	Cancer group only
Gamagami et al.	NO	Symptomatics, Asymptomatics	Proven prior to study	NO		Methods are not detailed
Head et al.	YES	Asymptomatics	-	NO, but results were retrospectively compared to prior exams, thermography had abnormal results 1 year prior todiagnosis, some up to 8 years prior	3 risk factors compared to therm results from 1st and 2nd gen technology, but they did not correlate with findings from either system, so abnormal thermogam is an independent risk factor ; tumour size (based on palpation, but not surgical measurements) was related to thermographic findings (larger were more likely to have abnormal thermograms)	No report on benign findings or on actual diagnosis when comparing 1st and 2nd generation
Geser et al.	NO	Symptomatics	Proven prior to study	NO		
Amalric et al.	YES	-	histology	NO		statistics for normal not included
Davey et al.	NO	mostly Asymptomatics	biopsy	NO		
Dodd et al.	NO	at least 320 Asymptomatics	biopsy	YES, 3mo-2yrs, 19 cancers		
Head et al.	YES	Symptomatics	biopsy	NO	proliferation rate markers by thermography	benign were all mastopathies, no real normals
Isard et al.	NO	56% Symptomatics, 44% Asymptomatics	biopsy	YES, clinically normal with abnormal thermograms followed seveeral years, 9 cancer	entire analysis compares symptomatics to asymptomatics	benign with abnormal thermograms, #'s don't add up
Jones et al.	YES	33% Symp 6tomatics 7% Asymptomatics	biopsy	YES, for survival rates (1-72 mo)	172 cancer survival rate compared to thermograms, stage, grade of tumour	no outcome for benign given
Keyserlingk et al.	NO	94% Symptomatics, 6% Asymptomatics	biopsy	NO	thermogram grading scale, relative sensitivity of 3 modalities	1. doesn't define benign #'s; method of reporting clinical exam results changed over course of study
Parisky et al.	NO	-	biopsy	NO	types of cancer & benign disease listed, not by thermography	1. there were 875 biopsies, but statistics include 3 evaluations each (n=2299), but each assessment was weighted accordingly; 2. evaluators had mammograms and clinical findings prior to thermography assessment
Stark	NO	Asymptomatics	-	YES, 10-16.5 years, 5 cancers	risk factors association with results	1. no mention of benign vs. normals; 2. some #'s don't add up
van Dam et al.	NO	Symptomatics	histology	NO	sensitivity vs. tumor size for each modality, sensitivity vs. tumour as function of menopause status, indep results by modality, % of cancers by types	2 radiologists interpret thermograms (but says they are experienced), no mention of thermographic equipment used
Lloyd-Williams et al.	NO	Symptomatics	histology	YES, 6-18 mo, no report	temperature of thermograms	1. bias for cancer; 2. exam room temperature not controlled; 3. equipment outdated
Lloyd-Williams et al.	NO	at least 229 Symptomatics	-	YES, 5 years, 60 cancers (17 with abnormal thermograms, 28%; 43 with normal thermograms 72%)	thermogram vs. tumor size	1. Thermography was assessed before clinical exam-possible bias for exam results; 2. no mention of benign lesions found; 3. no mention of how cancer was confirmed

Table 3 continued

Author	Strengths	# of negative tests: cancer	# of negative tests: benign	# of negative tests: normal	# positive test: cancer	# positive test: benign	# positive test: normal
Arena et al.	-	1 of 67 (1.5%)	-	131	66	-	107
Head et al.	-	-	-	-	-	-	-
Ng et al.	-	-	-	-	-	-	-
Qi et al.	-	-	-	-	-	-	-
Qi et al.	-	-	-	-	-	-	-
Yahara et al.	-	5	-	-	43	-	-
Gamagami et al.	91% of cases had detectable angiogenesis long before abnormalities were detectable by mammography; 15% cases thermography prompted biopsy of unsuspicious area on mammography and found cancer	-	-	-	-	-	-
Head et al.	As a study: well-characterized data base with many factors compared; As a diagnostic tool: 2nd gen helps provide semi-quantitative risk subgroups	-	-	-	.	-	-
Geser et al.	-	14	130	-	37	32	-
Amalric et al.	large study=experience	418 of 3847 (11%)	2631 of 2975 (88%)	-	3429 of 3847 (89%)	344 of 2975 (12%)	.-
Davey et al.	Thermography lead to mammography for some that seemed normal, 2 cancers found	4 of 15 (26%)	-	1516 of 1520 (99.7%)	11 of 15 (73%)	-	186 of 197 (94%)
Dodd et al.		9 of 69 (13%)	combo w/ norm	342 of 528 (65%)	60 of 69 (87%)	combo w/ norm	186 of 528 (35%)-
Head et al.	abnormal thermogram is independent risk factor	live 35 of 100 (35%), dead 15 of 126 (12%)	72 of 100 (72%)	-	live 65 of 100 (65%), 111 of 126 (88%)	28 of 100 (28%)	-
Isard et al.		88 of 306 (29%)	combo w/ norm	6895 of 9749 (71%)	218 of 306 (71%)	combo w/ norm	2854 of 9749 (29%)
Jones et al.	3 cases in situ cancer found in asymptomatic, 61% occult cancer detected	68 of 363 (19%)	690 of 1101 (63%)	-	248 of 363 (68%)	240 of 1101 (22%)	-
Keyserlingk et al.	found 3 of 4 in situ cancers	17 of 100 (17%)	81 of 100 (81%)	-	83 of 100 (83%)	19 of 100 (19%)	-
Parisky et al.	Thermography detected smaller tumors than mammography, found 4 of 4 with ductal carcinoma in situ(DCIS)	1 of 292 (.3%)	171 of 939 (18%)	-	291 of 292 (99.6%)	768 of 939 (82%)	-
Stark	w/out abnormal thermogram as a risk factor 7 separate evaluators 99 cancers missed	58 of 414 (14%)	-	9683 of 9741 (99%)	346 of 414 (23%)	-	1153 of 1499 (77%)
van Dam et al.	modalities done independent of others	48 of 95 (51%)	91 of 106 (86%)	-	47 of 95 (49%)	15 of 106 (14%)	-
Lloyd-Williams et al.	shows fibroadenomas as abnormal 50%, hot tumors are often cancer and inflammation-cold are degenerative lesions (except fat necrosis)	3 of 57 (5%)	32 of 43 (74%)	-	54 of 57 (95%)	11 of 43 (26%)	-
Lloyd-Williams et al.	7 of 11 tumours <10mm found by thermography	23 of 59 (39%)	-	9683 of 9741 (99%)	36 of 59 (61%)	-	2444 of 10170 (24%)

Tabelle 3 continued

Author	Sensitivity	Specificity	Overall Accuracy	PPV	NPV	False positives	False negatives	Under-recognized	Mean tumor size	Cancer x therm	Cancer x combo	Different iation	Meta-analysis
Arena et al.	98	55	76	38	99	45	1	No	-	--	2 had either abnormal manmography or Ultrasound and abnormal thermography found to have atypical hyperplasia	No	No-A priori knowledge of cancer
Head et al.	-	-	-	-	-	-	-		-	--	-	-	No-did not provide follow-up for diagnoses
Ng et al.	-	-	-	-	-	-	-		-	-	-	-	No-technical paper
Qi et al.	-	-	-	-	-	-	-		-	-	-	-	No-technical paper
Qi et al.	-	-	-	-	-	-	-		-	-	-	-	No-technical paper
Yahara et al.	90	-	-	-	-	-	10		-	-	-	-	No-only cancer analyzed, A priori knowledge of cancer
Gamagami et al.	-	-	-	-	-	-	-		-	-	-	-	No-A priori knowledge of cancer; no methods described; results are conference presentation
Head et al.	-	-	-	-	-	-	-		-	-	-	-	No-do not provide actual diagnosis when comparing 1st and 2nd gen
Geser et al.	73	80	78	54	90	20	27	YES	-	-	-		YES
Amalric et al.	89	88	89	91	86	12	11	NO	54% were 2-5cm	74% missed by exam, 81% missed by mammography, thermography found 6 of 10 nonpalpable cancers missed by both others	2 of 220 (1%)	Yes	YES
Davey et al.	73	89	89	6	100	11	27	YES	13 of 15 palpable	-	-	Yes	YES
Dodd et al.	87	65	67	24	97	35	13	NO	-	-	-	No	YES
Head et al.	65	72	69 living, 81 dead, total 76	70	67	28	35	YES living, NO dead	-	.	-	No, Yes	YES
Isard et al.	71	72	71	7	99	29	29	equal	-	10 missed by thermography were found by mammography	4 found by blind biopsy	No	YES
Jones et al.	68	63	64	51	91	22	19	NO	-	-	-	No	YES
Keyserlingk et al.	83	81	82	81	83	19	17	NO	Exam average 2.5cm average by thermography 1.28 average by mammography 1.6	10 of 15 missed by mammography, 6 of 8 missed by clinical exam	2 missed by all 3 modalities	Yes	YES
Parisky et al.	97	18	38	27	99	82	0	NO	-	-	-	No	YES
Stark	86	89	89	23	99	11	14	YES	-	-	-	Yes	YES
van Dam et al.	49	86	69	76	65	14	51	YES	48% <2cm, 52% >2cm	2 of 6 missed by mammography	3 missed by all 4 modalities	No	YES
Lloyd-Williams et al.	95	74	86	83	91	26	5	NO	-	-	-	Yes	YES
Lloyd-Williams et al.	61	76	76	1	100	24	39	YES	<10mm +	-	-	No	YES

4 studies compared thermograms from patients with breast cancer with women without cancer [5,19, 21, 27,], 9 other studies compared cancer with benign lesions [3,8,10,20, 22, 23, 24,25,26]. One study compared thermograms recorded with 1st generation equipment with thermal images taken with 2nd generation imagers [18], another investigation evaluated thermal findings from cancer free women versus newly diagnosed patients versus previous cancer cases in patients after lumpectomy 1 to 10 years prior [11].

Evaluation of thermograms

Asymmetry of heat patterns was the predominant classification of abnormal thermograms [3,5,10,12,16,18,21,22, 23,27], 3 studies applied a 5-step rating system [19,20, 26), 1 study used the 4-step Ville Marie Grading Scale [8] and another study a 3-step scale [24]. Two studies, both authored by H.Qi, reported a system for automatic analysis of asymmetry [14,15]. Parisky developed a numerical index of suspicion from 0 to 100, in which higher numbers represent an higher suspect of malignancy [25]. Arena et al. based their diagnosis of breast cancer on the results of an algorithm that calculated the risk from temperature values and differences from and between various areas of the breast during a controlled cooling procedure with air [11].

Only 6 papers [3,5,12,21,24,27] mentioned temperature thresholds of normality. These abnormal temperatures varied between 0.5 and 1.5 degrees Celsius.

Reference method for proven cancer

2 studies reported that breast cancer was proven prior to the study [17, 19]. In 12 studies [3,8,10,11,16,20,21,22,23,24, 25,26] the diagnosis breast cancer was confirmed by histological findings from biopsies.

Follow-Up

The patients from studies[8,11,12,16 17, 18, 19, 20, 21, 23,25,26] have not been followed up.The time interval from the end of the original study to re-examination varied between from 3 months to 2 years [22] and 10 to 16,5 years [5].

Diagnostic value (sensitivity, specificity, accuracy)

As groups with various breast health conditions have been compared to patients with breast cancer using different reference methods, the diagnostic sensitivity, specificity and total accuracy varied between studies. Table 4 shows the diagnostic values calculated with the data from Lloyd-Williams et al [27]. While the sensitivity for established breast cancer is moderate with 61% (table 4a), the sensitivity for developing malignancy is 28.3% only (table 4b). The specificity, a measure of the ability s to detect healthy women without breast disease was good with 76 % and 74% respectively. Parisky et al investigated a group of 769 females who previously had in total 875 biopsied lesions resulting in 187 malignant and 688 benign findings [25]. In this sample a high diagnostic sensitivity of 97% was obtained, but specificity was very poor (table 5).

The final example is taken from a study by Keyserlingk et al [18].The authors investigated 100 females with malignant findings in biopsies and 100 females with benign histological changes and compared the diagnostic ability of thermography related to clinical examination, mammography and biopsy (table 6). For biopsy results only, a

Table 4a
Diagnostic value of thermography for patients with clinical or radiological evidence of breast cancer at screening examination [27]

	Cancer	Healthy	Total	PPV	NPV	Sensitivity	Specificity	total accuracy
Positive test	36	2444	2480	1.5	99.7	**61.0**	76.0	75.9
Negative test	23	7726	7749					
Total	59	10170	10229					
False positive		2444						
False negative	23							

Table 4b
Diagnostic value of thermography for patients with clinical or radiological evidence of breast cancer five years after screening [27]

	Cancer	Healthy	Total	PPV	NPV	Sensitivity	Specificity	total accuracy
Positive test	17	2540	2557	0.7	99.4	**28.3**	74.0	73.7
Negative test	43	7219	7262					
Total	60	9759	9819					
False positive		2540						
False negative	17							

Table 5
Diagnostic value of thermography for patients with biopsies prior to the thermographic examination [25]

	Cancer	Benign	Total	PPV	NPV	Sensitivity	Specificity	total accuracy
positive test	482	1544	742	23.8	95.2	97.4	14.4	32,3
negative test	13	260	1557					
Total	495	1804	2299					
False positive		1544						
False negative	13							

PPV = positive predictive value; NPV = negative predictive value

Table 6
Diagnostic value of thermography for patients with cancer signs in the clinical examination, in mammography or biopsies [8]

biopsy	Cancer	Benign	Total	PPV	NPV	Sensitivity	Specificity	total accuracy
positive test	83	19	102	81.4	82.7	83.0	81.0	82.0
negative test	17	81	98					
Total	100	100	200					
False positive		19						
False negative	17							
clinical exam	Cancer	Benign	Total	PPV	NPV	Sensitivity	Specificity	total accuracy
positive test	61	19	80	76.3	67.5	61.0	81.0	71.0
negative test	39	81	120					
Total	100	100	200					
False positive		19						
False negative	39							
mammography	Cancer	Benign	Total	PPV	NPV	Sensitivity	Specificity	total accuracy
positive test	66	19	85	77.6	70.4	66.0	81.0	73.5
negative test	34	81	115					
Total	100	100	200					
False positive		19						
False negative	34							

PPV = positive predictive value; NPV = negative predictive value

good sensitivity and specificity about 80% was found. At the same level of specificity, the sensitivity of infrared imaging to detect signs of breast cancer by clinical examination or mammography did not exceed 61% and 66% respectively.

Caveats to Interpreting Thermography Literature

Several of these studies examine the use of thermography on subjects that represent the general population (asymptomatic screenings). While other reports focus on special subgroups, such as women with a palpable lump in one breast, or women considered to be at high risk for breast cancer because of family history or other factors. Any data or conclusions that are drawn from these specialized groups should be interpreted with the population in mind, as these groups run the risk of pre-test bias due to the presumably higher incidence of cancer compared to the general population. Additionally, false-positives are less likely to occur compared to the general population and therefore specificity is more difficult to interpret. Although false-positives are minimized in the aforementioned situation, it is really false-negatives that are more detrimental to the patient— failing to detect a cancer when one exists.

Another factor to consider when interpreting this literature is the fact that follow-up reports are typically limited to the subset of patients with abnormal thermograms. These are the patients who have concurrent or follow-up mammograms and subsequent biopsies and/or histological assessments. While this provides valuable information about the types of breast abnormalities being detected by thermography, it omits any cases of present or future cancers that thermography may have failed to detect.

Probably the most confounding factor throughout the history of reporting this procedure is the lack of uniform criteria established for what is considered an abnormal thermogram, how the scans should be interpreted (i.e. skill and experience varies widely) and how data should be reported. So, it may not be practical to average the sensitivity (the probability of positive test given the disease) or specificity (the probability of negative test without the disease) across studies; instead, when looked at as a whole, these studies will help to define the overall strengths and weaknesses of this technique in the detection of breast cancer.

With the aforementioned issues in mind, some commonly asked questions about the use of thermography in breast cancer detection and the answers suggested by the available literature will follow in the second part of this review.

References

1.Gershon-Cohen J, Haberman-Brueschke JA., Brueschke EE, Medical thermography: a summary of current status. Radiologic Clinics of North America, 1965. 3(3): 403-431.

2.Lawson R. Implications of surface temperatures in the diagnosis of breast cancer. Canadian Medical Association Journal, 1956. 75(4): 309-311.

3.Lloyd-Williams K, Lloyd-WilliamsFJ, Handley RS. Infra-red thermometry in the diagnosis of breast disease. Lancet, 1961. 2(7217): 1378-1381.

