Assessment of hand osteoarthritis: correlation between thermographic and radiographic methods

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Objective. Anatomical stages of digital osteoarthritis (OA) have been characterized radiographically as progressing through sequential phases from normal to osteophyte formation, progressive loss of joint space, joint erosion and joint remodelling. Our study was designed to evaluate a physiological parameter, joint surface temperature, measured with computerized digital infrared thermal imaging, and its association with sequential stages of radiographic OA (rOA).

Methods. Thermograms, radiographs and digital photographs were taken of both hands of 91 subjects with nodal hand OA. Temperature measurements were made on digits 2–5 at distal interphalangeal (DIP) joints, proximal interphalangeal (PIP) joints and metacarpophalangeal (MCP) joints (2184 joints in total). We fitted a repeated measures ANCOVA model to analyse the effects of rOA on temperature, with handedness, joint group, digit and NSAID use as covariates.

Results. The reliability of the thermoscanning procedure was high (generalizability coefficient 0.899 for two scans performed 3 h apart). The mean joint temperature decreased with increasing rOA severity, defined by the Kellgren–Lawrence (KL) scale. The mean temperature of KL0 joints was significantly different from that of each of the other KL grades ($P \leq 0.002$). After adjustment for the other covariates, there was a strong association of rOA with joint surface temperature ($P < 0.001$). The earliest discernible radiographic disease (KL1) was associated with a higher surface temperature than KL0 joints ($P = 0.01$) and a higher surface temperature than any other KL grade. Joint erosions were not associated with a change in joint temperature.

Conclusion. Joint surface temperature varied with the severity of rOA. Joints were warmer than normal at the onset of OA. As the severity of rOA worsened, joint surface temperature declined. These data support the supposition that digital OA progresses in phases initiated by an inflammatory process. The cooler surface temperatures in later stages of the disease may in part explain the paucity of symptoms reported by patients with hand OA.

KEY WORDS: Thermography, Osteoarthritis, Imaging, Hand, Radiography.

Temperature is a fundamental physical property and a rise above normal is one of the four classical signs of inflammation, along with redness, swelling and tenderness. Infrared thermal imagers provide a non-contact means of measuring surface temperature [1]. This technology is based on the principle that any object whose temperature is above 0° Kelvin (K) radiates infrared energy. The human body has a temperature of about 310°K and radiates primarily in the far infrared spectrum. Infrared thermal imagers capture a portion of this radiated energy and are calibrated to indicate specific temperatures. A thermal image is therefore a spatial map of temperatures created by surface scanning. Abnormalities such as malignancies, inflammation and infection can cause localized increases in tissue temperature, which appear as hot spots or areas of inhomogeneity in the thermographic image. The quality of these instruments has improved dramatically over the last decade [1]. Computer-enhanced digital infrared thermal imaging (cDITI) systems now have much improved spatial and thermal resolutions and are used widely in industrial applications [2].

Several thermographic studies have been performed to evaluate rheumatic diseases of the hand, including rheumatoid arthritis [3], scleroderma [4], Raynaud's phenomenon [5–7] and reflex sympathetic dystrophy [8]. There have also been several studies using thermography to assess osteoarthritis (OA) of the knees and hands [9–11] and the temporomandibular joint [12]. In some of these studies, thermography has been used as a tool to provide objective data on joint inflammation in response to therapeutic interventions. For example, thermography has been used to measure the change in hand joint temperature in response to non-steroidal anti-inflammatory agents (NSAIDs) [10]. The same investigators evaluated temperature changes in knee OA in response to intra-articular steroids [11]. They showed a significant reduction in joint surface temperature 1 week after intra-articular steroid injection in a small number of patients ($n = 12$).

OA is believed to arise from a complex interaction of multiple factors, including genetic predisposition, local inflammation, mechanical forces, and cellular and biochemical processes [13]. Despite multiple aetiologies, distinct anatomical stages of digital OA have been described and characterized radiographically as progressing through sequential phases from normal to osteophyte formation, progressive loss of joint space, joint erosion and joint remodelling [14]. Our study was designed to evaluate the phasic activity reported for hand OA using cDITI to measure radiant skin temperature at joint sites. We hypothesized that joint surface temperature could complement the radiographic evaluation of OA by contributing information on a dynamic and physiological component to augment the static information obtained from X-ray and thereby potentially yield valuable information on the inflammatory phases of the disease process.

