Application of Infrared Thermography as a Diagnostic Tool of Knee Osteoarthritis

Ahlem Arfaoui, Mohamed Amine Bouzid, Hervé Pron, Redha Taiar, Guillaume Polidori

Journal of Template

Vol. 00, No. 0, 0000

Application of infrared thermography as a diagnostic tool of knee osteoarthritis*

Ahlem Arfaoui ** Mohamed Amine Bouzid*** Hervé Pron** Redha Taiar*** and Guillaume Polidori **

** Université de Reims Champagne-Ardenne, GRESPI/Thermomécanique (EA4301)
Moulin de la Housse, BP1039, 51687 Reims cedex 2, France
E-mail:ahlem.arfaoui@univ-reims.fr
*** UFR STAPS, Moulin de la Housse, BP 1039, 51687 Reims cedex 2, France

Abstract

This paper aimed to study the feasibility of application of infrared thermography to detect osteoarthritis of the knee and to compare the distribution of skin temperature between participants with osteoarthritis and those without pathology.
All tests were conducted at LACM (Laboratory of Mechanical Stresses Analysis) and the gymnasium of the University of Reims Champagne Ardennes. IR thermography was performed using an IR camera.
Ten participants with knee osteoarthritis and 12 reference healthy participants without OA participated in this study. Questionnaires were also used. The participants with osteoarthritis of the knee were selected on clinical examination and a series of radiographs. The level of pain was recorded by using a simple verbal scale (0-4).
Infrared thermography reveals relevant disease by highlighting asymmetrical behavior in thermal color maps of both knees. Moreover, a linear evolution of skin temperature in the knee area versus time has been found whatever the participant group is in the first stage following a given effort. Results clearly show that the temperature can be regarded as a key parameter for evaluating pain.
Thermal images of the knee were taken with an infrared camera. The study shows that with the advantage of being noninvasive and easily repeatable, IRT appears to be a useful tool to detect quantifiable patterns of surface temperatures and predict the singular thermal behavior of this pathology. It also seems that this non-intrusive technique enables to detect the early clinical manifestations of knee OA.

Key words: Thermographic images, diagnostic, Skin Temperature, Pain intensity, Student's t-Test,

1. Introduction

Through its involvement in the activities of most humans, the knee is likely to be the seat to many diseases and injuries like osteoarthritis which is the participant of several clinical and scientific researches. Osteoarthritis is a degeneration of the cartilage without infection or special inflammation. This multi-factorial disease led to a more or less rapid destruction of cartilage that coats the ends of bones. Anatomically, this destruction is accompanied by a proliferation of bone under the cartilage. During cartilage destruction, small pieces of cartilage may break off and "float" in the articular pocket: then they trigger inflammatory attacks that result in mechanical hyper-secretion of fluid and swelling of the joint.

Osteoarthritis is a chronic disease and a major cause of pain. 7-11% of the populations

*Received XX Xxx, 200X (No. XX-XXXX)
[DOI: 00.0000/ABCDE.2006.000000]

in developed countries are suffering from symptomatic OA, and 27-44% have radiographic disease [(1)-(4)]. In addition to its economic consequences, osteoarthritis is a major cause of disability, of decline in the quality of life and of social dysfunction. Over the last twenty years, many studies have focused in part on the effect of certain risk factors such as sport, age, overweight [(5)-(9)] and partly on the different diagnostic techniques like radiography [(10)], arthroscopy [(11)], the method of Lechman (CT) [(12)] and magnetic resonance imaging (MRI) [(13)]. However, little research has been devoted to the thermal aspects associated with osteoarthritis of the knee before and after exercise.

The application of infrared thermography (IRT) has a long history in musculoskeletal trauma. Albert et al. [(14)] were the first to assess pain by infrared thermography. Subsequently, many studies that approve or deny this new technique have been widely criticized. Some authors challenge the medical use of IRT because of its low diagnostic and localizing values, poor stability, and nonspecific findings.