4.Keyserlingk JR, Ahlgren P, Yu E, Belliveau N, Yassa M, Functional infrared imaging of the breast. IEEE Engineering in Medicine and Biology, 2000. 19(3): 30-41.

5.Stark A. The value of risk factors in screening for breast cancer. European Journal of Surgical Oncology, 1985. 11(2): p. 147-150.

6.Jones B, A reappraisal of the use of infrared thermal image analysis in medicine. IEEE Transactions on Medical Imaging, 1998. 17(6): 1019-1027.

7.Arora N, MartinsD, Ruggerio D, Tousimis E, Swistel AJ, Osborne MP, Simmons RM, Effectiveness of a noninvasive digital infrared thermal imaging system in the detection of breast cancer. American Journal of Surgery, 2008. 196(4): 523-526.

8.Keyserlingk JR, A.P., Yu E, Belliveau N, Infrared Imaging of the Breast: Initial Reappraisal Using High-Resolution Digital

Technology in 100 Successive Cases of Stage I and II Breast Cancer. The Breast Journal, 1998. 4(4): 245-251.

9.Ng EYK, Ng FC, Sim LS, Statistical analysis of healthy and malignant breast thermography. Journal of Medical Engineering & Technology, 2001. 25(6): 253-263.

10.Isard HJ, B.W., Shilo R, Ostrum BJ, Breast Thermography After Four Years and 10,000 Studies. American Journal of Roentgenology, Radium Therapy, and Nuclear Medicine, 1972. 115(4): 811-82111.

11.Arena F, Baone C, DiCicco T. Use of digital infrared imaging in enhanced breast cancer detection and monitoring of the clinical response to treatment. Engineering in Medicine and Biology Society, 2003. Proceedings of the 25th Annual International Conference of the IEEE, 2003. 2: 112-1132

12. Head JF, Lipari CA, Elliott RL. Determination of Mean Temperatures of Normal Whole Breast and Breast Quadrants by Infrared Imaging and Image Analysis. Proc. IEEE Eng. Med. Biol. 23:666(CDROM) ,2001

13.Ng EYK, Sudharsan NM.Computer simulation in conjunction with medical thermography as an adjunct tool for early detection of breast cancer. BMC Cancer 2004, 4:17

14.Qi H, Head JF. Asymmetry Analysis Using Automatic Segmentation and Classification for Breast Cancer Detection in Thermograms. In Proc. of the 23rd Annual International Conference of the IEEE EMBS, volume 3, pages 2866-2869, Turkey, Octover 2001. IEEE.

15. Qi H, Synder WE, Head JF, Elliott RL. Detecting Breast Cancer from Infrared Images by Asymmetry Analysis. Proc. IEEE Eng. Med. Biol. 22:CDROM, 2000.

16.Yahara T, Koga T, Yoshida S, Nakagawa S, Deguchi H, Shirouzu K. Relationship between microvessel density and thermographic hot areas in breast cancer. Surgery today 2003, 33(4), 243-248.

17.Gamagami P, SilversteinMJ, Waisman JR. Infra-red Imaging in Breast Cancer. Engineering in Medicine and Biology Society, 1997. Proceedings of the 19th Annual International Conference of the IEEE, 1997. 2: 677-680.

18.Head JF, Wang F, Lipari CA, Elliott RL. The Important Role of Infrared Imaging in Breast Cancer: New Technology Improves Applications in Risk Assessment, Detection, Diagnosis and Prognosis. IEEE Eng. Med. Biol. 2000; 19:52-57

19.Geser HM, Boesinger P, Stucki D, Landolt C. Computer- Assisted Dynamic Breast Thermography. Thermology 1987, 2: 538-544.

20.Amalric RGD, Altschuler C, Amalric F, Spitalier JM, Brandone H, Ayme Y, Gardiol AA, Does infrared thermography truly have a role in present-day breast cancer management? Progress in Clinical and Biological Research, 1982. 107: 269-278.

21.Davey JB, Greening WP, McKinna JA. Is screening for cancer worth while? Results from a well-woman clinic for cancer detection. British Medical Journal, 1970. 3(5724): 696-699.

22.Dodd GD, Wallace JD, Freundlich IM, Marsh L, Zermino A. Thermography and Cancer of The Breast.Cancer, 1969. 23(4): 797-802.

23.Head JF, Wang F, Elliott RL. Breast thermography is a non invasive prognostic procedure that predicts tumor growth rate in breast cancer patients. Annals of the New York Academy of Sciences, 1993. 698: 153-158.

24.Jones CH, Greening W, Davey JB, McKinna JA, Greeves VJ. Thermography of the female breast: a five-year study in relation to the detection and prognosis of cancer. The British Journal of Radiology, 1975. 48(571): 532-538

25.Parisky YR, Sardi A, Hamm R, Hughes K, Esserman L, Rust S, Callahan K, Efficacy of computerized infrared imaging analysis to evaluate mammographically suspicious lesions. AJR 2003 180(1): 263-269

26.van Dam PA, Van Goethem MLA, Kersschot E, Vervliet J, Van den Veyver IB, De Schepper A, Buytaert P., Palpable solid breast masses: retrospective single- and multimodality evaluation of 201 lesions. Radiology, 1988. 166(2): 435-439.

27. Lloyd Williams K, Phillips BH, Jones PA, Beaman SA, Fleming PJ. Thermography in screening for breast cancer. Journal of Epidemiology and Community Health, 1990; 44(2) 112-113.

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Evaluation of three thermal imaging cameras for skin temperature measurement using a blackbody reference source and a spatial resolution test object

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SUMMARY

BACKGROUND. We evaluated three modern focal plane array uncooled microbolometer thermal imagers to assess their suitability for measuring skin temperature in a clinical setting. The imagers were the FLIR A40M, A320, and the portable E30.

METHOD. Test equipment comprised of the Land P80P blackbody source and a heated spatial resolution test object. For each camera we tested drift in reading after switch-on and with varying ambient temperature, agreement between the device and the blackbody across the typical skin temperature range, linearity, uniformity of reading across the image field, and spatial resolution.

RESULTS. When measuring a fixed blackbody cavity temperature, all three cameras gave stable temperature readings to within ±0.2°C within 45 minutes of switch-on. Agreement between the blackbody and imager was different for each camera: the bias was 0.83°C for the A40M, -0.08°C for the A320, and 0.09ºC for the E30. Plots for linearity showed r^2>0.99 for each camera. When the blackbody was placed in the four quadrants of the field of view, the maximum difference in temperature recorded between quadrants by any of the cameras was only 0.2°C. When ambient temperature was varied across an 8°C range, no camera drifted in its reading of the blackbody temperature by greater than 0.4°C. The A40M and A320 detectors (320 x 240 pixels) showed a better spatial resolution than the E30 detector (160 x 120 pixels).

CONCLUSIONS. All three cameras showed a radiometric performance that would be suitable for most skin thermal imaging applications. The offset bias of the A40M device highlighted the importance of regular quality assurance: this offset could be easily corrected once detected. Of particular note was the performance of the low-cost E30 device: despite its limited functionality and low spatial resolution, it performed comparably to the more expensive devices in the blackbody tests.

KEY WORDS: Blackbody reference, quality assurance, infrared thermal imager,

BEWERTUNG VON DREI WÄRMEBILDKAMERAS ZUR HAUTTEMPERATURMESSUNG UNTER VERWENDUNG EINER SCHWARZKÖRPER-TEMPERATUR-REFERENZ UND EINES OBJEKTS ZUR TESTUNG DER RÄUMLICHEN AUFLÖSUNG

HINTERGRUND: Um ihre Eignung für die Messung der Oberflächentemperatur in einem klinischen Umfeld zu bestimmen, untersuchten wir drei moderne, ungekühlte Wärmekameras, die mit Detektoren der "Focal-Plane- Microbolometer-Technologie" ausgestattet waren. Die Kameras waren die Modelle FLIR A40M, A320 und die tragbare E30.

METHODE. Als Testgeräte dienten die Schwarzkörper-Temperatur-Referenz Land P80P und ein heizbares Test- objekt zur Bestimmung der räumlichen Auflösung. Für jede Kamera prüften wir die zeitliche Veränderung der Temperaturmessung nach dem Einschalten bei unterschiedlichen Umgebungstemperaturen, die Übereinstimmung zwischen der Temperaturangebe am Gerät und am schwarzen Körper im Bereich der typischen Hauttemperatur, die Linearität und Einheitlichkeit der Ergebnisse über dem gesamten Bildausschnitt und hinsichtlich der räumlichen Auflösung.

ERGEBNISSE: Bei Messung einer festgelegten Hohlraumtemperatur eines schwarzen Körpers, zeigten alle drei Kameras stabile Temperaturwerte mit einer Abweichung von ±0.2°C innerhalb von 45 Minuten nach dem Einschalten. Die Übereinstimmung zwischen dem schwarzen Körper und der Kamera war für jedes Gerät unterschiedlich: der systematische Fehler betrug 0.83°C für die A40M, -0.08°C für das A320 und 0.09ºC für die E30. Die Streudiagramme für die Linearität zeigten r^2>0.99 für jede Kamera. Wenn die Referenztemperatur in die vier Quadranten des Blickfeldes gelegt wurde, war bei allen Kameras der maximale Temperaturunterschied zwischen Quadranten nur 0.2°C. Bei Veränderung der Umgebungstemperatur im Umfang von 8°C maß keine Kamera größere Abweichungen als 0.4°C für die Temperatur des Schwarzkörperstrahlers. Die A40M- und Detektoren A320-(320 x 240 Pixel) zeigten eine bessere räumliche Auflösung als der Detektor E30 (160 x 120 Pixel).

SCHLUSSFOLGERUNG: Alle drei Kameras boten eine radiometrische Leistung, die für die Wärmebildanwendungen an der Haut geeignet sein würde. Der systematische Fehler des A40M-Gerätes hob die Bedeutung der regelmäßigen Qualitätssicherung hervor: dieser Fehler konnte, einmal ermittelt, leicht korrigiert werden. Bemerkenswert war die Leistung des preiswerten Gerätes E30, das trotz seiner begrenzten Funktionalität und niedrigen räumlichen Auflösung, im Test am Schwarzkörperstrahler ähnliche Ergebnisse erzielte als die teureren Geräte.ow spatial resolution, it performed comparably to the more expensive devices in the blackbody tests.

SCHLÜSSELWÖRTER: Schwarzkörper-Temperatur-Referenz, Qualitätssicherung, Infrarot-Wärmebildkamera

Thermology international 2013, 13(1) 17-23

Background.

A wide variety of thermal imagers based on uncooled focal plane array microbolometer detectors are now on the market. Recent years have seen the cost of this technology reduce significantly. The introduction of low-resolution, hand-held infrared devices (primarily for the building inspection industry) means basic thermography is now possible for a start-up equipment cost of well under €5000.

The suitability of these low-cost devices for medical applications has been largely unexplored. If the radiometric performance of portable thermal imagers is comparable to that of more expensive models, it might open up medical opportunities for thermography that were previously not available due to financial constraints.

In fact, without careful quality assurance in place, even expensive "fixed installation" thermal cameras offer no guarantee of radiometric temperature accuracy. Although Simpson et al. (1) showed that three thermal imagers that had been recently calibrated all had an offset from blackbody temperature of less than the manufacturers' specifications of 2ºC, one device that had not been calibrated in 20 years was offset from true blackbody temperature by as much as 3ºC. Ring et al. (2) demonstrated a drift in offset from true blackbody temperature over two hours of almost 5ºC in one thermal imager evaluated in 2007.

Mindful of the continual improvements in detector technology, and the recent introduction of hand-held devices to the marketplace, we set out to evaluate the performance of three modern uncooled imagers and assess their suitability for measuring skin temperature in a clinical setting.

Equipment and methods

Fig. 1 shows the three thermal imagers evaluated in the study. All were uncooled FPA microbolometer cameras sensitive in the 7 – 14 μm waveband, manufactured by FLIR Systems Ltd (West Malling, UK).

The A320 and A40M models were "fixed installation" cameras in regular clinical use in a hospital setting, whereas the E30 was a portable hand-held device purchased for evaluation with a view to possible future use in a clinical research setting. Image capture was managed by FLIR's Thermacam Researcher PC software for the A320 (via Ethernet connection) and A40M (via Firewire). Thermograms captured by the E30 were recorded on an onboard SD memory card, and could be transferred to Thermacam Researcher or FLIR's "Reporter" software for offline analysis. Table 1 summarises the specifications for each imager: note the lower pixel resolution of the E30. It would be expected that at least 95% of all temperature readings should lie within the stated "accuracy" range either side of the true target temperature

Table 1.
Specifications of the three thermal imaging cameras

	A40M	A320	E30
Approximate cost when new / €	21,000	16,000	3,500
Approximate date of purchase	2004	2008	2011
Resolution (pixels)	320 x 240	320 x 240	160 x 120
Accuracy / °C	±2	±2	±2
Portable	No	No	Yes

All tests were performed in the Microvascular Diagnostics Laboratory at the Freeman Hospital, Newcastle- upon-Tyne, UK over a two-day period. Fig. 2 shows the test equipment used to evaluate the thermal imagers. Each camera was calibrated against a Land P80P blackbody source (BBS) (Land Instruments, Dronfield, UK) with a calibrated platinum resistance thermometer (PRT) inserted into the cavity to confirm the cavity temperature. The uncertainty of the PRT was quoted by the manufacturer as < ±0.1°C at 50°C, and cavity emissivity was >0.995. The spatial resolution of each camera was evaluated using the test object described by Ring and Dicks (3), consisting of an array of etched copper bars and dots of various spacings which could be resistively heated by connecting the test object to a DC power supply. We decided upon five key tests of camera performance that could be performed

Figure 1
Thermal cameras l to r: the FLIR A40M, A320 and E30

Figure 2
Test equipment l to r: platinum resistance thermometer, Land P80P blackbody source and spatial resolution test object

within the laboratory time available. These were adapted in part from the British standard for calibration of thermal imagers BS EN 80601-2-59:2009 (4) and the quality assurance protocol described by Plassmann *et al.* (5). Each test was performed on all three cameras in succession. For tests 1, 2 and 4 detailed below, the distance from the BBS was fixed for each camera to give a view of the cavity filling >80% of the height of the image, taking into account the different lens specifications of each imager. The emissivity of the target was set to 1 in the analysis software.

1. Drift after switch on

The BBS was set at a stable temperature of 36.0ºC as determined by the PRT. After switch-on of the thermal camera, images were captured at 15 second intervals for one hour. The mean temperature of a 10 x 10 pixel region of interest (ROI) at the centre of the BBS cavity was calculated from each image in Thermacam Researcher.

2. Linearity and agreement

With the camera stable after more than one hour of operation, BBS cavity images were captured at eight PRT temperatures over the range 20ºC - 39ºC. Additional images were recorded at the high end of the temperature range because of our interest in each camera's ability to measure inner canthus temperature for fever screening applications. Once again, mean temperature of a 10 x 10 pixel ROI at the centre of the BBS cavity was calculated from each image. Bland-Altman plots (6) were con- structed to show the difference between the PRT and image temperatures versus the mean of the PRT and image temperatures across the 19ºC measured range. For each camera, PRT temperature was also plotted against image temperature to produce a calibration curve. The best straight-line fit to the data was calculated by the method of least squares.

3. Uniformity

Uniformity of temperature reading across the camera field of view was assessed with each imager at a fixed distance from the BBS. Four thermal images were captured with each camera, with the BBS cavity filling a different quadrant in each image. Fig. 3 shows how we numbered the quadrants in the field of view, and features an example thermogram from the E30 with the BBS cavity in quadrant 2 (top left corner of the image field). Basic uniformity was assessed by placing a 10 x 10 pixel ROI at the centre of the BBS cavity in each quadrant, and calculating the mean pixel value from each ROI.