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Methods

Subjects

We enrolled 91 subjects over a 10-month period (August 2000 to May 2001) on the basis of bilateral clinical hand OA involving a minimum of three joints with bony enlargement, including a DIP. Subjects were recruited independently of hand symptoms. The subjects' written consent was obtained according to the Declaration of Helsinki [15] and the study was approved by the Duke University Medical Center Institutional Review Board. Subjects were excluded if they had a clinical diagnosis or radiographic evidence of joint disease due to rheumatoid arthritis, gout or psoriasis or a clinical history of systemic lupus erythematosus. Subjects were also excluded if they had a history of Raynaud's phenomenon with a classical three-phase digital colour change. The presence of chondrocalcinosis or CPPD was recorded but did not disqualify a subject. Subjects underwent physical examination of their hands (to evaluate for joint swelling, tenderness and bony enlargement). A digital posterior–anterior image (1.2 megapixel resolution) of both hands was taken with a black background using a Kodak Zoom Camera model DC 260 (Eastman Kodak, Rochester, NY, USA). These images were collected for documentation and verification of the physical examination.

Thermoscan procedure

Computerized colour thermograms of the hands were obtained using a Compix PC2000e Digital Infrared Thermal Imaging system (Compix, Lake Oswego, OR, USA). This device is thermoelectrically cooled and each temperature measurement (50 000 in each scan) is compared with a stable point of reference within the camera, allowing information to be compared within scans and between scans with accuracy. The guidelines followed for the scanning procedure were those recommended by the International Academy of Clinical Thermology (www.iact-org.org). In brief, subjects were asked to remove all jewellery and were seated with their hands uncovered for 15 min prior to thermoscanning. All images were performed in the same draught-free room with stable ambient temperature (21°C), lacking windows and illuminated by a fluorescent ceiling light. The subjects' hands were placed palms down on a board covered with black velvet cloth. The infrared camera was positioned 15 inches (38.1 cm) perpendicular to and above the hands and a thermal image was taken in 8 s. Twelve subjects underwent two thermographic studies on the same day, 3 h apart, to evaluate the reliability of the imaging technique.

Thermoscan analysis

The cDITI had a temperature resolution of 0.1°C. Data collection and thermogram analyses were performed by the same individual (GV), blinded to the radiographic data, using WinTES software (Compix). The mean absolute temperature (absT) was determined for operator-defined regions of interests (ROI) of 8×8 mm positioned over the DIPs, PIPs and MCPs of digits 2–5. The mean temperature of an 8×8 mm area positioned over the middle of the wrist was also recorded for purposes of controlling within subject variability. The difference in temperature between a joint and this fixed reference point was designated the delta temperature (deltaT). The surface temperatures over joints of digit 1 were not included for the purposes of this analysis due to oblique positioning of this digit on the images.

The localization of DIP and PIP ROIs was determined by measuring the distance of the midpoint of each joint from the fingertip in 15 subjects (10 females, five males, 120 joints) (Table 1). These mean distances determined in 15 subjects dictated the correct proportional distances from the fingertip for the positioning of the

TABLE 1. The mean distances (s.d.) of DIPs and PIPs from fingertip as a proportion of the fingertip-to-MCP distance

Joint group	2nd digit	3rd digit	4th digit	5th digit	All digits
DIPs	32.92% (4.01)	30.59% (4.14)	32.62% (2.79)	34.56% (4.01)	32.68% (1.63)
PIPs	65.53% (6.98)	64.89% (3.15)	66.12% (5.71)	65.35% (5.71)	65.47% (0.51)

ROIs. MCP joint ROIs were localized on the basis of digital photographs taken at the same focal distance as the thermoscans.

Hand radiograph

A posterior–anterior hand radiograph focused on the third MCP joint was performed for the right and left hands separately. Hand radiographs were read by a single radiologist (JBR) for evidence of OA using the Kellgren Lawrence (KL) grading system with a standard atlas [16]: grade 0 = normal joint; grade 1 = small osteophyte of doubtful significance; grade 2 = definite osteophyte; grade 3 = osteophyte and joint space narrowing; grade 4 = severe joint space narrowing. Radiographs were also read for erosions and features related to the exclusion criteria. All radiographs were read blinded to the clinical and thermographic data.