However, interest in IRT is up today because of improved devices and methods of calculation. The special characteristic of IRT studies is that we can get additional information about the skin's thermal aspect and about the complex thermoregulatory process. IRT gives a possibility to evaluate the effect of the sporting activity and to detect possible trauma or dysfunctions, which cannot be shown by present conventional methods, it can measure skin temperature over inflamed joints. Horvath and Hollander [(15)] measured the intra-articular temperature in patients with rheumatoid arthritis and noted that it could be used as a guide to the acuteness of inflammation. Bacon et al. [(16)] showed that measurement of mean skin temperature could be used as a measure of disease activity.

Infrared thermography is a diagnostic method providing information on the normal and abnormal sensory and nervous systems, trauma, or inflammation locally and globally. Infrared thermography shows physiological changes rather than anatomical changes and could be a new diagnostic tool to detect the pathology of the knee. The objective assessment of disease activity in OA is difficult. Many parameters are based on patients' symptoms, which may not give an accurate indication of the progress of the disease, and laboratory evaluation can be unhelpful.

The thermographic images have previously been used to examine anterior knee [(17)-(19)]. Ben Alyahu et al. [(20)] investigated the clinical utility of infrared thermography in the detection of sympathetic dysautonomia in patients with patellofemoral pain syndrome. They have shown that the incidence of patellar thermal asymmetry was found to be statistically significant when tested by chi-2 analysis.

More recently, the researches of Selfe et al. [(21)] were aimed to investigate if palpation of the knee could classify patients into those with and those without cold knees and if this classification could be objectively validated using thermal imaging. They were unable to deduce a different response in skin temperature with cold stimuli between females whatever the initial temperature of knees is, namely cold and not. Selfe et al. [(21)] concluded that further research was needed to assess the validity and reliability of the methods used to identify this subgroup of patients, to confirm the clinical profile.

The purpose of this study is to assess the usefulness of IRT in detecting osteoarthritis of the knee and to evaluate the relationship between pain intensity and the measurement of skin temperature.

2. Methods

Ten participants with unilateral knee osteoarthritis (Men, between the ages of 17-26 years) and twelve reference participants without OA (Men, age range, 18-30 years) participated in this study (Table 1). For each participant, we reported the age, weight, height, body mass index (BMI), the dominant side, the existence of pain or other symptoms of functional knee.

Patients were excluded if they had other pain. To exclude other causes of knee pain, all patients underwent a thorough history taking, a physical evaluation, as well as standard and dynamic series of plain radiographs of femur, patella, and tibia. No medication or other additional conservative treatments were given after enrollment.

The assessment of pain was based on the simple verbal scale on a scale of 0 to 4 (0=none; 1=low; 2=moderate; 3=severe; 4= Maximum).

Table 1 Characteristics of the participants by subgroups

Group	GA (Participants with knee osteoarthritis)	GB (Healthy participants)
Sex	Men	Men
Age (y) (Mean ± DS)	21,50 ± 2,51	23,08 ± 3,6
Weight (kg) (Mean ± DS)	73,46 ± 5,61	72,17 ± 3,67
Height (m) (Mean ± DS)	1,75 ± 0,06	1,76 ± 0,04
BMI (kg/m²) (Mean ± DS)	11,76 ± 2,27	12 ± 2,8
Assessment mean of pain (scale 0-4)	2,5±1,5	0

All tests were conducted at the University of Science and Technology of Physical Activities and Sports in Reims (France). The participants of two groups (with and without osteoarthritis of the knee) ran on a treadmill (slope 0%) during 5 minutes, at a fixed speed of 8 km/h.

The patients were asked to avoid smoking, alcohol, coffee, and exercise for at least 5 hours before testing. We checked each patient's body temperature to ensure that there was no one with extreme body temperature (below 36.4 °C or above 37.2 °C). Air temperature and relative humidity were recorded at the start of measurement periods. IRT has been carried out in a room where the temperature was maintained at 18 °C ± 0.5 °C and the relative humidity was 60%. It is important to ensure that the patient was relaxed before imaging so that his emotional state will not influence the measurements.

Before the testing, the patient must wear a short to allow the taking of thermograms of the knees. 30 minutes were needed to balance the patient's body temperature with the environment before resuming testing.