The range of these values across all four quadrants was the *maximum difference between average quadrant temperature* for the camera

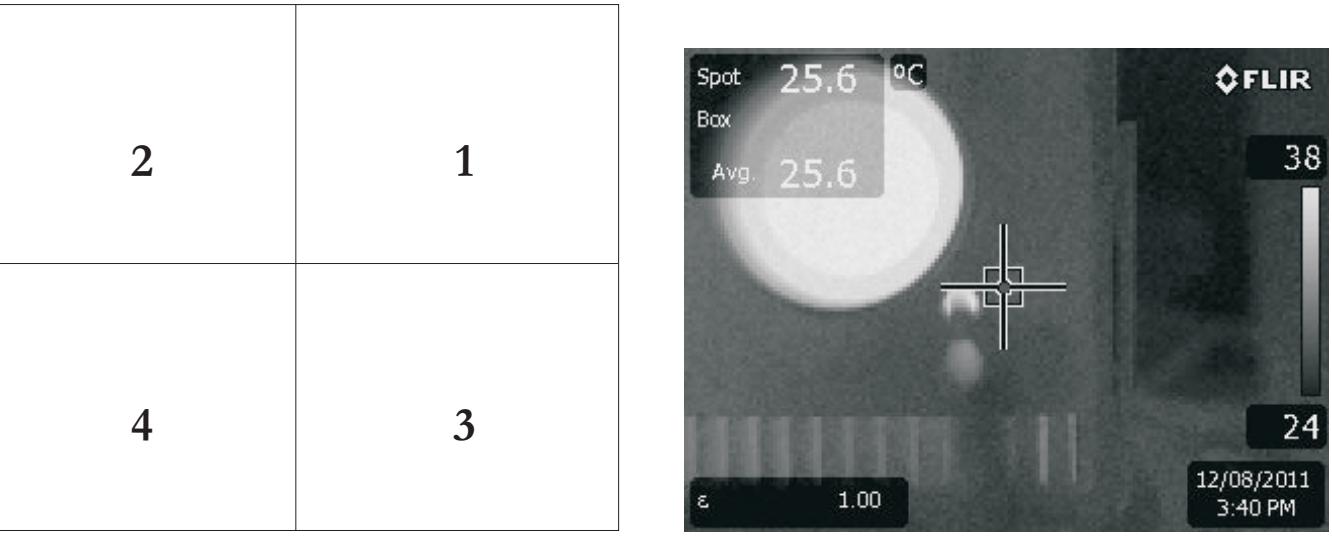


Figure 3
Labels for each quadrant in the field of view, and an E30 thermogram of the BBS cavity in quadrant

We also recorded spot (single pixel) temperature readings from five randomly-allocated pixels within the BBS cavity area in each quadrant. Uniformity was then calculated from the equation:

Uniformity = 100 x $[(T_{max}-T_{min})/(T_{max}+T_{min})]$

where T_{max} and T_{min} were the maximum and minimum pixel values recorded in °C.

Differential uniformity was calculated across the five spot readings in each quadrant, whereas *integral uniformity* was calculated by considering the 20 spot readings across all four quadrants i.e. across the entire image

4. Drift with varying ambient temperature.

With the BBS cavity temperature fixed at 36°C, ambient room temperature was varied stepwise across the range 19°C to 27°C. Thermograms of the BBS cavity were captured with each imager at each ambient temperature. Room temperature was stabilised prior to the recording of each set of images. The imager temperature was calculated from the mean value of a 10 x 10 pixel ROI at the centre of the BBS cavity.

5. Spatial resolution

For each camera the spatial resolution test object was positioned so that the test pattern filled the entire field of view. This enabled the amount of resolvable detail to be compared between imagers whilst allowing for the different lens specifications (i.e. field of view). The test object was connected to a power supply, and heated to a temperature of 37°C, as determined from each thermal image. Thermograms captured by the three imagers were reviewed to ascertain the smallest resolvable detail in the horizontal and vertical planes.

Results

1. Drift after switch on

Fig. 4 shows the response of the three cameras in the hour after switch-on. The BBS cavity temperature was set to read 36°C on the PRT; this temperature is shown on the plot by the dotted line.

For the E30 during the first minute after switch-on there was a significant increase in the measured temperature (from 33.8 to 36.4°C), but thereafter the readings fluctuated by only a few tenths around the BBS cavity value. After 45 minutes the E30 was stable to within ±0.2°C of the cavity value.

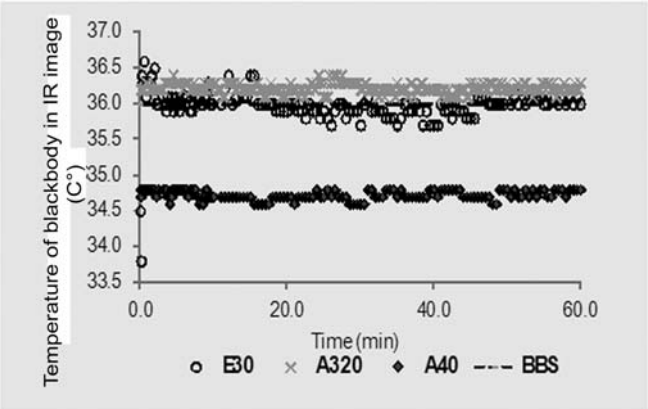


Figure 4
Drift after switch-on for the three cameras (BBS cavity temperature 36°C)

The A320 showed slightly less fluctuation in its output during the hour, and was stable to within ±0.2°C within around 30 minutes of switch-on (although this reading was offset from the true BBS cavity value by approximately 0.2°C – 0.3°C).

The A40M demonstrated a similar stability to the A320 throughout the experiment, but readings were consistently offset from the true BBS cavity temperature by a mean of -1.5°C.

2. Linearity and agreement

Agreement between the camera readings and the BBS cavity temperatures is shown using the Bland-Altman plots in the left column of Fig. 5. Perfect agreement between the imagers and the BBS cavity would be indicated by all the data points lying along the line of identity (difference between readings = 0°C at all cavity temperatures). The mean offset across the entire measured temperature range is termed the *bias*. Also plotted are the lines indicating the boundary at ± 2 standard deviations from the bias: we would expect 95% of data points to lie within these *limits of agreement*.

The A40M showed an increasing offset with rising BBS cavity temperature. The bias was 0.83°C. The A320 also showed a tendency to increasing offset with rising BBS cavity temperature, but the bias was much smaller at -0.08°C. The E30 demonstrated a decreasing offset with rising BBS cavity temperature, and the bias was 0.09ºC. The limits of agreement spanned 0.6ºC for the A320, 1.1ºC for the E30, and 2.6ºC for the A40M.

BBS cavity temperature is plotted against camera reading in the right column of Fig. 5. All three cameras showed $r^2>0.99$ with statistically significant straight lines, but the best fit straight line was different for each camera. The equations shown could be used to correct camera reading to arrive at the true value of the target temperature.

3. Uniformity

The BBS cavity temperature was monitored throughout the experiment using the PRT, and varied by less than 0.05°C. Table 2 shows the differential and integral uniformity, and the maximum difference between average quadrant temperatures for the three imagers

4. Drift with varying ambient temperature.

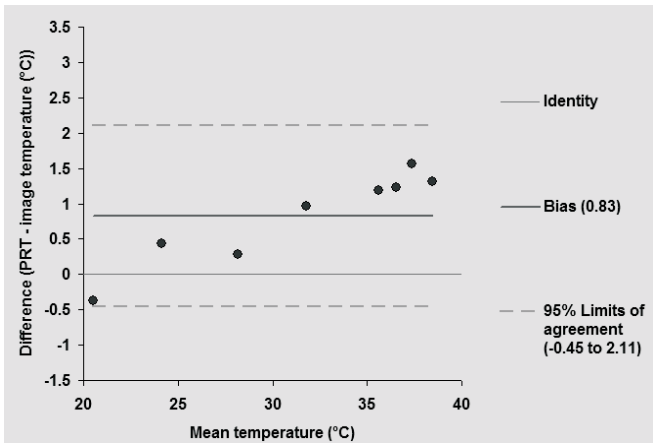
Fig. 6 shows the response of the three imagers to varying ambient temperature when measuring a BBS cavity temperature of 36ºC.

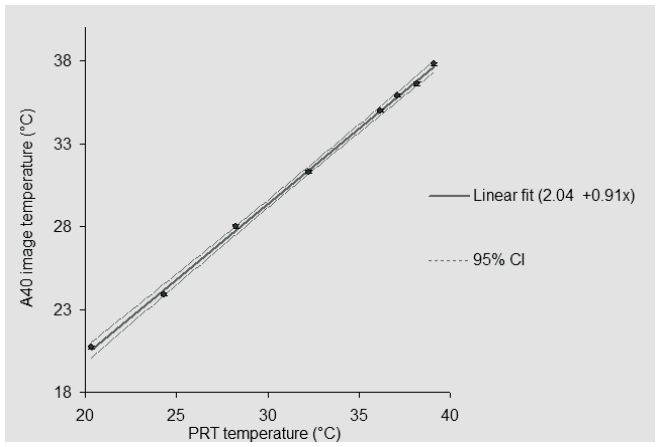
Although the A40M again demonstrated its offset from the BBS cavity temperature, its output showed the least dependency of the three cameras on ambient temperature. The A320 and E30 both showed a general tendency to under-read the cavity more with increasing ambient temperature: the range of readings across the ambient temperature range investigated was 0.4ºC for both cameras.

Agreement between camera and BBS cavity temperature

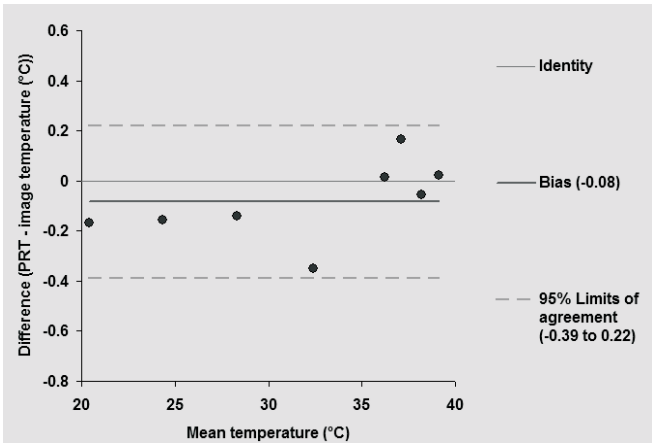
Linearity

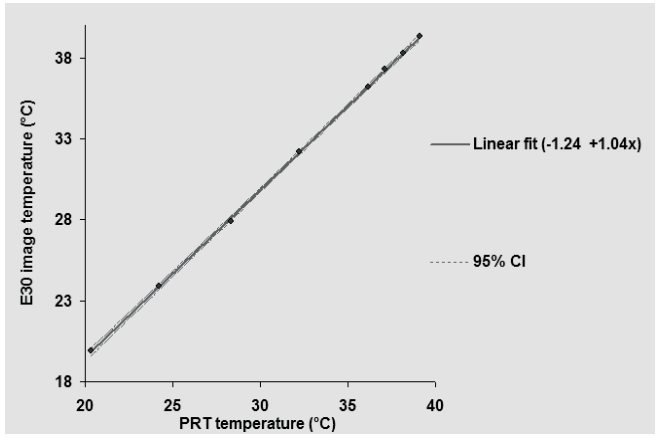
A40M



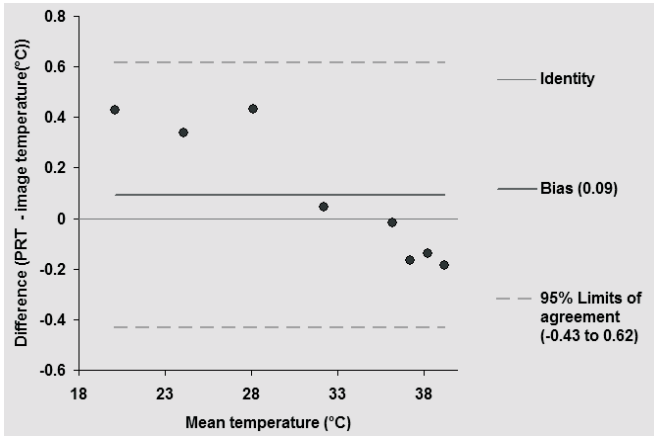


A320





E30



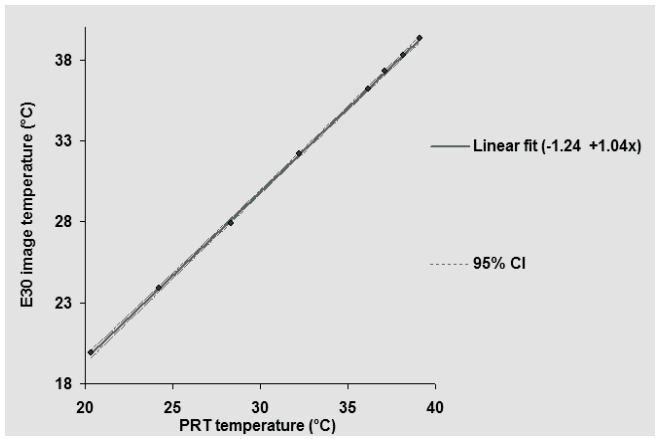


Figure 5
Bland-Altman plots and calibration curves for the three thermal imagers across the BBS cavity temperature range of 20º –39ºC

Table 2. Uniformity for the three thermal cameras.

Camera	Quadrant	Differential uniformity (%)	Integral uniformity (%)	Maximum difference between average quadrant temperature (°C)
A40M	1	1.12	1.40	0.2
	2	0.98		
	3	1.27		
	4	1.27		
A320	1	0.95	1.22	0.1
	2	0.68		
	3	0.67		
	4	0.54		
E30	1	1.07	1.07	0.2
	2	0.93		
	3	0.67		

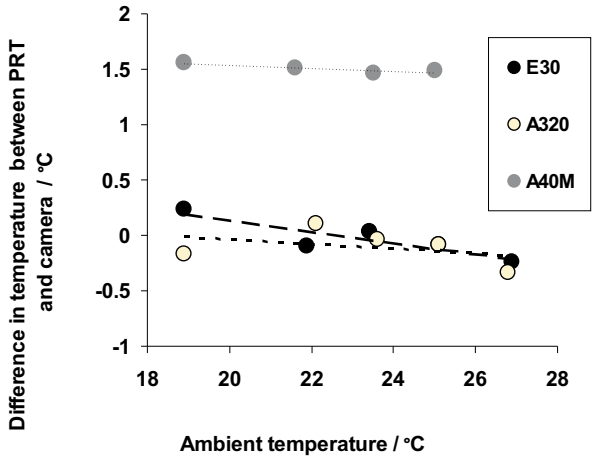


Figure 6
Affect of varying ambient temperature on camera reading

5. Spatial resolution.

Fig. 7 shows thermograms of the spatial resolution test pattern for the A320 and E30 (the A40M has an identical pixel array size to the A320, and produced a similar thermogram of the test object to the A320). The optical axis of both cameras was normal to the test object, and so a reflection from its polished surface was visible in each thermogram.

Discussion

Our evaluation of three modern uncooled thermal imagers has revealed performance from low-cost devices undreamt of even a decade ago (1,2). Radiometrically, all three cameras were impressive: they were all stable to a few tenths of degree Celsius within 40 minutes of switch-on, and indeed for some low-end medical applications these devices could be considered useable within five minutes of switch-on.

All three devices have a stated accuracy of ±2ºC, but the agreement of the A320 and E30 with the BBS cavity temperature was very much better than this across the medical temperature range evaluated. Even the A40M (which showed the poorest performance in this regard because of a large bias) gave no reading outside of the stated manufacturer's specifications.

Uniformity of temperature reading across the field of view was acceptable for all the imagers. This is important in medical thermography because not all measurements in biomedical imaging are performed at the centre of the field of view: indeed many investigations require an assessment of the symmetry of temperature distribution (or lack of it) across the human body.

As expected for uncooled microbolometer cameras, varying ambient temperature had a small influence on target reading. All thermal imagers must account for contributions to the signal from reflected radiation (7), and our results probably indicate differences between the pro-

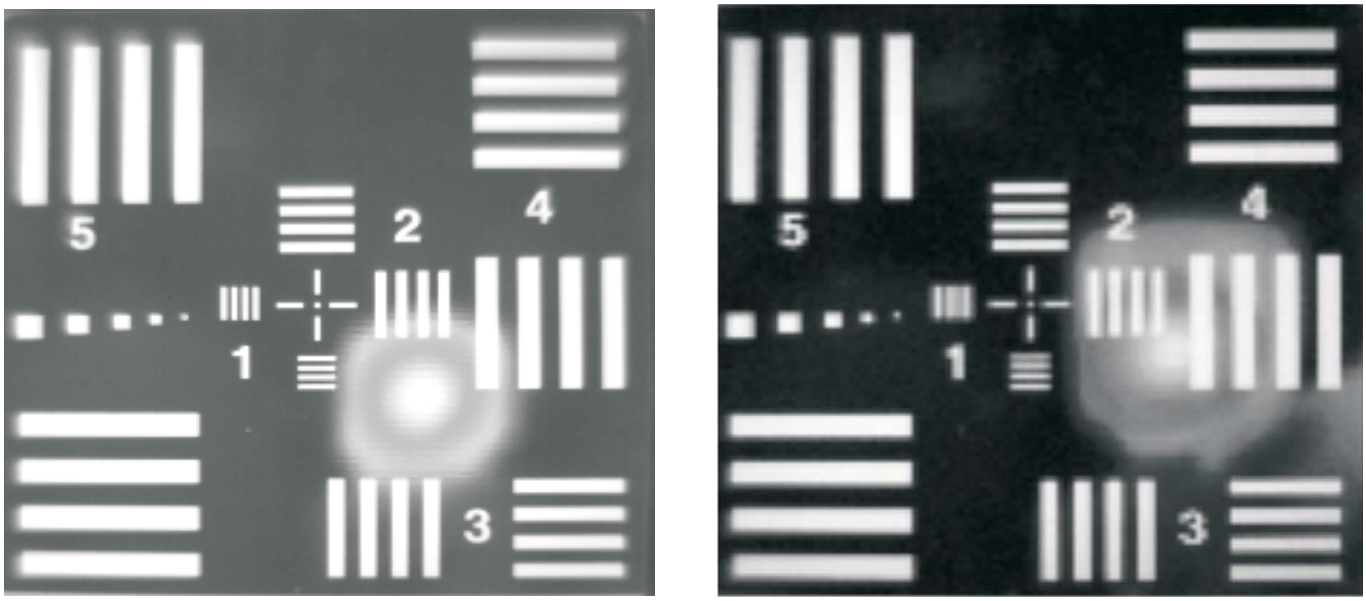


Figure 7
Thermograms of the spatial resolution test object from the A320 [320 x 240 pixels] (left) and the E30 [160 x 120 pixels] (right).

prietary algorithms used to adjust for this in each camera. The size of this effect was small and would not unduly influence most medical thermography performed in temperature-controlled environments. Thermography performed "in-the-field," where the temperature of the surroundings varies by more than a few degrees, might however require more rigorous evaluation of this effect in order to fully account for its contribution to variability in the readings.