Statistical analysis

All statistical analyses were carried out with SAS (Cary, NC, USA). Measures of central tendency and variability were computed by means and standard deviations for continuous variables and by percentages for discrete variables. To assess test–retest reliability, we employed an extension of classical test theory reliability [17] when factors other than time are present (generalizability theory) [18]. That is, since at any one time and for any one person, temperature was measured across 24 joints (see below), the estimated test–retest reliability coefficient was computed across the numerous joints simultaneously.

To assess the relationship between KL grade and temperature, a repeated measures ANCOVA model was employed. For the first analysis, the effects of NSAID and KL grade on absolute and delta temperatures were evaluated. For subsequent analyses of both absolute and delta temperature, joint group (MCP, DIP, PIP), digit and handedness were entered into the model as covariate factors to provide a controlled analysis for the effect of KL grade on temperature. If an omnibus significance test for the effect of KL level (4 degrees of freedom) was declared significant ($P < 0.05$), *post hoc* paired comparison tests were performed for KL1-4 using KL0 as a reference.

Results

A total of 91 subjects were enrolled on the basis of clinical hand OA. The majority of subjects were women ($n = 73$, 80.2%) and most were right-handed ($n = 86$). Mean age was 69.5 yr (range 46–87 yr). About half of the subjects ($n = 51$, 56%) consumed NSAIDs on a regular basis, but none were receiving systemic steroids. The hands of each subject were evaluated thermally and radiographically. A total of 24 index joints per subject were evaluated: eight DIPs, eight PIPs and eight MCPs. Observations were made on a total of 2184 joints (546 joints for each of the digits 2–5, or 728 joints for each of the three joint groups). Surface temperature was measured over the dorsal midpoint of each joint and expressed as absT and deltaT. The values for absT ranged from 22.41 to 37.17°C. DeltaT values ranged from −11.62 to +4.13°C. Most joint surface temperatures were lower than the
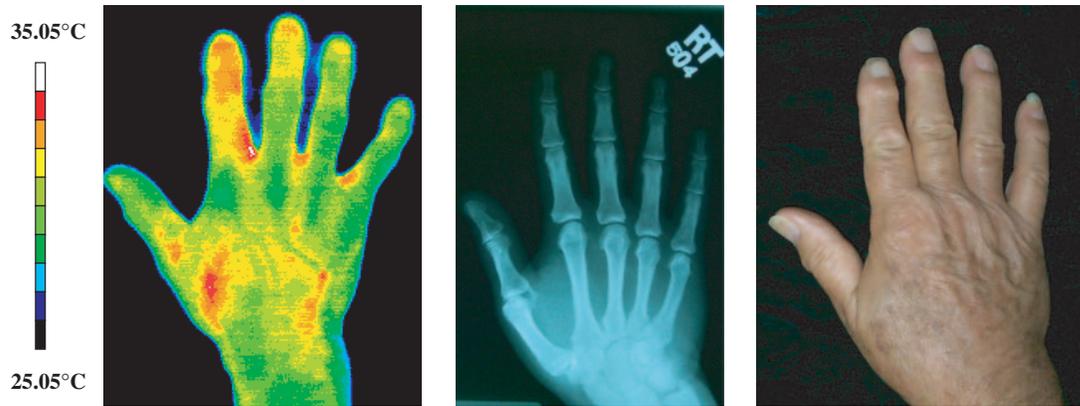
FIG. 1. Representative hand images. A representative thermogram, radiograph and digital hand photograph are shown for a single subject. The hands were imaged thermographically with a Compix PC2000e Digital Infrared Thermal Imaging system. The absolute and delta temperatures at the DIP, PIP and MCP joints were determined, along with the radiographic (Kellgren–Lawrence) grade of OA at each joint of digits 2–5. The proportional distances in Table 1 were used to identify the location of the DIP and PIP joints for placement of regions of interest (ROIs) for the purposes of thermal measurements. The hand photographs were used to identify the location of the MCP joints for thermal measurements.
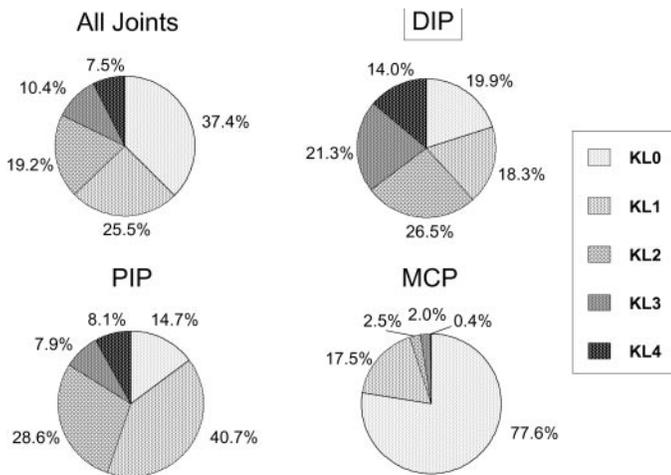