The participants remained motionless and the recording was made in the anatomical position: the body upright, feet in the longitudinal axis of the leg, forearm supination and the palms facing forward. IR thermograms of right and left knees were taken before and after the race at a distance of 1.50 m:

- Before the effort: IR images were taken.
- After effort, recordings were taken during 5 minutes.

According to Maly, Culham and Costigan [22] in normal conditions, 71-91% of body weight is transmitted to the tibia-femoral junction and can reach 100% in the presence of osteoarthritis. Average temperatures were recorded in two areas of each knee (points: 1 to 4 for right knees, and points: 5 to 8 for left knees) as shown in Fig. 1. For the healthy participants, the temperature was averaged from theses eight points, while only four points were considered for a participant having pathology of the knee.

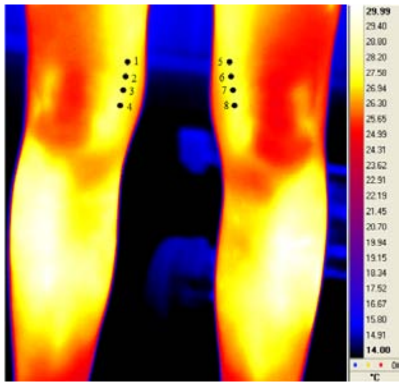

Fig. 1 Infrared thermography of right and left knees with the points selected for measuring the local temperature

3. Equipment

IR thermography was performed using an IR camera (CEDIP TITANIUM HD560M) sensitive to wavelengths from 3.5 to 5 µm ± 0.25 µm. The focus of the camera was 10 to 100 mm ± 0.5 mm, and the resolution of the camera is 640 × 512 features high quantum efficiency (> 70%). Thermal sensitivity was 0.04 °C per grayscale level over the physiological temperature range. Camera is equipped with a system integration instantaneous variable of 1µs to 10 ms and speed frame rate of up to 100 frames / s in full window.

The thermal image obtained was sent instantly to a portable computer connected to the camera, and it was immediately processed in real time using the software "ALTAIR 5.50" that allows:

- To deal with static images,
- Treat video and infrared data in real time,
- To process and analyze digital data at very high speed
- To assign a given color to each gray-scale shade, captured by the camera.

All statistic data are presented as mean ± standard deviation (SD). The statistical analysis is performed using software Statistica 6.1 and Microsoft Excel 2007. We used a Student's paired t-Test to assess the differences before and after running on the treadmill and the surface temperature captured by IRT.

It should be noted that to compare the difference for the same knee before and after exercise, we used the Student's t-Test for paired samples. However, to compare the difference between two knees before or after exercise, we used the Student's t-Test for independent samples.

For all tests, a P value less than 0.05 was considered statistically significant.

4. Results

4.1 Imagery analysis

To ensure statistical conclusions, the temperature deduced from thermographic images is averaged over the study area and on all the participants of each group. It is recalled that 10 participants had knee osteoarthritis diseases while 12 participants were healthy. It is clearly shown in Fig. 2 that infrared thermography technique qualitatively enables highly visual estimate of such pathologies. For example in the case of a participant having osteoarthritis pathology in the right knee, the IR thermography in Fig. 2(a) reveals relevant disease by highlighting asymmetrical behavior in thermal color maps of both knees. It clearly appears by comparing a participant at rest (Fig. 2(a)) with the same participant undergoing sporting activity (Fig. 2(b)) that the more the knee is loaded, the more the warm thermal zone is extended. This is probably due to the overuse of the knee, repetitive strain injury during the race increases inflammation in the knee and consequently the temperature of the skin. These findings have been observed in all participants of the GA group, while no temperature gradients appear between right and left knee thermal maps in healthy participants.

Qualitatively, and only from imagery examination, it seems that IR thermography as a simple and non-intrusive experimental device can be easily used as a powerful tool for rapid diagnosis of osteoarthritis of the knee.