It was also no surprise to us to see a relationship between pixel array size and spatial resolution, with the E30 (160 x 120 pixels) being outperformed by the A320 and A40M (320 x 240 pixels). Image quality is not just about pixel array size however: it also depends on the quality of the infrared optics. In this regard the image aberration of the portable E30 was evidence of the lower-budget lens and optics employed in comparison to the A320 and A40M.

Our assessments reinforced the importance of quality assurance (QA) of medical thermography. In the case of the A40M in particular (the only device which had not been factory calibrated and serviced within the last two years), our QA protocol revealed issues which would have had a significant effect on clinical accuracy i.e. a bias of around 0.8°C, with the offset rising to around 1.5ºC at a blackbody temperature of 36°C. Even so, it was easy to correct for this bias after calibration and the A40M was in all other radiometric respects suitable for biomedical work. This demonstrates that non-ideal camera performance need not be a block to reliable medical thermography, but issues must be identified and rectified by a regular QA programme.

We were particularly interested in the performance of the E30, since to the best of our knowledge the suitability of portable uncooled imagers for medical thermography has not been extensively evaluated. Radiometrically the E30 performed as well as its more expensive counterparts, and we concluded that portable thermography could be seriously considered for some low-end medical thermography applications. The limitations of the particular portable device we evaluated were its lower spatial resolution and lens quality and limited functionality (real-time control from a PC for sequential imaging is not possible, for example). More work is required to investigate the agreement in clinical practice between portable thermography and higher resolution devices. A number of practical factors may limit the agreement: the different number of pixels in equivalent ROIs may influence readings, and handheld versus tripod-mounted imaging protocols could be very different with regard to the experimental errors they induce.

Despite these unknowns, it is clear that thermal imaging technology is continuing to advance in a manner not unlike that experienced by the computer industry in recent years. Costs continue to reduce while imaging performance improves. The challenge remains simply how to utilise this rapidly-evolving technology appropriately for biomedical applications. This includes governance issues associated with the use of imaging equipment not CE-marked to the Medical Devices Directive (8).

References

1.Simpson R, Machin G, McEvoy H, Rusby R. Traceability and calibration in temperature measurement: a clinical necessity. J Med Eng Technol 2006, 30:212-217.

2.Ring FJ, Ammer K, Wiecek B, Plassmann P, Jones CD, Jung A, Murawski P. Quality assurance for thermal imaging systems in medicine. Thermology International 2007, 17:103-106.

3.Ring, EF, Dicks JM. Spatial resolution of new thermal imaging systems. Thermology International 1999, 9:7-14.

4.British Standards Institution. BS EN 80601-part 2-59: 2009. Medical Electrical Equipment. Particular requirements for the basic safety and essential performance of screening thermographs for human febrile temperature screening. London: BSI, 2010.

5.Plassmann P, Ring EFJ, Jones CD. Quality assurance of thermal imaging systems in medicine. Thermology International 2006, 16:10-15.

6.Bland JM, Altman DG. Statistical methods for assessing agreement between two methods of clinical measurement. Lancet 1986, 8476:307-310.

7.Ring EFJ, Thomas RA, Howell KJ. Sensors for medical thermography and infrared radiation measurements. In Biomedical Sensors. Edited by Jones DP. Momentum Press; 2010:317-442.

8.Howell KJ, Smith RE. Guidelines for specifying and testing a thermal camera for medical applications. Thermology International 2009, 19:5-12.

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Analysis of skin temperature changes by infrared thermography using an elastic thigh bandage during rest and physical exertion: a pilot study

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SUMMARY

Knee- and ankle elastic bandages are common therapeutic devices exercising their stabilizing effects through external compression of underlying soft tissue. This mechanism has an impact on local microcirculation, and together with the insulating abilities of the bandage, on skin temperature. As blood flow in cutaneous and subcutaneous tissue changes, so does heat transfer from deeper tissues to skin, which can be observed by thermal imaging. This is the first study on using high-resolution infrared(IR)-thermography for the examination of skin temperature differences in 17 volunteers wearing a unilateral elastic thigh bandage during rest and a steady load 10 minute treadmill test. Our results showed a maximum increase of 1.1 ± 0.3 °C in local skin temperature after the bandage was removed. In conclusion, we found that (1) skin temperature of the non-bandaged areas decreased after steady load exercise while (2) there was a distinct skin temperature pattern underneath a unilateral elastic thigh bandage during rest and physical exertion. Further trials are needed to investigate, if these observations could be beneficial for faster healing and recovery after soft tissue injury or if local hyperthermia caused by an elastic bandage impairs transportation of metabolites in injured tissue.

KEY WORDs: thermal imaging; soft orthosis; exercise; thermoregulation; skin microcirculation

ANALYSE DER VERÄNDERUNG DER HAUTTEMPERATUR MITTELS INFRAROT-THERMOGRAPHIE BEI VERWENDUING EINER ELASTISCHEN OBERSCHENKELBANDAGE IN RUHE UND NACH KÖRPERLICHER BELASTUNG- EINE PILOTSTUDIE

Elastische Knie- und Sprunggelenksbandagen werden häufig als therapeutische Hilfsmittel verwendet, deren stabilisierende Wirkung durch äußere Kompression des daruntergelegenen Weichteilgewebes vermittelt wird. Dieser Mechanismus hat Auswirkungen auf die lokale Mikrozirkulation und, zusammen mit den Isolationseigenschaften der Bandage, auf die Hauttemperatur. Bei Änderung des kutanen und subkutanen Blutflusses kommt es gleichzeitig auch zu einer Änderung des Wärmeabtransportes aus tieferen Gewebeschichten zur Haut, welche man mittels Thermographie messen kann. Erstmals konnte in dieser Studie bei 17 gesunden Probanden der Einfluss einer elastischen Oberschenkelbandage in Ruhe und während einer 10-minütiger Laufbelastung auf die Hauttemperaturänderungen mittels hochauflösender Infrarot(IR)-Thermographie gezeigt werden. Unseren Ergebnissen nach kommt es zu einer maximalen Erhöhung der Hauttemperatur von 1.1 ± 0.3 °C in dem Areal, auf dem die Bandage getragen wurde. Zusammengefasst 1) verringert sich die Hauttemperatur des nicht bandagierten Beines nach gleichmäßiger körperlicher Belastung, während 2) im Bereich der Bandage ein unterschiedliches Verteilungsmuster der Hauttemperaturänderungen sowohl in Ruhe als auch nach körperlicher Belastung vorliegt. Weitere Studien müssen zeigen, ob diese Ergebnisse den Heilungsprozeß nach Weichteilverletzungen günstig beeinflussen oder ob eine lokale Hauterwärmung den Abtransport von Stoffwechselmetaboliten eher behindert.

SCHLÜSSELWÖRTER: Thermographie; Bandage; Belastung; Thermoregulation; Kutane Mikrozirkulation

Thermology international 2013; 23(1) 24-32

Introduction

Elastic bandages are common therapeutic devices in the prevention and rehabilitation of sports injuries (1,2,3). The effect of passive stabilization is achieved by application of external pressure forces on underlying soft tissue through interaction with the cutaneous and subcutaneous microcirculation (4). Higher hydrostatic pressures created by circular elastic bandages contribute to better venous backflow at rest. During physical activity, however, the combination of orthostasis, exercise and heat stress leads to a competition for local blood flow between the peripheral (skin, muscle) and central organs. An elastic bandage would act as a second skin layer, which would not only accumulate heat but evoke circular external pressures on soft tissue and cutaneous microcirculation.

Skin temperature is an indicator of cutaneous microcirculation, which can be measured non-invasively through infrared thermography. This method can detect temperature irregularities and is used as a diagnostic tool in various medical conditions such as systemic sclerosis (5) or breast cancer (6). Moreover, it is becoming an important non-invasive device in the detection of musculoskeletal disorders and sports injuries (7,8,9,10,11). To the best of our knowledge, there are no published clinical trials examining the effects of elastic bandages on skin temperature by means of infrared thermography to date.

The aim of our pilot study was to determine the effects of a unilateral worn elastic bandage on lower limb skin tempera-

ture in conditions of rest and physical exertion by thermal imaging in healthy adults. Thermoregulatory mechanisms and the impact of exercise on local cutaneous temperature under the bandage as an indicator of the state of cutaneous microcirculation are discussed in the following article.

Methods

Subjects

Seventeen healthy male volunteers [mean ± SD: 27.2 ± 4.5 years] participated in this study. Anthropometric data for the subjects were: body mass 80.0 ± 11.2 kg, height 181 ± 7 cm, and body fat (four-site caliper method) 18.3 ± 4.5 %, rectal temperature of the individuals was 36.6 ± 0.3 °C. The circumference of the thigh (measured 15 cm above the superior border of the patella) was 50.2 ± 2.8 cm. All subjects were free of any injuries of the lower extremities with full functionality of the hip, knee and ankle joints. They all were non-smokers and had abstained from alcohol and caffeine-containing beverages within the prior 24 hours.

Experimental setup

All subjects undertook two experimental sessions, which were separated by three days. At the beginning of each test series, all participants had to acclimatize to the examination room (ambient room temperature: 20-21 °C; relative humidity 20% ± 5%; no direct ventilation) for 15 minutes to minimize fluctuation of body temperature and adapt to the experimental conditions (12,13). The subjects took up a defined erect body position on a treadmill using a custom-built bar frame and footboard to minimize body sway and standardize repeated measurements. Thereafter, thermal image series of the posterior leg surface were obtained while the participants were standing upright during rest (Fig. 1). In the first experimental session, an elastic bandage (thickness 6 mm, width 13.7 cm) was wrapped around the left thigh 15 cm above superior border of the patella. In the second experimental session, the bandage was placed on the right thigh. Prior to this investigation, thermoconductivity measurements of the bandage material (mixture of neoprene and polyurethane foam) revealed a specific thermal conductivity of 0.037 $W \bullet K^{-1} \bullet m^{-1}$. The bandage was adjusted to the individual circumference of each leg to a predefined tensile force of 25 N which was verified by a tensiometer through straps. We chose the dimension of the tensile force according to the participants´ preferred level of tightening thigh straps of a knee brace in a study conducted by Lundin and Styf (14). Then another thermal image was taken (Fig. 2). For steady load exercise, subjects executed a 10 minute treadmill-test with a velocity of 9 km/h. Immediately after exercise was stopped, we acquired a third thermal image (Fig. 3) followed by a final thermogram after the elastic bandage was removed (Fig. 4).

Thermal imaging

We used a high-resolution infrared camera with an uncooled microbolometer focal plane array (FPA-) detector to record skin temperature (FLIR S60, FLIR Systems, AB, Danderyd, Sweden). The camera had a spatial resolution of 320 x 240 pixels, longitudinal section accuracy of 0.1°C, spectral range 7.5-13 µm, sampling rate 60 Hz and thermal sensitivity of 0.06°C at 30 °C (15). The specific settings for our series were: modified temperature calibration range from 27.5°C to 32.8 °C, air humidity 20%, air pressure 1013 bar, air room temperature 20.0 ± 1°C, emissivity 0.98 and focal distance 2 meters. With a thermographic imaging analysis tool (ThermaCam Researcher Professional, V. 2.7, FLIR Systems, AB, Danderyd, Sweden), we defined the regions of interest (ROI) as box matrixes placed in the center of the bandaged thigh area. The matrix size was 572 (22 x 26) pixels (Fig. 1). The ROI were only placed on image regions where the image surface was at an angle of more than 45° to the scanner lens to avoid measurement errors created by curved surfaces (16). To ensure that every participant was in the same upright standing position, we constructed a bar frame and footboard and tested the reliability and variability of gathered data in a pre-study design.

Statistics

The results are presented as mean values with one standard deviation (SD), calculated from the sum of single temperature values represented by each pixel of the ROI matrix. The dependent variable (skin temperature) was assessed by repeated measures two-way analysis of variance (ANOVA) with time (pre- and post-exercise) and surface (elastic bandage, no bandage) as factors. To meet the requirements for a normal distribution, we examined each variable independently with a Shapiro-Wilk test. For homogenity of variances, a Levene-test was used. Bonferroni´s post-hoc tests for multiple comparisons were used where differences displayed statistical significance. Based on the results of a pre-study measurement in our laboratory, the camera system had an intra-subject variability of 0.34%, the longitudinal and cross section analysis of variance showed no significant difference between both legs ($p \geq 0.29$).

The SPSS statistical software package 15.0 for Windows (SPSS Inc., Chicago, Illinois) was used for statistical analysis. Significance was accepted when p was less than 0.05. When the software package displayed "0.000", p was recorded as "<0.0005".

Results

At rest, we observed a distinct, uniform pattern of skin temperature distribution. Due to anatomical and physiological characteristics, areas around bony structures are subject to emission of less infrared radiation than other tissue. Here, thermograms show cooler spots, as heat radiation is lower due to the smaller volume of skin blood perfusion. Areas with higher heat dissipation around muscle, cutaneous and subcutaneous fatty tissues of the thigh and calf are depicted as hyperthermal spots. Those areas include parts of the M. biceps femoris and M. gastrocnemius (see Fig. 1 and 2).

The thermal pattern after ergometer exercise is inconsistant. Hyper- and hypothermic regions are scattered over the posterior leg surface in a point-shaped, irregular structure. The course of the superficial veins, such as the Vena saphena and its branches, is distinguishable in terms of hyperthermal tracts (Fig. 3 and 4). Near those areas, thermograms are blurred because of lateral heat dissipation from surrounding deeper veins filled with warm blood during physical exertion.