FIG. 2. Distribution of Kellgren–Lawrence (KL) grades by joint group. Radiographic grading was performed on a total of 2184 hand joints (DIPs, PIPs and MCPs of digits 2–5) by one reader. The pie charts depict the relative percentages of each radiographic grade of OA, for all joints combined (All Joints) and for each of the joint groups.

reference region at the wrist, resulting in negative deltaT values. A representative example of a matched thermoscan, radiograph and digital photograph from a single subject is shown in Fig. 1.

Joints of every KL grade were represented in this study: 817 KL0 joints; 556 KL1 joints; 419 KL2 joints; 228 KL3 joints; and 164 KL4 joints. The most prevalent grades were KL2 for DIPs, KL1 for PIPs and KL0 for MCPs, although all radiographic grades were represented in each joint group (Fig. 2).

A reliability study was conducted on 12 subjects. In these subjects, thermoscanning was performed twice, 3 h apart on the same day. The generalizability coefficient was calculated on the basis of all the 24 index joints. The generalizability coefficient was 0.899 for absT and 0.739 for deltaT. These results demonstrated good reliability of the thermoscanning procedure.

Significant temperature differences were observed between non-OA and OA joints. Overall, joint temperature and radiographic OA severity were inversely correlated (Fig. 3). With increasing KL grade, absT decreased significantly ($P < 0.002$ for KL0 vs any other KL grade). DIP and PIP joints were similar, showing an inverse

relationship between temperature and OA severity. In contrast, MCP joints showed little change in temperature for mild OA (KL1–2) and increased temperature with more severe OA (KL3–4). A similar pattern between temperature and radiographic OA was observed for deltaT (Fig. 4). However, these results for MCP joints are less reliable than the results for DIP and PIP joints because relatively few MCP joints were radiographically affected. For instance, a total of 830 DIPs and PIPs were affected with mild OA (KL1–2) in contrast to only 145 MCP joints with mild OA. Moreover, for more severe OA (KL3–4), a total of 374 DIPs and PIPs were radiographically affected in contrast to 18 MCP joints.

Although chronic NSAID use was reported by slightly more than half of the subjects, there was no effect of NSAID use on joint surface temperature or any interaction with radiographic grade of OA. There was also no association between temperature and radiographic evidence of joint erosion. A total of 102 out of 2184 joints displayed marginal joint erosions on radiograph. The association of absT and deltaT with radiographic OA was unchanged when erosions were included in the ANCOVA model (with and without erosions, $P < 0.05$ for absT and $P = 0.0001$ for deltaT for the association with KL grade).

We explored the effects of handedness, joint group (MCP, DIP, PIP) and digit using a repeated measures analysis of covariance (ANCOVA) model, to provide a controlled analysis for the effect of KL grade on temperature. The dominant hand was slightly, but not significantly, warmer than the non-dominant hand (difference of 0.08°C, $P = 0.56$). Significant associations were found between absT as well as deltaT and KL grade ($P < 0.001$), joint group ($P < 0.001$) and digit ($P < 0.001$). Adjusting for the individual, handedness, joint group and digit, KL1 joints were significantly warmer than KL0 joints ($P = 0.01$), while KL2–4 joints were colder than KL0 joints (Table 2).