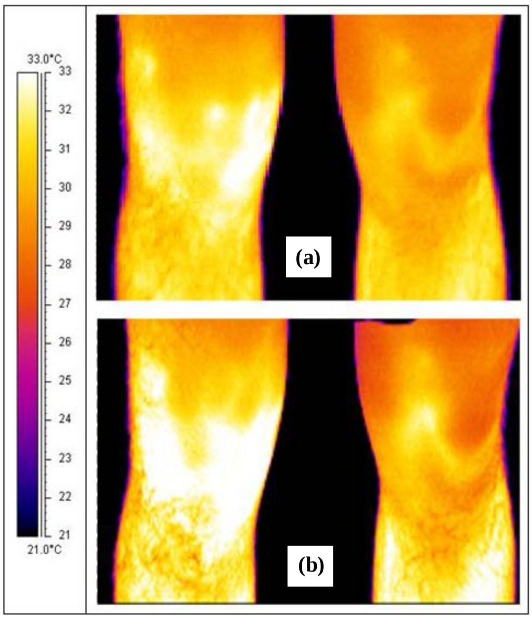

Fig.2 Infrared thermography of right and left knees before and after race for a participant with right knee OA

4.2 Temperature distributions versus time

In Fig. 3 is represented the arithmetic average of the measured skin temperature in the knee area(s) versus time before and after the running protocol in place for both participant groups. At rest, significant differences occur depending on whether the knee is healthy or not. Thus we get an average measure of 25.83 °C in case of healthy knees while the presence of OA results in a 28.75 °C average temperature. This difference of almost 2 °C far exceeds the accuracy of the IR process, making it efficient for a reliable visual diagnosis of this disease.

After the race and whatever the participant group is, one observes a gap in the average temperature, namely about 1.15 °C for group with OA and 2.31 °C for healthy participant. This result is not paradoxical. It reflects only the fact that initially, at rest, the knee surface temperature was already high for this group of participants. During the acquisition time limited to five minutes, a similar behavior is observed in the temporal temperature evolution for both groups. One observes a perfect linear evolution (with a determination coefficient very close to the unit) of the temperature versus time during less than 5 minutes, followed by a tendency to an asymptotical behavior traducing the beginning of a relaxation thermal process. The slope of the linear regression is roughly the same order of magnitude whatever the group is. This means that there is no over-inflammation of the synovial fluid in OA after the race.

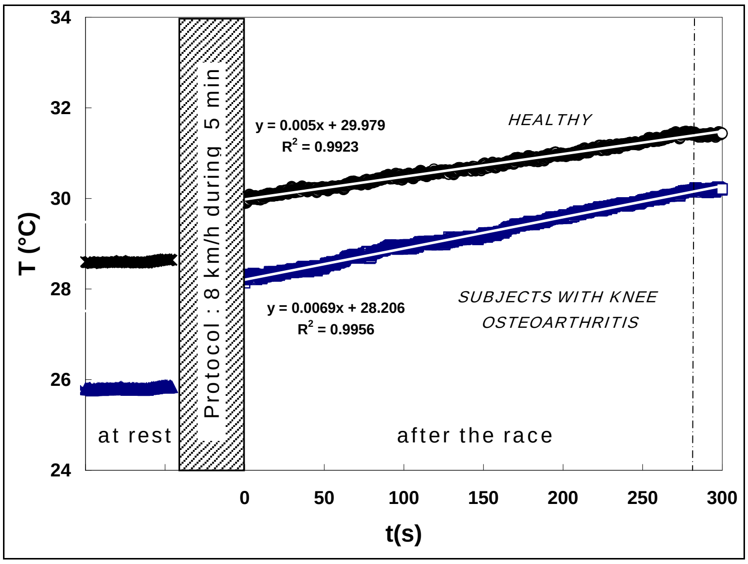

Fig. 3. Average temperature evolution versus time

4.3 Relationship between pain intensity and the knee skin temperature

It seems reasonable and interesting to answer the question of pain experienced by participants with OA, even if this question is based on a subjective analysis. Is there a relationship between the pain intensity and the knee temperature, itself being a feature of inflammation? Obviously, this study did not aim to establish a universal law but to draw a trend of feeling pain in participants with OA. In Fig. 4 is reported the pain intensity given by the participants versus the corresponding average temperature during the protocol. As a reference is also reported the pain sensation in the case where participants are in rest. Although approximations are rough, these developments clearly show that the temperature can be regarded as a key parameter for evaluating pain. This reinforces the idea that the capture of temperature maps by infrared thermography as a diagnostic tool is certainly an interesting way to develop.