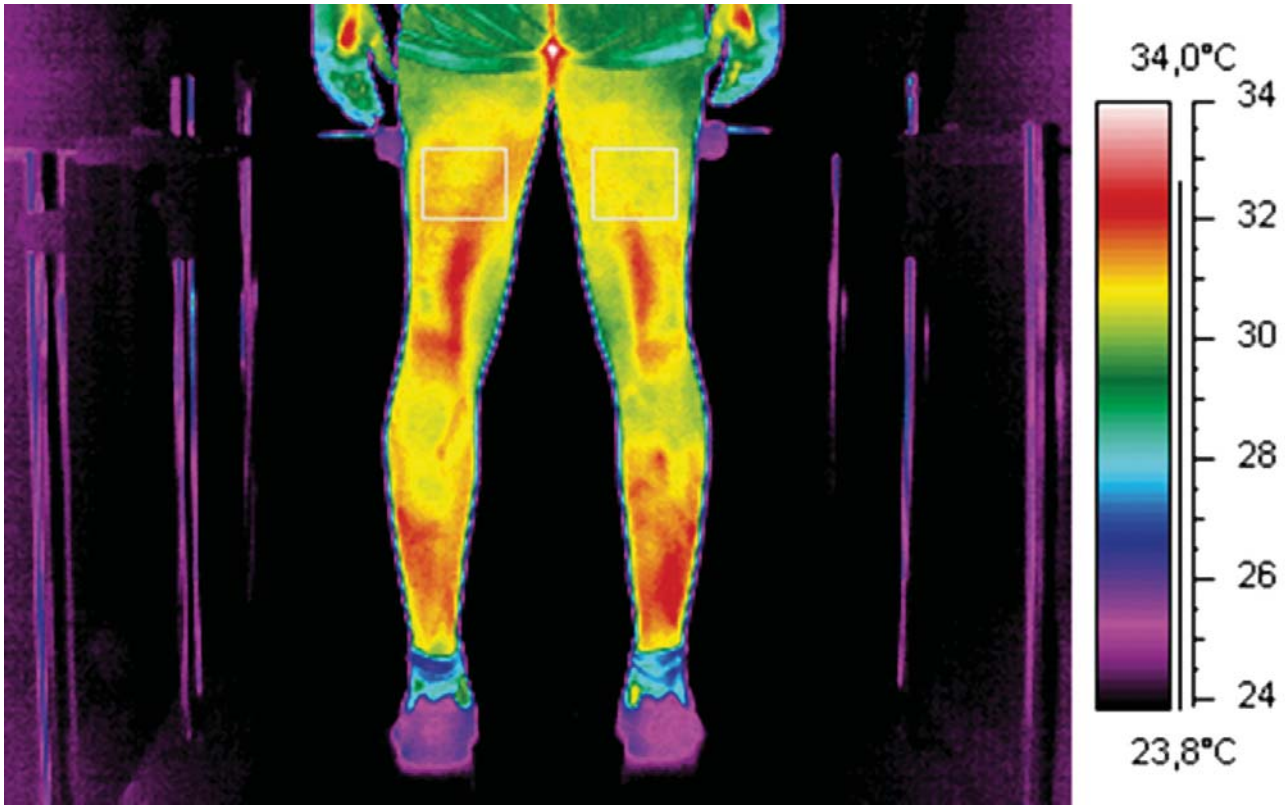

Figure 1
Infrared image of the posterior leg surface during rest of subject 4. Boxes define regions of interest (ROI) for calculation of skin temperature distribution, which is given in degree Celsius (°C). A predefined pseudo-color bar visualizes the thermographic image scale. Notice the standardized set up for measurement with adjustment of body posture using a custom-built bar frame.

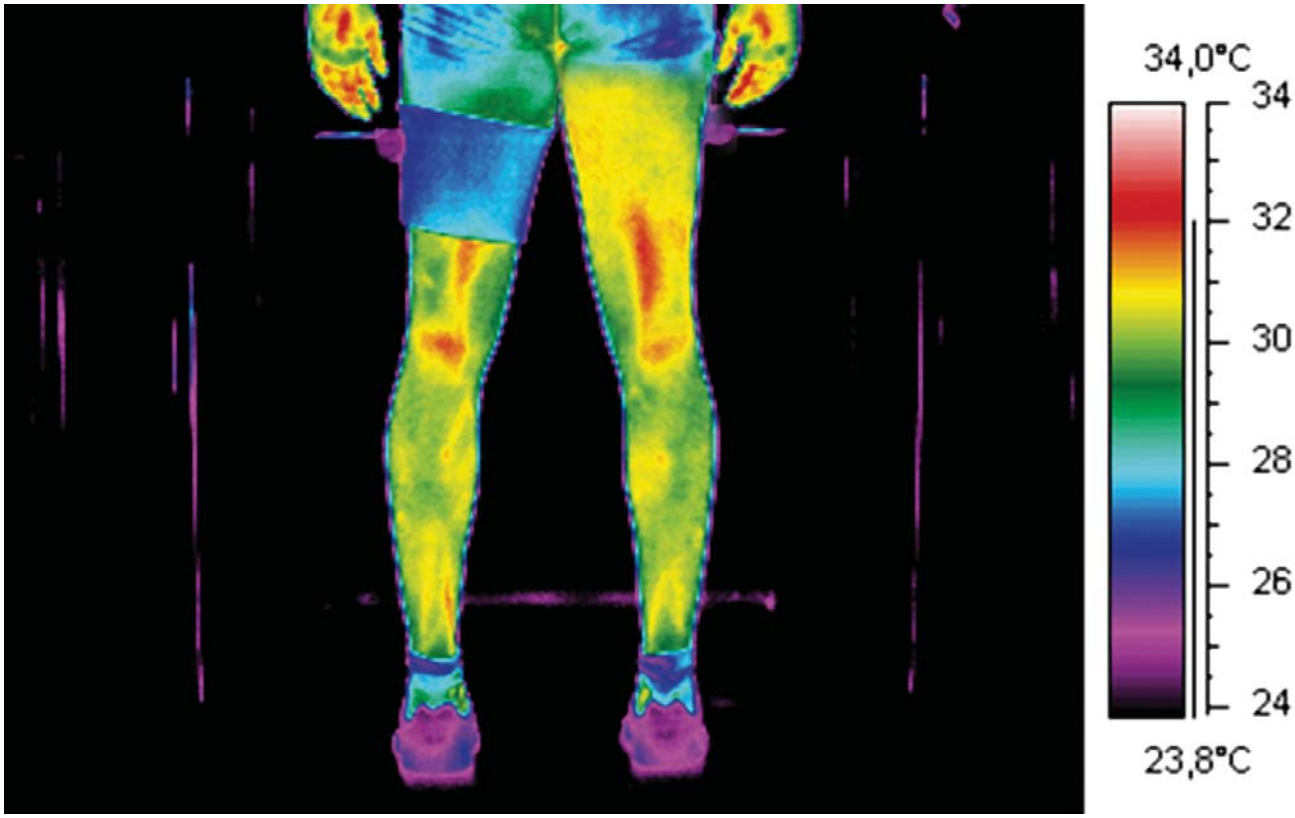

Figure 2
Thermal image with the elastic bandage wrapped around the left thigh. The reduced heat dissipation through the elastic bandage is displayed as a cooler area. Skin temperature patterns are given in degree Celsius (°C).

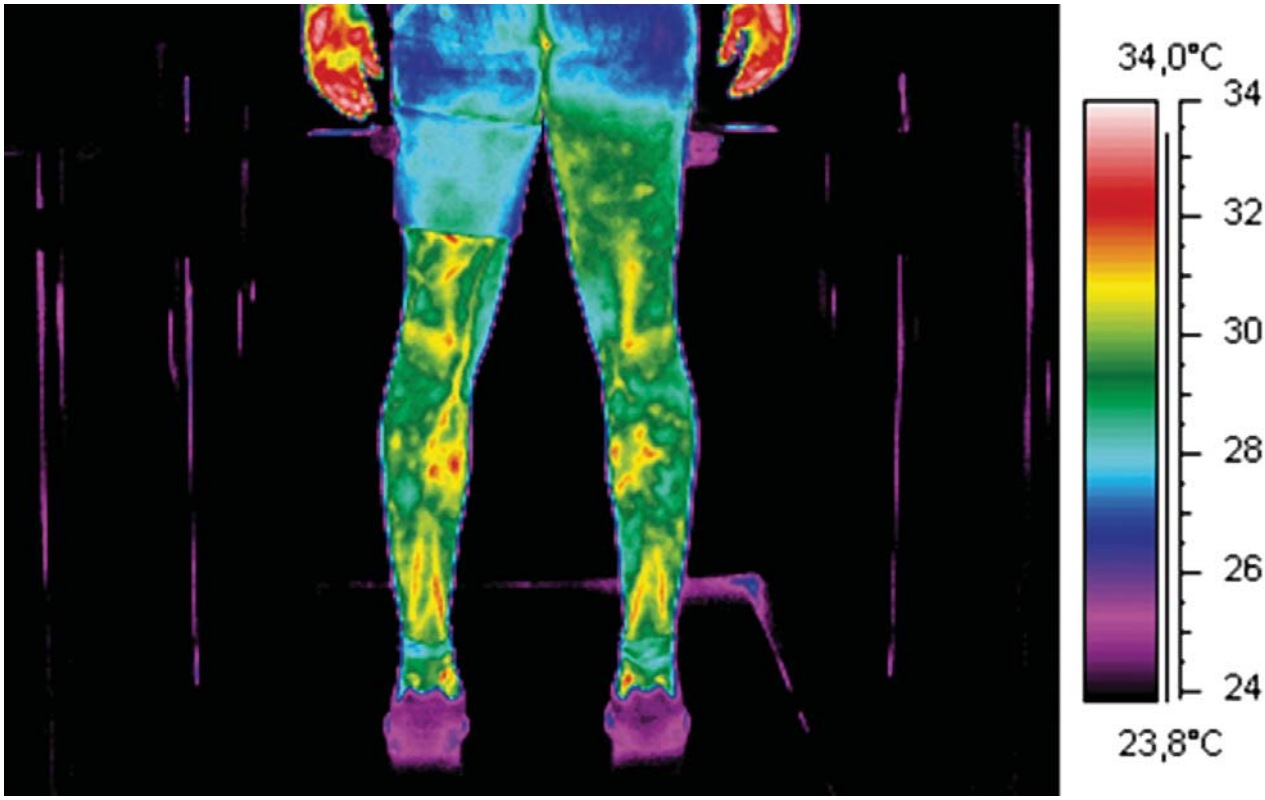

Figure 3
Thermogram recorded after physical exertion. The temperature distribution is inhomogeneous according to a different blood flow and heat dissipation in superficial and deep veins. Instead of a lower skin temperature as seen on the non-bandaged right thigh, the temperature of the bandaged thigh increased. Skin temperature patterns given in degree Celsius (°C).

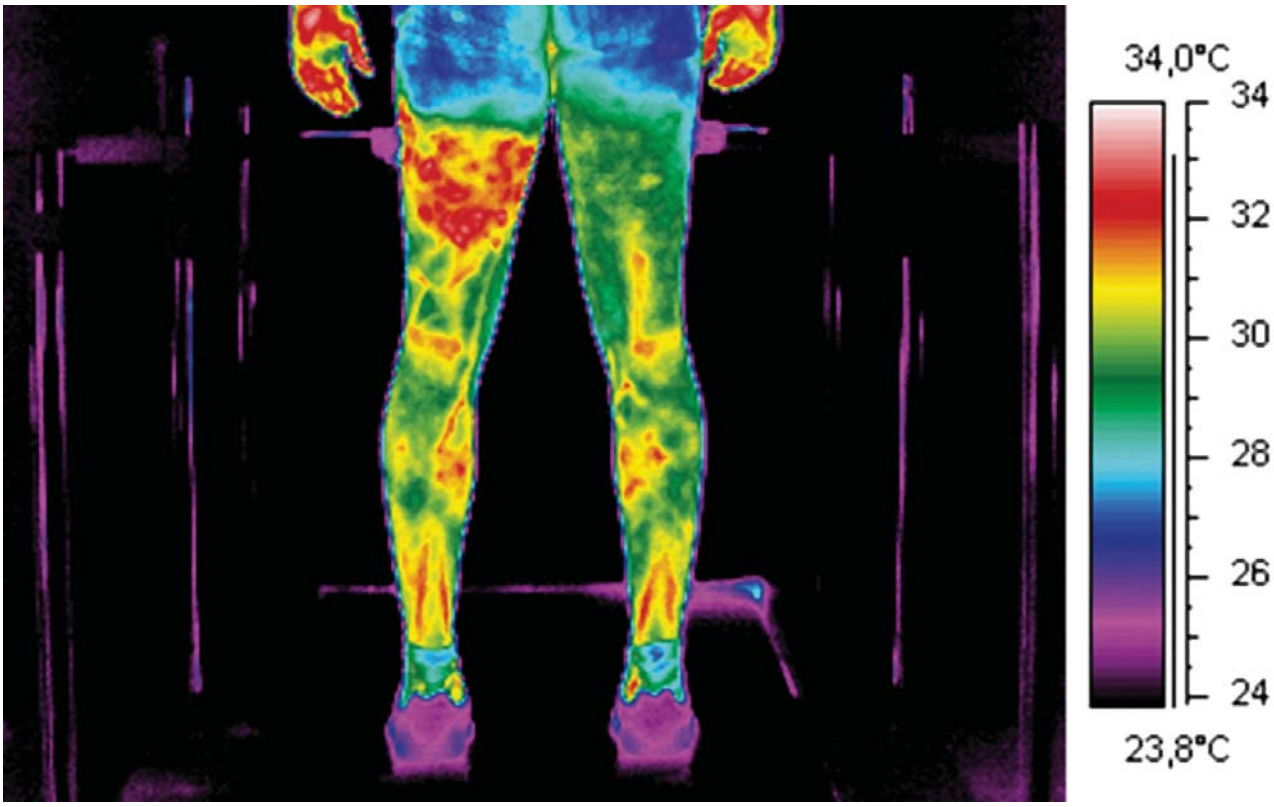

Figure 4
Thermal image after removal of the bandage. The distinct hyperthermia can be seen in the covered thigh region. Skin temperature patterns given in degree Celsius (°C).

Table 1
Mean (± SD) skin temperature in degrees Celsius (°C) of the right and left thigh areas

	Without bandage		Bandage on right/left thigh	
	right	left	right	left
Rest	30.5 ± 1.0	30.5 ± 0.9	26.6 ± 0.7	26.7 ± 0.5
Post exercise	29.7 ± 1.0	29.7 ± 0.9	28.5 ± 0.7	28.4 ± 0.6
Post exercise after removal of bandage	-	-	31.7 ± 0.6	31.5 ± 0.6
ΔT with/without bandage (rest)	-	-	3.9 ± 0.3**	3.9 ± 0.4**
ΔT without bandage (pre-/post exercise)	0.9 ± 0.1*	0.8 ± 0.0*	1.1 ± 0.3**	1.0 ± 0.3**
ΔT with bandage (pre-/post exercise)	-	-	1.8 ± 0.0**	1.7 ± 0.1**

Two-way ANOVA results with post-hoc *p<0.05 and **p<0.0005; ΔT = temperature difference in °C

The temperature difference between pre- and post-exercise in subjects not wearing an elastic bandage was 0.8 ± 0.1°C. Wearing an elastic bandage led to a decrease of thermal dissipation through the bandage during rest, which was recorded as a reduction in skin temperature of 3.9 ± 0.3°C (Fig. 2). After exercise, heat dissipation through the bandage was increased, leading to a temperature rise of 1.7 ± 0.1°C (Fig. 3). Removing the bandage caused a further elevation of skin temperature of 1.1 ± 0.3°C in the covered thigh area (Fig. 4). A detailed description of results is given in Table 1.

Discussion

The novelty of this study lies within the analysis of skin temperature during rest and steady load exercise, as well as the interaction of a unilateral elastic thigh bandage using high-resolution infrared thermography. We observed a decrease in skin temperature of 0.8 ± 0.1 °C after physical exertion when no bandage was worn. Heat dissipation was reduced in the bandage-covered area during rest, however, local hyperthermia occurred after exercise and was accentuated even more when the bandage was removed. This resulted in a 1.1 ± 0.3 °C higher skin temperature compared to the non-bandaged condition. These seemingly trivial and obvious results are derived from complex physiological mechanisms, which are affected by the elastic bandage in several ways.

As skin temperature is determined by the cutaneous and subcutaneous circulation, thickness of the tissue layers and temperature gradients between skin and the surrounding environment, we argue that the elimination of thermal energy is hampered through an elastic bandage during exercise by two possible factors:
a) impedance to heat elimination via skin due to the isolating properties of the additional layer of bandaging material
b) impedance to cutaneous microcirculation due to the external compression of cutaneous and subcutaneous tissue, which in turn leads to a thermoregulation-mediated additional increase in local blood flow.

We deal with these issues against the background of brief pathophysiological considerations about thermoregulation, exercise and the impact of an elastic bandage on cutaneous circulation.

Thermoregulation and exercise

Mechanisms by which thermal energy can be transferred to the environment include convection, conduction, evaporation and radiation. The latter depends on the thermal conductivity of the skin and the subcutaneous fatty layer and accounts for about half of the total loss of heat when the body is in a cooler environment (17,18,19,20). In this study, high-resolution thermal imaging was applied to measure skin temperatures by means of infrared radiation from the skin surface.

The most common cause of a rise in body temperature is through metabolic heat generation during daily physical activity (21). As heart rate and cardiac output increase due to higher sympathetic activity, blood flow and blood volume in working muscles boost the production of thermal energy through muscle fibre contraction (22,23). In general, basic thermoregulatory reflexes are dependent on "thermal" and "non-thermal" factors (24). Thermal factors have an impact on cutaneous blood flow and sweating through changes in body core temperature. Hydration status, physical fitness and acclimation are examples of non-thermal factors, which are believed to regulate the competition between blood supply for skin and muscle, core temperature and the conservation of body fluids during changing states of physical activity (25).