Discussion

We measured surface temperature in normal and osteoarthritic joints of the hand in a cross-sectional study that captured information on hand joints in different stages of the disease. The thermoscanning procedure was very reliable, with a slightly stronger correlation between scans analysed for absT. This was not unexpected since deltaT is derived from the difference of two measurements, each with its own inherent measurement variability. Another possible explanation for greater variability of deltaT than for absT may relate to the presence of subacute OA of the wrist, the site used for the reference temperature for deltaT.
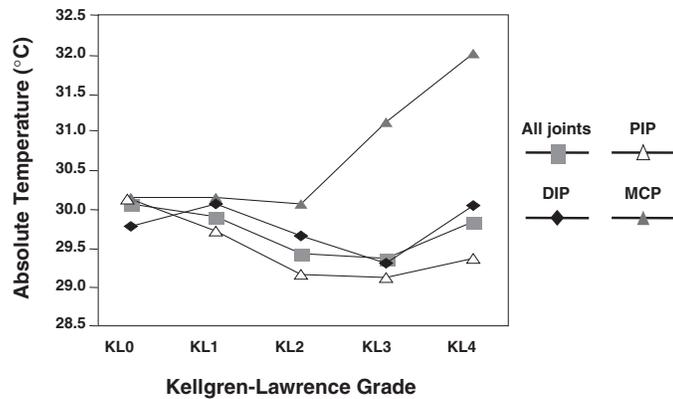
FIG. 3. Absolute temperature (absT) of hand joints relative to radiographic OA status. AbsT was measured thermographically as the dorsal surface temperature at the midpoint of each DIP, PIP and MCP of digits 2–5. Mean absT is plotted for all joints and for each joint group by severity of OA, based on the Kellgren–Lawrence radiographic grading system. Overall absT of KL0 *vs* KL1, $P = 0.002$; KL2, $P < 0.001$; KL3, $P < 0.001$, KL4, $P < 0.001$.

Although the wrist is not normally a site associated with OA, several studies have documented wrist abnormalities in subjects with hand OA of the digits [19–21]. One of these studies [19] demonstrated early-phase bone scan abnormalities in up to 33% of wrists of 35 patients with OA of the hands. The early-phase scan, acquired for 5 min after radiotracer injection, reflects skeletal blood flow. Thus, the use of the wrist as a reference site may introduce additional variability due to variations in skeletal blood flow at the reference site in subjects with subacute OA of the wrist.

Overall, a significant decline in temperature was observed with increasing KL grade of OA. After controlling for effects due to the individual, handedness, joint group and digit, the earliest discernible radiographic disease (KL1) was associated with a higher surface temperature than any other grade, including KL0. These results support the supposition that the earliest discernible radiographic stage of hand OA (KL1) represents an inflammatory phase of the disease. From these results we also infer that the KL1 grade represents a distinct phase of OA, distinguishable from KL0 and KL2.

The KL1 grade is defined as an osteophyte of 'doubtful significance', and is categorized in some studies with normal KL0 cases and in other studies with the KL2 grade of OA. These thermographic analyses support the categorization of the KL1 grade abnormality of a hand joint as a valid stage of OA. Interestingly, a KL1 grade at another joint site, the knee, has also been shown to be a valid stage of OA. Using entirely different methods, individuals with KL1 grade knee OA in Chingford, UK, were more likely to progress (62% rate of progression) to 'true knee OA' of KL2 grade over 10 yr than were individuals with KL0 knees at baseline (22% rate of progression) [22].

Joints of grades KL2–4 displayed lower surface temperatures than KL0 joints. The cause of decreased surface temperature over KL2–4 joints is unclear, although results reminiscent of these have been yielded by bone scintigraphic assessment of hand OA [19, 21, 23, 24]. Investigators have noted increased radiotracer uptake by hand joints on late-phase bone scans, reflecting increased metabolic bone activity that preceded radiographic abnormalities. They also have noted diminished bone scan activity with increased radiographic disease severity. Thus, like thermography, bone scintigraphy has demonstrated a phasic pattern of OA disease activity in hand joints and a discordance between scan results and radiographic severity of disease [21, 23]. Both techniques, thermography and bone scintigraphy, provide physiological assessments of
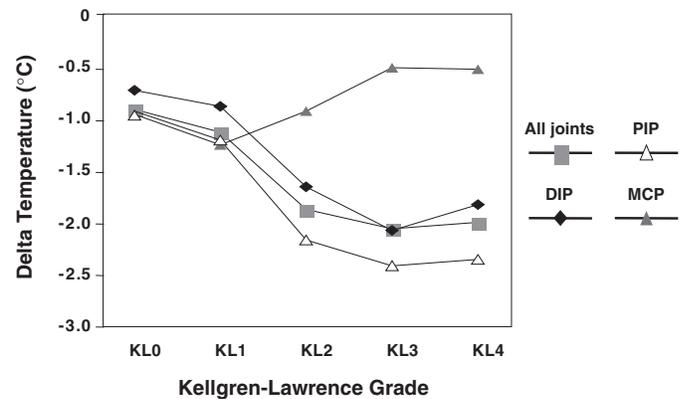

FIG. 4. Delta temperature (deltaT) of hand joints relative to radiographic OA status. DeltaT was measured thermographically as the difference between the dorsal surface temperature at the midpoint of a joint and the dorsal surface temperature at a reference point at the wrist. DeltaT was determined for each DIP, PIP, and MCP of digits 2–5. Mean deltaTs were plotted for all joints and for each joint group by severity of OA, based on the Kellgren–Lawrence radiographic grading system. Overall deltaT of KL0 *vs* KL1, $P = 0.002$; KL2, $P < 0.001$; KL3, $P < 0.001$; KL4, $P < 0.001$.

TABLE 2. Variation in joint surface temperature by OA radiographic grade

KL grade	Temperature difference (°C)	P
0	0	
1	+0.168	0.01
	(0.064)	
2	−0.062	0.44
	(0.079)	
3	−0.202	0.04
	(0.098)	
4	−0.079	0.49
	(0.114)	

The mean surface temperature of KL0 joints was used as the reference standard and set to 0°C. The absolute temperature difference (and s.e.) from KL0 is shown for each of the other Kellgren–Lawrence (KL) grades of OA. We fitted a repeated measures ANCOVA model to analyse effects of KL grade on temperature with covariates of individual, joint group, digit, handedness, NSAID use and their two- and three-way interactions.

joints in contrast to the anatomical assessment provided by radiography.

A number of studies, evaluating a variety of joint sites including the hand, knee and hip joints, have found an association between bone scan abnormality and the subsequent development of radiographic evidence of OA [23–26]. By analogy, it may be possible to use thermographic techniques to predict OA disease progression. Although our study demonstrated the stability of thermographic measures over a brief period (3 h), it will be necessary to establish the long-term stability of these measures in order for longitudinal assessments to be reliable.

Pain and stiffness have been shown to be significantly correlated with joint surface temperature in subjects with rheumatoid arthritis [3]. Thus, the evolution to colder joint surface temperatures as hand OA progresses in radiographic severity may explain in part the relative paucity of hand symptoms reported by individuals suffering from radiographic hand OA (estimated at 10%) [27].

Our study demonstrated that the physiological parameter of joint surface temperature was strongly associated with radiographic OA. These data support the contention that digital OA

progresses in phases. On the basis of our findings, thermography may provide a non-radioactive and non-invasive method of evaluating nodal OA presence and severity. Moreover, thermography may provide a sensitive modality for following the response of digital OA to disease-modifying agents.

	Key messages
Rheumatology	• The Compix PC200e Digital Infrared Thermal Imaging device is thermoelectrically cooled and with an internal temperature reference standard that provides highly reliable surface temperature measurements. • Joint surface temperature varied with radiographic OA status. The earliest discernible radiographic stage of hand OA (KL1), was associated with higher joint surface temperature. Joints with increasingly severe radiographic OA (KL 2–4) were associated with lower surface temperatures than normal joints and KL1 joints. • Joint erosions were not associated with alterations in joint surface temperature. • These thermographic analyses support the categorization of KL1 grade radiographic hand joint abnormality as a valid stage of OA.

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