At the onset of exercise, the sympathetic-induced vasoconstriction of cutaneous blood vessels reduces skin temperature of the upper and lower extremities between 0.4°C - 2°C (26,27,28,29). After 5-10 minutes of non-gra- ded exercise, however, a thermoregulatory vasodilation is initiated for better heat dissipation (21,30). This is achieved by an increase of tissue perfusion and blood volume in skin, facilitating the transport of thermal energy from deep blood vessels of the muscle tissue to the terminal capillary loops near the skin surface (19,31). A higher blood flow in cutaneous and subcutaneous tissue causes pooling of blood volume, which is shifted towards the capillary-venous system. This challenges the cardiocirculatory system, which

has to maintain blood pressure despite the translocation of blood volume, and its ability to regulate body temperature (24,26).

An increase in body core temperature is met with sweating and evaporation, which are the main thermoregulatory mechanisms of skin and core temperature reduction during exercise. Here, the amount of heat dissipation depends on the temperature gradient between the skin and surrounding surfaces. During the first minutes of moderate exercise, the sweating response rises immediately before body and skin temperature rises (32) but after the increase of cutaneous blood flow (24). The regulation of the sweating rate is influenced by the extent of changes in skin temperature (ΔT). Local heating, which is caused by an additional skin layer (bandage) in our study, is known to raise sweat rate (33) as well as an increase in cutaneous blood perfusion during heat stress (34). Ventilation around the legs during treadmill exercise could favour a decrease in skin temperature through a different convection ratio.

Once exercise is stopped, the circulatory system lowers blood perfusion in muscle and skin. Vasodilatation and blood flow in skin are still elevated at first, though, because of thermal heat elimination. Non-thermal factors are accounted for a rise of cutaneous blood flow and sweating rate during the post-exercise period. This causes core temperature to fall back toward initial values more slowly than blood flow and sweat rate, which decrease rapidly after 1-3 minutes. One reason for this threshold change could be the translocation of venous blood volume to the deep and superficial veins, decreasing venous return (see above, 24).

Elastic bandage

In our study, the elastic bandage worked as a second thermal skin layer on the thigh. This leads not only to a change in local evaporative heat dissipation (sweating), but has also an impact on non-evaporative mechanisms such as conduction, convection and radiation. The results of this pilot study show that mean temperature values underneath the elastic thigh bandage were higher after exercise compared to the non-bandaged limb.

Local skin heating, as seen in our experiment and induced through wearing a bandage, can lead to a increase in sweat rate, which is also accompanied by an increase in local skin blood flow (35,36,37). In a study by Pearson and co-workers (38), skin temperature heat stress was induced by wearing a water-perfused leg suit during rest and knee-extensor exercise. Leg skin blood flow was higher during exercise and even more raised during local hyperthermia, which induced vasodilatation along with an augmentation of muscular blood flow. These findings are consistant with other investigations (30).

At the same time, external pressure forces applied by circular elastic bandages antagonize the capacity of the superficial and deep veins (4,39,40,41). By releasing external pressures after the bandage is taken off, the venous capacity is now increased, which leads to a reactive elevation of cutaneous blood flow. This mechanism could explain local hyperthermia in the area of the bandaged thigh as seen in our series. While other studies indicate that a relevant reduction in sub-bandage skin blood flow of the lower limbs occurs at pressures between 30 and 40 mm Hg (42,43), we argue that lower external pressures still could affect blood flow of the superficial capillary-venous system (44). The external compression which is exerted through a tensile force of 25 N in our series creates an intramuscular pressure of approximately 20 mm Hg in standing postion (14), which might be enough to impair blood flow of the embedded cutaneous veins. Together with the isolating properties of the bandaging material, further vasodilatation and increase in skin blood flow occurs during exercise in order to eliminate more heat. Another explanation of the local hyperthermia seen underneath the elastic bandage could be that musculocutaneous perforating blood vessels are activated through local thermoregulation. This could be the reason for the "hot spot" temperature pattern depicted in Figure 4.

As mentioned in the previous section, we would expect an increase in skin temperature after 5-10 minutes under steady load exercise, however, our findings show a decrease in skin temperature in non-bandaged skin areas. Compared to the continous cutaneous vasoconstrictor response during graded load exercise (45), a possible explanation of our results might be the dynamic temperature pattern under steady loads that has been observed in other studies (28,29). Hunold and colleagues (28) reported on an initial decrease of thigh skin temperature after 5 minutes followed by a gradual increase after 10 minutes of steady load exercise, which correlated with changes in local skin blood flow measured by laser Doppler flowmetry. Zontak and co-workers (29) recognized a triphasic pattern with an initial descent of finger temperature, which appeared approximately during the first 6 minutes followed by an increase after 8 and a steady state period after 13 minutes of ergometer exercise. It was postulated that at the beginning of steady load exercise, the demand of blood flow to working muscles was met by reflectory skin vasoconstriction. As body core temperature rises through further duration of physical activity, thermoregulation causes cutaneous vasodilatation in order to eliminate more heat. This hypothesis was also suggested by Formenti and colleagues (46), who observed a decrease in skin temperature of the calves in some subjects after the first 60 seconds during a steady load heels raise test. As the authors note themselves, the amount of heat produced after 2 minutes of exercise could not possibly lead to an activation of global thermoregulatory mechanisms. Thus, we speculate that the prolonged decrease in skin temperature in our subjects, which is present even after 10 minutes of treadmill exercise, could be due to different levels of duration and intensity of exercise and the related changes in body core temperature or hemodynamic imbalances between skin and muscle blood flow (26,29,47). Another possibility could be a different distribution of local cutaneous tissue innervation and vascularization of the thigh regions compared to the forearm as mentioned by Merla and colleagues (45).

One could argue that the observed higher skin temperature underneath the circular elastic bandage would be favourable since higher skin temperatures indicate an increase in

cutaneous blood flow (21,27,28). However, a rise in local skin temperature results in a strong positive feedback on cellular levels due to the high activation energy of most metabolic processes (19). Ring and co-workers (48) compared two designs of studded shoe soles and found that reactive hyperemia of the skin occurs mainly at high pressure sites, which can lead to blister formation. A study by DiBennedetto and colleagues (8) showed that high pressure on soft tissues cause increased infrared heat emission leading to early injury detection.

These results indicate that heat accumulation can cause severe strain on soft tissue, which is even more prominent during prolonged exercise. Especially during the post-acute phase, which is considered from 24 hours up to 2 weeks after (soft tissue) injury, impaired microcirculation in the capillary beds of knee joints and ankles as well as slower reduction of tissue swelling and delayed wound healing have been reported (49,50,51,52,53). In one of our recent studies, we measured local microcirculation underneath a unilateral thigh bandage in healthy subjects and patients with ruptures of the anterior cruciate ligament (ACL) during the post-acute phase. We found that the knee injury group had an impeded capillary-venous backflow when the bandage was not worn. While wearing an elastic bandage, venous blood flow is increased after isometric exercise (54).

Limitations of this study

Limitations in our study are the known restrictions that apply for non-invasive diagnostic tools. Infrared imaging is only capable of measuring skin temperature, not skin blood flow, and is therefore an indicator of qualitative and not quantitative (absolute) changes in skin microcirculation. As mentioned before, heat radiation is dependent on thermal conductivity and therefore dependent on the variable thickness of subcutaneous tissue, which could lead to different results (55). Moreover, extrinsic factors such as tobacco, alcohol, caffeine and drugs affect thermal heat production and dissipation (56). In our study, we have tried to minimize these factors by choosing a homogeneous pool of participants. One of the major advantages of thermal imaging is the real-time, regional (not punctual) measurement, which gives reliable and valid data of temperature differences (57,58). Hunold and co-workers (28) showed that there is a correlation between higher skin blood flow measured by laser Doppler flowmetry and skin temperature. With knowledge of regional thermal body patterns and the thermoregulatory mechanisms, this method is very useful to evaluate regional microcirculation (10,59).

Although elastic knee bandages are generally available in different sizes, we focused on a simple thigh bandage to standardize the tensile force und thus the degree of external compression, which was measured according to the individual thigh circumference. Although we did not measure the external pressure on tissue, the dimension of tensile force is based on semi-quantitative analysis of Lundin and Styf (14). External forces were not measured directly or at different sites, which assumes much more elaborate experimental settings. Moreover, we simplified measurement settings by taking standardized pre/post-exercise thermograms at rest rather than continuous motion images, where the ROIs are subject of distinct measurement errors.

Conclusion

To our knowledge, this is the first study using IR-thermography to determine the impact of an elastic thigh bandage on skin temperature during rest and physical exertion. During steady load exercise, the regulation of skin blood flow is determined by thermoregulatory and cardiocirculatory mechanisms. A sympathetic-induced vasoconstriction of cutaneous blood vessels reduces skin temperature of the limbs at the beginning of physical exertion. Contrary to an exercise-induced decrease of heat dissipation in non-bandaged subjects, we observed an increase of skin temperature over the covered thigh area. As an additional layer on skin surface, the elastic bandage effectively reduces heat loss pathways. After the bandage was removed, hyperthermia was even more pronounced in the covered skin area. Mechanisms leading to this local hyperthermia are decreased elimination of thermal energy by means of conduction, convection, radiation and evaporation. Possible effects of the elastic bandage may include heat accumulation through the isolating properties of the bandage material and congestion of superficial veins, which lead to a reactive hyperemia after withdrawal of external pressure forces. Further studies are needed to clarify these factors and how the observed hyperthermia can contribute in the course of soft tissue injury, where elastic bandages are commonly used.

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Conflict of interest

The authors declare that they have no conflict of interest.

References

1.Boyce SH, Quigley MA, Campbell S. Management of ankle sprains: a randomised controlled trial of the treatment of inversion injuries using an elastic support bandage or an Aircast ankle brace. Br J Sports Med 2005; 39: 91-6.

2.Birmingham TB, Bryant DM, Giffin JR, Litchfield RB, Kramer JF, Donner A et al. A randomized controlled trial comparing the effectiveness of functional knee brace and neoprene sleeve use after anterior cruciate ligament reconstruction. Am J Sports Med 2008; 36: 648-55.

3.Palm HG, Laufer C, Achatz G, von Lübcken F, Friemert B. Can knee braces improve postural stability in patients with meniscus injuries? Dtsch Z Sportmed 2010; 61: 40-4.

4.Mayrovitz HN, Sims N. Effects of ankle-to-knee external pressures on skin blood perfusion under and distal to compression. Adv Skin Wound Care 2003; 16: 198-202.

5.Moore TL, Vij S, Murray AK, Bhushan M, Griffiths CE, Herrick AL. Pilot study of dual-wavelength (532 and 633 nm) laser Doppler imaging and infrared thermography of morphoea. Br J Dermatol 2009; 160: 864-7.

6.Ng EY. A review of thermography as promising non-invasive detection modality for breast tumor. Int J Therm Sci 2009; 48: 849-59.

7.Eliyahu B. Infrared thermography and the sports injury practice. Dyn Chiropr 1992; 10: 27-8.

8.DiBenedettto M, Yoshida M, Sharp M, Jones B. Foot evaluation by infrared imaging. Mil Med 2002; 167: 384-92.

9.Hildebrandt C, Raschner C, Ammer K. An overview of recent application of medical infrared thermography in sports medicine in Austria. Sensors (Basel) 2010; 10: 4700-15.

10.Jiang LJ, Ng EY, Yeo AC, Wu S, Pan F, Yau WY et al. A perspective on medical infrared imaging. J Med Eng Technol 2005; 29: 257-67.

11.Ring EF, Ammer K. Infrared thermal imaging in medicine. Physiol Meas (2012); 33: R33-46.

12.Seifalian AM, Stansby G, Jackson A, Howell K, Hamilton G. Comparison of laser Doppler perfusion imaging, laser Doppler flowmetry, and thermographic imaging for assessment of blood flow in human skin. Eur J Vasc Surg 1994; 8: 65-9.

13.Zaproudina N, Ming Z, Hänninen OO. Plantar infrared thermography measurements and low back pain intensity. J Manipulative Physiol Ther 2006; 29: 219-23.

14.Lundin O, Styf JR. Intramuscular pressure in the leg and thigh related to tensile strap force during knee brace wear. An experimental study in man. Am J Sports Med 1998; 26: 567-70.

15.FLIR Systems AB. ThermaCam Researcher Professional Ed. 2.7: User´s manual 2003; FLIR Systems AB, Danderyd, Sweden.

16.Watmough DJ, Fowler PW, Oliver R. The thermal scanning of a curved isothermal surface: implications for clinical thermography. Phys Med Biol 1970; 15: 1-8.

17.Swain ID, Grant LJ. Methods of measuring skin blood flow. Phys Med Biol 1989; 34: 151-75.

18.Sanyal DC, Maji NK. Thermoregulation through skin under variable atmospheric and physiological conditions. J Theor Biol 2001; 208: 451-6.

19.Anbar M. Assessment of physiologic and pathologic radiative heat dissipation using dynamic infrared imaging. Ann N Y Acad Sci 2002; 972: 111-8.

20.Ring EF. The historical development of thermometry and thermal imaging in medicine. J Med Eng Technol 2006; 30: 192-8.

21.Johnson JM. Exercise and the cutaneous circulation. Exerc Sport Sci Rev 1992; 20: 59-97.

22.Laughlin MH. Skeletal muscle blood flow capacity: role of muscle pump in exercise hyperemia. Am J Physiol 1987; 253(5 Pt 2): H993-H1004.

23.Zhang Q, Lindberg LG, Kadefors R, Styf J. A non-invasive measure of changes in blood flow in the human anterior tibial muscle. Eur J Appl Physiol 2001; 84: 448-52.

24.Waterhouse J, Aizawa S, Nevill A, Edwards B, Weinert D, Atkinson G et al. Rectal temperature, distal sweat rate, and forearm blood flow following mild exercise at two phases of the circadian cycle. Chronobiol Int 2007; 24: 63-85.

25.Kenny GP, Niedre PC. The effect of exercise intensity on the post-exercise esophageal temperature response. Eur J Appl Physiol 2002; 86: 342-6.

26.Rowell LB. Cardiovascular adjustments to thermal stress. In: Sheperd JT, Abboud FM, editors. Handbook of Physiology, Section 2. The cardiovascular system, Vol. III: Peripheral circulation and organ blood flow, Part 2. American Physiological Society, Bethesda Md; 1983. p. 967-1023.

27.Roddie IC. Circulation to skin and adipose tissue. In: Sheperd JT, Abboud FM, editors. Handbook of Physiology, Section 2: The cardiovascular system: Peripheral circulation and organ blood flow, Part 1. American Physiological Society, Bethesda Md; 1983. p. 285-317.

28.Hunold S, Mietzsch E, Werner J. Thermographic studies on patterns of skin temperature after exercise. Eur J Appl Physiol Occup Physiol 1992; 65: 550-4.

29.Zontak A, Sideman S, Verbitsky O, Beyar R. Dynamic thermography: analysis of hand temperature during exercise. Ann Biomed Eng 1998; 26: 988-93.

30.Heinonen I, Brothers RM, Kemppainen J, Knuuti J, Kalliokoski KK, Crandall CG. Local heating, but not indirect body heating, increases human skeletal muscle blood flow. J Appl Physiol 2011; 111: 818-24.

31.Laughlin MH, Korthuis RJ, Duncker DJ, Bache RJ. Chapter 16: Control of blood flow to cardiac and skeletal muscle during exercise. In: Rowell LB, Sheperd JT, editors. Handbook of Physiology, Section 2. Exercise: Regulation and Integration of Multiple Systems. American Physiological Society, Bethesda Md; 1996. p. 706-69.

32.Kondo N, Nakadome M, Zhang K, Shiojiri T, Shibasaki M, Hirata K et al. The effect of change in skin temperature due to evaporative cooling on sweating response during exercise. Int J Biometeorol 1997; 40: 99-102.

33.Shibasaki M, Wilson TE, Crandall CG. Neural control and mechanisms of eccrine sweating during heat stress and exercise. J Appl Physiol 2006; 100: 1692-701.

34.Hori S. Adaptation to heat. Jpn J Physiol 1995; 45: 921-46.

35.Vuksanovic V, Sheppard LW, Stefanovska A. Nonlinear relationship between level of blood flow and skin temperature for different dynamics of temperature change. Biophys J 2008; 94: L78-80.

36.Wingo JE, Low DA, Keller DM, Brothers RM, Shibasaki M, Crandall CG. Skin blood flow and local temperature independently modify sweat rate during passive heat stress in humans. J Appl Physiol 2010; 109: 1301-6.

37.Charkoudian N. Optimizing heat dissipation for every environment: the cool ability of the skin to locally regulate sweating. J Appl Physiol 2010; 109: 1288-9.

38.Pearson J, Low DA, Stöhr E, Kalsi K, Ali L, Barker H et al. Hemodynamic responses to heat stress in the resting and exercising human leg: insight into the effect of temperature on skeletal muscle blood flow. Am J Physiol Regul Integr Comp Physiol 2011; 300: R663-73.

39.Ogata K, Whiteside LA. Effects of external compression on blood flow to muscle and skin. Clin Orthop Relat Res 1982; 168: 105-7.

40.Jerosch J, Castro WH, Hofstetter I, Reer R. Secondary effects of knee braces on the intracompartmental pressure in the anterior tibial compartment. Acta Orthop Belg 1995; 61: 37-42.

41.Styf J. The effects of functional knee bracing on muscle function and performance. Sports Med 1999; 28: 77-81.

42.Dai XQ, Lu YH, Lin H, Bai L. Mechanisms of control of human skin blood flow under external pressure. Biol Rhythm Res 2012; 43: 267-78.

43.Mayrovitz HN, Delgado M. Effect of compression bandaging on lower extremity skin microcirculation. Wound 1996; 8: 200-7.

44.Fromy B, Legrand MS, Abraham P, Leftheriotis G, Cales P, Saumet JL. Effects of positive pressure on both femoral venous and arterial blood velocities and the cutaneous microcirculation of the forefoot. Cardiovasc Res 1997; 36: 372-6.

45.Merla A, Mattei PA, Di Donato L, Romani GL. Thermal imaging of cutaneous temperature modifications in runners during graded exercise. Ann Biomed Eng 2010; 38: 158-63.

46.Formenti D, Ludwig N, Gargano M, Gondola M, Dellerma N, Caumo A et al. Thermal imaging of exercise-associated skin temperature changes in trained and untrained female subjects. Ann Biomed Eng 2012; Dec 11 Epub ahead of print.

47.Kenney WL, Johnson JM. Control of skin blood flow during exercise. Med Sci Sports Exerc 1992; 24: 303-12.

48.Ring EF, Hawkes R, Elvins DM. Evaluation of the effects of plastic and metal studded football boots on the plantar foot. In: Ammer K, Ring EF, editors. The Thermal Image in Medicine and Biology. Uhlen Verlag, Wien; 1995. p. 220-4.

49.Hecht PJ, Bachmann S, Booth RE Jr, Rothman RH. Effects of thermal therapy on rehabilitation after total knee arthroplasty. A prospective randomized study. Clin Orthop Relat Res 1983; 178: 198-201.

50.Coté DJ, Prentice WE Jr, Hooker DN, Shields EW. Comparison of three treatment procedures for minimizing ankle sprain swelling. Phys Ther 1988; 68: 1072-6.

51.Schubert V. The influence of local heating on skin microcirculation in pressure ulcers, monitored by a combined laser Doppler and transcutaneous oxygen tension probe. Clin Physiol 2000; 20: 413-21.

52.Lin YH. Effects of thermal therapy in improving the passive range of knee motion: comparison of cold and superficial heat applications. Clin Rehabil 2003; 17: 618-23.

53.Breger Stanton DE, Lazaro R, Macdermid JC. A systematic review of the effectiveness of contrast baths. J Hand Ther 2009; 22: 57-69.

54.Sommer B, Berschin G. Neue Erkenntnisse zur Durchblutungssituation von VKB-Patienten in der Postakutphase. Medizinisch-Orthopädische Technik 2012; 1: 33-42.

55.Livingston SD, Nolan RW, Frim J, Reed LD, Limmer RE. A thermographic study of the effect of body composition and ambient temperature on the accuracy of mean skin temperature calculations. Eur J Appl Physiol Occup Physiol 1987; 56: 120-5.

56.Gold JE, Cherniack M, Buchholz B. Infrared thermography for examination of skin temperature in the dorsal hand of office workers. Eur J Appl Physiol 2004; 93: 245-51.

57.Selfe J, Hardaker N, Thewlis D, Karki A. An accurate and reliable method of thermal data analysis in thermal imaging of the anterior knee for use in cryotherapy research. Arch Phys Med Rehabil 2006; 87: 1630-5.

58.Buono MJ, Jechort A, Marques R, Smith C, Welch J. Comparison of infrared versus contact thermometry for measuring skin temperature during exercise in the heat. Physiol Meas 2007; 28: 855-89.

59.Fujimasa I. Pathophysiological expression and analysis of far infrared thermal images. IEEE Eng Med Biol Mag 1998; 17: 34-42.

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Annual Meeting of the American Academy of Thermology, Greenville, South Carolina, October 27, 2012

Programme

Jeffrey Lefko Greenville, SC, Executive Director, American Academy of Thermology
Welcome remarks

Session 1: Basic Science, Clinical Conditions, Skin Temperature Regulation, AAT Guidelines & Indications

Dr. Robert Schwartz, Greenville, SC, President of American Academy of Thermology
Introduction to Thermal Imaging,
The AAT Neuro-Musculoskeletal Guidelines,
Vasomotor Mapping and Sympathetic Generators

Dr. Philip Getson, Marlton, NJ, Chairman of AAT Committee on Guidelines for Breast Thermography
The AAT Breast Guidelines

Dr. Philip Getson:
Breast Pain Syndromes & Predictive Value of Thermography in CRPS

Session 2: Medical Thermal Imaging: Its Role in Objective Measurement and Treatment Planning

Dr. William Hobbins, Madison, WI:
Somatovisceral Pain & Thermal Imaging

Dr. Kamayni Argawal Hamburg, Germany
Thermographic Monitoring of Sympatheticomy and SCSG Blocks

Dr. Timothy Conwell, Denver, CO
Distinct Infrared Signatures in Patients with Neuropathic Abnormalities of the Limbs

Session 3: Vasomotor Monitoring, Neurovascular Considerations, Pitfalls and Look Alikes

Dr. Robert Schwartz
RSD Look Alikes

Dr. William Hobbins
Breast Imaging Significance and Suggestions

Dr. Kamayni Argawal
Thermal Imaging in Acupuncture

Dr. Debra Sime, Raleigh, NC:
Thermal Imaging Applications in Animal Care

Dr. Kenneth Marcella, Canton, GA
Infrared Imaging in Equine Sports

Session 4: Infrared Thermal Imaging Case Presentations and Paper Presentations

Dr. Andrzej Zielke, North Huntingdon, PA
Infrared Monitoring & Laser Therapy

Dr. Bryan O'Young, New York City, NY
Acupotomy: Soft Tissue Release with Thermal Monitoring

Martin Bales, Solana Beach, CA
Integrative Pain Therapies Monitored by Thermal Imaging

Dr. Tashof Bernton, & Dr. Geroge Schakaraschiwili, Denver, CO
Setting up a Thermal Imaging Lab

James Melton, Cary, NC
Medical Publishing: The Duke Clinical Research Institute Experience

Abstracts

INTRODUCTION TO THERMAL IMAGING THE AAT NEURO-MUSCULOSKELETAL GUIDELINES VASOMOTOR MAPPING AND SYMPATHETIC GENERATORS

Robert G. Schwartz
Greenville, South Carolina

HEADLINES OF SLIDES

Peripheral Nerve Anatomy - Sympathetic Nerve Anatomy - NMSK Sympathetic Generators - RSD Differential Diagnosis - CRPS/RSD: History -Usually preceded by an identifiable injury or event (major or minor) - Burning, knawing, cold sensitive, allodynia - May directly involve any tissue (CRPS I) or nerve (CRPS II)- Physical Exam - oSympathetic pain: overly sensitive tissue - RSD With Dystonic Features - RSD & Spread -Somatovisceral Pain - Typical Injury Model - Expanded Injury Model - Diagnosis of RSD/CRPS - Efficacy Of Stellate Block - Electric Stellate Block - Flouroscopic Guidance & Sympathetic Block - Pain Score Tests - Three Phase Bone Scan - Bone Scan & Clinical Practice - SSR Studies Measure Skin Temperature & Maps SGI - Skin temperature is vasomotor & sudomotor dependant - SGI mapping provides insight into structures as generators - SSR is expected to be symmetric - Abnormal findings present as a side to side GSI or GSR asymmetry pattern (> 1 degree centigrade) - Controlled Conditions - SSR Asymmetry Patterns - LLE RSD - LLE RSD L5 Distribution - LUE RSD (Radial-Humeral Lig.) - Describing Asymmetry Patterns - SSR Impression - Variants Exist: ABC Syndrome - CCC Syndrome - Direct Clinical Impact: Drug Selection - RSD Generators: Trauma - RSD Generators: Bone - RSD Generators: Dura - RSD Generators: Disk - RSD Generators: SVN - RSD Generators: Tendinosis - RSD Generators: Ligament - RSD Generators: Vein - RSD Generators: Skin - RSD Generators: Treatment Should Address The Source - Block Above & Treat The Source - Block Above May Treat The Source - Block Above & Treat Below - AAT Guidelines: SSR Indications - AAT Guidelines: SSR Indications - Thermal Imaging is Clinically Important - Summary RSD Diagnosis

THE AAT BREAST GUIDELINES

Philip Getson
Marlton, New Jersey

HEADLINES OF CHAPTERS

General Statement: - Statement of Need - Breast Thermography (Purpose, Indications, Contraindications and Limitations) - Guideline 1: Patient Communication and Pre Examination Preparation - Guideline 2: Patient Assessment - Guideline 3: Examination Guidelines - Guideline 4: Review of the Infrared Thermography Examination - Guideline 5: Preparation and Storage of Exam Findings - Guideline 6: Exam Time Considerations - Guideline 7: Continuing Professional Education - Guideline 8: Informed Consent - Guideline 9: Reporting - References

SOMATOVISCERAL PAIN AND THERMAL IMAGING

Bill Hobbins
Madison, Wisconsin

In the 16th century it was believed that the skin of the human body was able to have effect on the viscera, and the viscera could have effect on the skin.

Since the 18th century, man has attempted to understand the relationship of skin to the viscera:

In 1893, H. Head in 131 pages, showed the cutaneous relationship between skin and viscera, when there is referred pain. Each specific territory would show the following changes with the visceral pain: with specific diagrams of territories of all viscera of the body, which showed the following changes when there was visceral pain: 1. Paresthesia 2. Hyperthermia 3. Tension (tenderness).

All of H. Head's diagrams and thermograms have been verified today by authors: Kellgren, Richter, Umeatsu, Travell and Hobbins. And examples of these observations will be demonstrated.

This age old discussion has in the past century been solved for a more satisfactory answer. In a capsule, it is that all referred visceral somatic pain is a result of the smooth muscle attitude expressed as blood flow, altered by the extra spinal sympathetic nervous system control. This pain system is expressed through the same pathways as our major temperature control, by the autonomic sympathetic ganglion, which is an extra spinal ganglion mediated system.

The paper proposes that any and all pains of this origin can be objectified by thermography, which will verify the suspected diagnosis. This will increase the accuracy of diagnosis and therapy.

DISTINCT INFRARED SIGNATURES IN PATIENTS WITH NEUROPATHIC ABNORMALITIES OF THE LIMBS

T. D. Conwell
Denver; Colorado

Infrared (IR) imaging sensitively detects and precisely delineates variations in skin temperature useful in the evaluation out in a painful conditions involving peripheral nerves of the limbs. IR imaging is useful in evaluating patients expressing positive sensory symptoms that originate from dysfunction of small caliber, mostly unmyelinated, nociceptor and sympathetic vasomotor nerve fibers. Conversely, conventional nerve conduction studies exclusively test nerve impulse conduction in large-caliber, myelinated sensory and motor fibers.

Distinct IR signatures result from neuropathic abnormalities, focal inflammation and vascular disease. There are four (4) distinct IR signatures which occur as a result of neuropathic abnormalities in an affected painful limb. There are two "cold" and two "hot" IR signatures. Provocative cold water autonomic reflex testing is helpful in differentiating the pathophysiological mechanisms of the two "cold" and the two "hot" IR signatures. Provocative cold water autonomic reflex testing is performed by immersion of an asymptomatic unaffected limb in a cold water bath, which produces systemic distal cooling (vasoconstriction) in the limbs in a normal asymptomatic population (i.e., patients with an intact and functioning SNS). In patients with impaired SNS function (inhibition/failure) in the affected limb there is observed paroxysmal warming.

Distinct "cold" IR signature I is due to a normal somato- autonomic reflex secondary to a peripheral pain generator(s) or excitation of a nociceptor commonly referred to somatosympathetic reflex vasoconstriction. Excitation or irritation of sensory receptors elicits vasoconstriction (cooling) of the skin predominately visualized in the territory of the affected nerve or in a

global nondermatomal pattern from excitation of a somatic nociceptor. This patient population demonstrates hypothermic IR signatures in the affected limb either in the skin territory of the involved nerve or in a global distribution from somatic nociceptor impulse. These patients respondednormally to provocative cold water autonomic reflex testing, indicative an intact and functioning SNS.

Distinct "cold" IR signature II isas a result of exaggerated catecholamine responsiveness as a result of receptor up-regulation related to reduced SNS outflow. Chronic inhibition or interruption of the postganglionic sympathetic neurons (impaired SNS function) innervating the microcirculation to the skin initially produces vasodilatation as a result of lower norepinephrine levels in the affected limb. This phenomenon eventually leads to vasospasm in arteriolar smooth muscle secondary to sympathetic denervation hypersensitivity to circulating catecholamines. This patient population demonstrates a global nondermatomal hypothermic IR signature in the involved limb with observed absent or minimal cooling to provocative cold water autonomic reflex testing.

Distinct "hot" IR signature I is aresult of altered SNS function due to inhibition/failure of the vasoconstrictor impulses following nerve trauma or sympathoparalytic vasodilatation post sympathetic blockade, sympathectomy, somatic nerve blockade or neurectomy. The vasodilatation is a result of removal of the sympathetic mediated vasoconstrictor tone. The hyperthermic IR signatureis specific to the involved nerve following somatic nerve block or neurectomy. The hyperthermic IR signature is in a global nondermatomal distribution following sympathetic blockade or sympathectomy. There is paroxysmal warming of the involved limb with provocative cold water autonomic reflex testing, indicative of inhibition/failure of the SNS vaso-co nstrictor reflex.

Distinct "hot" IR signatureII is due to neurogenic inflammation producing antidromic and humoral vasodilatation mediated by release of proinflammatory cytokines (e.g., TNF-alpha, interleukin-1β,-2,and-6) and proinflammatory neuropeptides (e.g., SP, CGRP, bradykinin). This hyperthermic IR signature is independent of sympathetic activity. This hyperthermic IR signature is visualized in the specific skin territory of the involved nerve (e.g., small caliber fiber neuropathy) or in a global non dermatomal distribution in patients with plexus (e.g., brachial plexopathy) or peripheral neuropathy (e.g., diabetes). Provocative cold water autonomic reflex testing results in a somatosympathetic reflex vasoconstriction that overrides the vasodilatation from proinflammatory cytokines and neuropeptides. This patient population demonstrates normal vasoconstriction with provocative cold water autonomic reflex testing, indicative of an intact and functioning SNS.

RSD LOOK ALIKES

Robert G. Schwartz
Greenville, SouthCarolina

HEADLINES OF SLIDE

Barre-Lieou - TOS - RSD Look Alike: Raynaud's Syndrome - RSD Look Alike: Vibration (White Finger) Syndrome - RSD Look Alike: Buerger's Disease - RSD Look Alike: Post Radiation Fibrosis -RSD Look Alike: Gout - RSD Look Alike: RTC Syndrome - RSD Look Alike: Livido Reticularis - RSD Look Alike: Coagulopathy - RSD Look Alike: Ligamentous Strain - RSD Look Alike: Erythromelalgia - RSD Look Alike: Cellulitis - RSD Look Alike: Pernio (Chilblains) - RSD Look Alike: Blue Toe Syndrome - RSD Look Alike: Ischemic Foot - RSD Look Alike: Venous Thrombosis - RSD & Co-morbid Disease - Co Morbid Disease: Guillan Barre - Co Morbid Disease: Breast CA - Conclusion: RSD/CRPS, Comorbid Diseaseand Look Alikes are Multifactorial

BREAST IMAGING SIGNIFICANCE AND SUGGESTIONS

Bill Hobbins
Madison, Wisconsin

The musings of a general surgeon of 63 yearspractice of breast health and disease and with special interest of integrating the thermography for the last 39 years.

This will deal with the anatomy, physiology and pathology of breast measurement of blood flow by means of qualitative and quantitative thermography.

Study of normal and abnormal breast expressionof blood flow by thermography. This is possible as the breast is a skin organ and the skin is a perfect black body and the observations are precise.

The thermography (blood flow) of the breast is modified by the the following vascular conditions of the breast: youth, fertility, pregnancy, nursing, inflammations, injury, influence of chemicals (drugs and hormones), neoplasia, and effects of therapy with anti-angiogenesis. Thus predicting recurrences and prognosis.

These must be studied to beable to use this modality in each detection of neoplasia. This willbeillustrated through the use of graphs, tables, and charts.

The major discussion of how to improve the thermographic standard and to use this information in relationship to the prevention and protection of the breast by awareness of influence of drugs, diets, and supplements on the health of the breast.

INFRARED THERMOGRAPHY APPLICATIONS IN ANIMAL CARE

Debra M. Sime, Rachel Cezar, Tracy A. Turner, Vaughan Langman
USDA-APHIS-Animal Care, Raleigh, North Carolina

The Animal Care program, which is part of the United States Department of Agriculture's Animal and PlantHealth Inspection Service, provides leadership for determining standards of humane care and treatment of animals covered under the Animal Welfare and Horse Protection Acts. The Animal Care program has added infrared thermography technology to its effort to achieve compliance through inspection, education, cooperative efforts, and enforcement. Underthe Animal Welfare Act infrared technology is used under the direction of the Biophysics Animal Care Specialist at the Center for Animal Welfare. Absolute temperatures from an infrared thermal camera are applied to biophysical ecology analysis of thermal neutral zones and insulation factors of animals. Using infrared thermography the Animal Care program has been able to identify insulation factors and thermal neutral zones in a wide range of animals. The Animal Care Horse Protection program isusing infrared thermography as a technology to screen horses forsoring prior to the inspection process. Under the Horse Protection Act horses that have been subjected to a practice called soring are prohibited from participating in shows, sales, exhibitions, or auctions. Infrared thermography identifies abnormalities by measuring thesurface temperature of a horse's legs anddepicting color patterns that are excessively warm or cool, both of which may reveal an abnormality indicative of soring. Horses thatexhibit a pattern of "Not Normal" are subjected to greater scrutiny under the inspection process to ensure sore horses are prohibited from participating in shows, sales, exhibitions, or auctions. The use of infrared thermography technology by the Animal Care program contributes to the latest information in animal welfare science and technology.

THERMOGRAPHIC MONITORING OF LASER THERAPY OF RSD PATIENT - A CASE STUDY

Andrzej Zielke
North Huntingdon, Pennsylvania

Laser therapy is known to restore the ATP levels in compromised cells, which enable the cells to regain homeostasis, accelerate healing and regenerate. Laser therapy can be used as direct irradiation of the affected tissues or as blood irradiation to take advantage of the systemic effect.

The treatment choice depends on the individual clinical problem. Inflammatory conditions such as arthritis, respond better to a direct irradiation of the affected joints. Reflex Sympathetic Dystrophy (RSD) on the other hand, is better treated with blood irradiation.

The patient involved in this case study was a 48 year old white female with well documented RSD of the right upper extremity following tendon injury of the first digit in 1999 which resulted in 11 reconstructive surgeries. Subsequently, the patient developed severe case of RSD that was poorly controlled with conventional approaches such as stellate ganglion blocks and pharmacologic treatments. For the last two years the patient has received laser therapy via percutaneous blood irradiation every two to four weeks which produced significant improvement of pain and other symptoms of RSD. For objective evaluation of the effectiveness of laser therapy, the patient was scheduled for treatment session under thermographic monitoring. The day of the study was chosen when the patient was severely symptomatic.

Equipment: Laser: 2 diodes, GaAs pulsing diode, wavelength 910nm, peak power 45W, pulse width 200ns and GaAs 635nm 12mW continues wave. Thermographic camera: FLIR A40.

Type of treatment: percutaneous blood irradiation via subclavian vein bilaterally. Subclavian veins are located immediately under the clavicles, and can be effectively irradiated percutaneously between one half and one third of the proximal part of the clavicles by pointing the laser beam up and medially just under the lower edge of the clavicles. Percutaneous subclavian vein irradiation may be performed either on the ipsilateral or contralateral side of the body in relation to the affected extremity with the same results. Subclavian veins offers an excellent approach for percutaneous blood irradiation because they carry 16% of cardiac output each and are easily accessible.

The study was performed in a climate control treatment room of the ambient temperature of 20 degrees Celsius. Patient was acclimated for 15 min before the study. Thermographic images were taken before, during and after irradiation. Percutaneous blood irradiation was first performed on the ipsilateral vein for 10 min followed by 5 min pause and then by irradiation of the contralateral subclavian vein for 8 min.

Results: the thermographic images showed a gradual and steady improvement of the skin temperature of the affected extremity which coincided with subjective reduction of symptoms. The patient reported a warming sensation of the extremity, elimination of numbness, and significant alleviation of pain. Patient follow up the next day revealed that the peak effect of Iaser therapy occurred in less than one hour alter treatment and Iasted about twelve hours. After that time, the effect started to wear oft. However, the pain Ievei was still significantly lower the next day.

ACUPOTOMY: SOFT TISSUE RELEASE WITH THERMAL MONITORING

Bryan O'Young
New York City, New York

Acupotomy is a novel approach to soft tissue release using an acupuncture needle with a blade at one end instead of the traditional needle tip to penetrate soft tissues in managing soft tissue pathologies. It is a synergistic combination of traditional Chinese acupuncture and western surgery to treat many difficult soft tissue cases including lumbar disc herniation with nerve root compression and shoulder adhesive capsulitis, with minimal soft tissue invasion in a matter of minutes in an outpatient setting. Acupotomy will be introduced in this presentation and this will be followed by a brief case study using thermal imaging to monitor the effects of acupotomy.

THERMAL EFFECT OF PULSED ELECTRO-MAGNETIC FIELD AND CLASS IV LASER THERAPIES ON HUMAN GASTROCNEMIUS

Martin Bales
Solana Beach, California

Two alternative pain therapies, Pulsed Electro-Magnetic Field (PEMF), and class IV Laser (Laser), have been shown to provide a myriad of benefits including increased local blood profusion, increased oxygenation of the blood, decreased inflammation, and an overall reduction in musculoskeletal healing times. There is much discussion as to the mechanisms of action of these modalities, and, as such, research on their thermal effect may provide additional information necessary to understand the science behind their efficacy. As a small study, 3 participants with healthy, asymptomatic gastrocnemius muscles were thermally imaged before and after each of PEMF and Laser therapies. The intensity of the PEMF was set to the highest tolerable by the volunteer while the intensity of the Laser was set to 8 watts (8000 mW) continuous wave, 800 and 910 nanometer combined wavelength. The PEMF utilized the "butterfly" treatment module wrapped around the gastrocnemius while the Laser was administered by hand in a circular motion over the gastrocnemius. Both therapies were administered for 6 minutes. All 3 participants showed no significant change in temperature (delta T) from the baseline image to the image captured directly after the administration of PEMF therapy. Conversely, all 3 participants showed a significant delta T from the baseline image to the image captured directly after the administration of Laser therapy. This data suggests that PEMF therapy has little to no effect on local area cutaneous blood profusion while Laser therapy has a significant, profound effect. As the sympathetic nervous system (SNS) is the governor of local area blood profusion, this data further suggests that the mechanism of action (MOA) of Laser therapy has direct effects on the SNS while the MOA of PEMF therapy has no direct effect on the SNS.

SETTING UP A THERMOLOGY LABORATORY:

George Schakaraschwili, J. Tashof Bernton
Colorado Rehabilitation and Occupational Medicine, Denver, Colorado

Our experience in setting up a laboratory for the use of thermography to aid in the diagnosis of CRPS is discussed. Guidelines for use of thermography, camera specifications, laboratory parameters, patient preparation, specific protocols and image capture are discussed. Imaging processing, data analysis and report generation are detailed. Pitfalls and alternate diagnoses are considered and two clinical cases are presented. At the end of the presentation, participants will be aware of the issues involved in setting up a laboratory for the clinical application of infrared imaging.

Meetings

March15th-17th,2013
17th National Congress of the Polish Association of Thermology in Zakopane.

Venue: HYRNY Hotel, Pilsudskiego str 20, 34-500 Zakopane, Poland

Abstract deadline: February 15th, 2013

Deadline for hotel reservation: March 1st, 2013

Registration fee: 250.-Euro

Local organizing comittee

Prof. Anna Jung (Chair)

Dr Janusz Zuber (deputy Chair)

Dr Boleslaw Kalicki,
Mgr ing Piotr Murawski

International Scientific Committee

Prof. A. Jung (Poland)

Prof. E.F.J.Ring (UK)

Prof. J. Mercer (Norway)

Prof K. Ammer (Austria)

Prof. B. Wiecek (Poland)

Dr. Kevin. Howell (UK)

Dr. R. Vadasca (Portugal)

Prof. A. Nica (Romania)

Prof. M. Sillero Quintana (Spain)

Registration fee for non Polish participants will be paid in cash on arrival at the conferrence.

Registration and information on line : ajung@wim.mil.pl or a.jung@spencer.com.pl

Abstracts will be published in Thermology International and in Acta Bio- Optica et Informatica Medica

Registration by e-mail is required before March 1st to ensure hotel reservation. After registration number is issued, delegates are committed to payment of the fee.

Registration includes welcome dinner Friday, farewell dinner Saturday, Lunches, coffee breaks and accommodation.

Accompaning person - 200.-Euro

March in Zakopane is very attractive, being surrounded by the Tatra Mauntains covered with snow. The International airport of Krakow, is a 2hr journey away. There is good connection from Krakow airport by railway to bus station in direct Zakopane.

Further information
Prof. Dr Anna Jung
ajung@wim.mil.pl ora.jung@spencer.com

29 April - 3 May 2013
SPIE, Defence, Security + Sensing

Baltimore Convention Center,
Baltimore, Maryland, United States

Thermosense: Thermal Infrared Applications XXXV

Tuesday-Wednesday 30 April - 1 May 2013
Infrared Applications
ThermoSense Mission Statement

Thermosense Background

Thermosense is the oldest and largest international technical meeting focused on scientific, industrial and general uses of Infrared Imaging and Infrared Temperature Measurements. Its regular printed proceedings are found in most scientific and engineering libraries, providing an unequaled depth and breadth of technical information and reference data.
Further information regarding Thermosense can be found at: www.thermosense.org

*Conference Chair*s

Gregory R. Stockton, Stockton Infrared Thermographic Services, Inc. (United States);
Fred P. Colbert, Colbert Infrared Services (United

Tuesday 30 April

Session 1: Building Applications

Panel Discussion: Building

Session 2: Security

Session 3: Security II

Panel Discussion: Security

Session 4: Research and Development

Session 5: Medical

Time: 4:00 PM - 5:00 PM

Session Chairs: Nicolas Avdelidis, National Technical Univ of Athens (Greece); Sheng-Jen Hsieh, Texas A&M Univ. (United States)

Paper 8705-15 Phillip Bretz, Richard Lynch, Desert Breast & Osteoporosis Institute (United States)
Results of the first 1000 patients: A method to defeat breast cancer without using traditional surgery, chemotherapy, or radiation: We must rethink breast cancer diagnosis and treatment

Paper 8705-16 Seung K. Jung, Univ. of California, Berkeley (United States); Sheng-Jen Hsieh, Che-Hao Chen, Texas A&M Univ. (United States) Experimental model for determining developmental stage of chicken embryo using infrared images and artificial neural networks

Paper 8705-17 Carl B. Cross, Julie A. Skipper, Wright State Univ. (United States) Thermal imaging to detect physiological indicators of stress in humans

Panel Discussion: Medical

Tribute to
Ermanno Grinzato and Sven Sven-Ake Ljungberg

Wednesday 1 May

Session 6: Additive Manufacturing

Session 7: Materials Evaluation

Session P4: Panel Discussion: Additive Manufacturing and Materials Evaluation

Session 8: NDT (Nondestructive Testing) I

Session 9: NDT (Nondestructive Testing) II

Panel Discussion: NDT (Nondestructive Testing)

Session 10: Professionalism

23-26 April, 2013
Veterinary Thermal Imaging Course in Epe, (The Netherlands)

Venue: Manege Hippisch Centrum;
Rietberglaan 10,
8162NE EPE
and
Marskamp Stable,
Wezeweg 9a,
8181PM Heerde (The Netherlands)

5-day course given by Prof. Dr. Ram Purohit, Dr. Tracy Turner and Dr.Daan Staller.

With topics as:

- Normal Equine thermographic examination.

- Artefacts in the thermographic exam.

- Video thermography

- Dermatome patterns of Horses.

- Clinical cases with spinal injuries in equine, bovine and canines.

- Practice session on how to image horses following a protocol. The session will begin with a demonstration of how to perform the basic equine thermal examination.

Several cameras are available onsite if you cannot bring a camera.

- 1 day "Part of the Body" Head and Neck. (anatomy, pathologies, biomechanics and much more...)

This course is organized for everyone working in the veterinary field, especially:

-Veterinarians and Technicians

-Physiotherapists

-Osteopaths and Chiropractors

-Farriers

-Horse owners and trainers

-Saddlers

-Thermographs

-Other veterinary professions.

Early bird discount till March 23th

Onlineregistration at
http://www.equine-thermography-course.eu

All courses are in English

Acomodation:

Hotel "De Witte Berken"
Oost Ravenweg 8
8162 PJ, Epe (Gelderland)
Nederland
Phone: 0031 578
From this hotel we offer a shuttle service to and from both course locations, for those who have no transport!

30thJune - 3thth July 2013.
International Centre of Biocybernetics (ICB)-Seminar "ADVANCES OF IR-THERMAL IMAGING IN MEDICINE" in Warsaw

The seminar will be devoted mainly to the following topics:

New technology trends in IR-thermal imaging,

TSR as a novel approach in medical applications,

Active Dynamic Thermography and Thermal Tomography,

Modelling and simulation of thermal processes,

Standardization of thermal images and series of images,

Multimodality with thermal imaging,

New applications in medical diagnostics

*For further information please conta*ct

Prof. Antoni Nowakowski, antowak@biomed.eti.pg.gda.pl (Chairman of the Seminar)
or
Dr Mariusz Kaczmerek, mariusz@biomed.eti.pg.gda.pl (Secretary of the Seminar)

3-5 July, 2013
18th International Conference on Thermal Engineering and Thermogrammetry (THERMO)

Budapest University of Technology and Economics(BME)
Budapest, XI.,Mûegyetem rkpt.3.,Hungary

THE CONFERENCE ORGANIZER:
Branch of Thermal Engineering and Thermogrammetry (TE and TGM),
Hungarian Society of Thermology (HST) at MATE,
European Association of Thermology (EAT),

SPONSORED BY:
- Hungarian Energy Office Budapest, (MEH),
- Budapest University of Technology and Economics (BME), Faculty of Mechanical Engineering (FME),
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- Hungarian Scientific Society of Energy Economics (ETE) Budapest
- Hungarian Association of District Heating Enterprises (MaTáSZSZ),,Budapest
- Hungarian Chamber of Engineers, Budapest (HChE),
- Research and Development Company for the Combustion Technology,Miskolc (TÜKI ZRt.),Hungary,
- 'Frédéric Joliot-Curie' National Research Institute for Radiobiology and Radiohygiene, Budapest (OSSKI),
- National Society for Medical Engineering,Budapest. (MEDING).

SCIENTIFIC COMMITTEE:

Chairman: Dr. I. Benkõ BME,FME,Hungary (EAT,HST,President of the TE and TGM),

Secretaries: I. Kovacsics, MSc. EGI-Contracting / Engineering Co.Ltd., Budapest,

L. Vannay,Dr. BME, Inst.of Physics, Hungary (HST, TE and TGM).

MAIN TOPICS

The structure of the sessions will be fixed after receiving the papers, but the topics will cover the following fields:

General thermal engineering; theory of measurements; thermal informatics, thermo-CAD and its applications; advanced thermodinamics and the new tendencies associated: industrial energy management and process control systems; practice of thermal engineering; infra-red imaging science & technology: thermogrammetry, micro- and nanoscale thermal phenomena and sensing techniques, thermal defectometry; applied thermo-optics; thermophysical properties; heat and mass transfer; cooling of electronic components; heat exchangers; combustion; thermophysics of the environment; building services; environmental aspects of energy use; thermo-ergonomy and thermo-psychology; thermo diagnostics; system analysis in thermo-biology; IR-imaging in biomedical and bio-engineering applications; remote sensing through IR- imaging, multidisciplinary topics.Solar hybrid & photovoltaic systems. Waste management research,hazardous materials, recycling & reuse.

VENUE

The conference is hosted by the Budapest University of Technology and Economics (BME, Budapest, XI. Budafoki út 4., Hungary) located near the Hotel 'Gellért' and the Danube. More information about the conference place and hotel accommodation will be sent after the arrival of the Registration Form: www.mate-net.hu/03menu/03index.htm

Information :

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and secretariat: mate@mate-net.hu

25-27 October 2013, American Academy of Thermology Annual Meeting in Greenville, South Carolina

Venue: Bon Secours St. Francis Hospital, Greenville, SC,

Further information

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