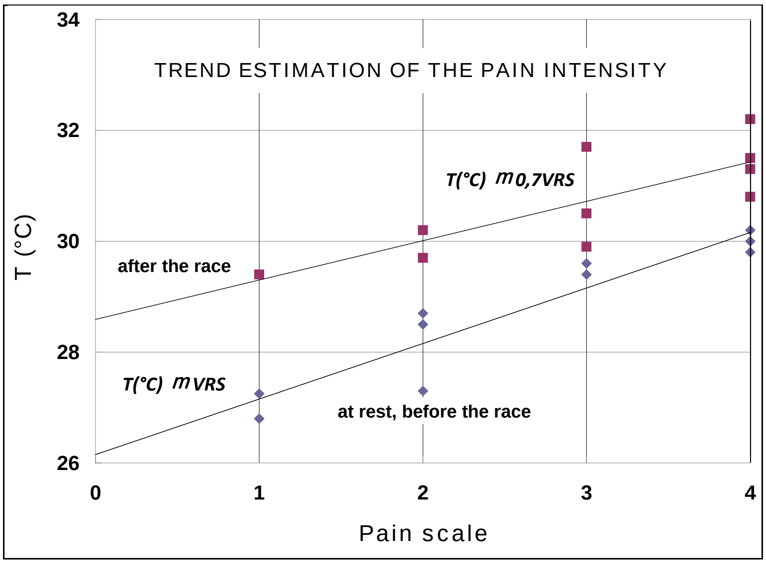

Fig. 4. Correlation between knee skin temperature and estimation of pain intensity

5. Discussion

We measured surface temperature in normal and OA joints of the knee for 22 participants. IRT was performed in a room at constant during experiments and patients were asked to follow strict instructions before examination. Many studies [(23)-(26)] have shown very good reproducibility of IRT in a temperature-controlled environment. The IRT was reliable to detect osteoarthritis of the knee by the way of distributions of skin temperature. In addition, correlation has been observed between knee skin temperature and the pain intensity due to OA.

Our study has demonstrated the stability of thermographic measurements over a very short period. It will be interesting to predict the disease progression of osteoarthritis and eventually determine a correlation between thermographic and radiographic images.

6. Conclusion

This study has shown that IRT appears to be a reliable diagnostic tool to detect quantifiable patterns of skin temperatures in participants with OA. It has been demonstrated that the temperature variation can be correlated with changes in pain intensity for the group GA that has osteoarthritis. We think that this non-intrusive technique enables to detect the early clinical manifestations of knee OA.

References

(1) Felson, D.T, Zhang, Y, Hannan M.T, Naimark, A, Weissman, B.N and Aliabadi, P., The incidence and natural history of knee osteoarthritis in the elderly, *The Framingham Osteoarthritis Study*, *Arthritis Rheum*, Vol. 38 (1995), pp. 1500-1505.

(2) Felson, D.T and Zhang, Y., An update on the epidemiology of knee and hip osteoarthritis with a view to prevention, *Arthritis Rheum*, Vol. 41 (1998), pp. 1343-1398.

(3) Hart, D.J, Doyle, D.V. and Spector, T.D., Incidence and risk factors for radiographic knee osteoarthritis in middle-aged women: the Chingford Study, *Arthritis Rheum*, Vol. 42 (1999), pp. 17-24.

(4) Rat, A.C., Coste, J., Poucho, J., Baumanna, M., Spitz, E. and Retel-Rude, N., *OAKHQOL: A new instrument to measure quality of life in knee and hip osteoarthritis*, Journal of Clinical Epidemiology, Vol. 58 (2005), pp. 47-55.

(5) Rolland, Y., Glisezinski, I., Crampes, F., Pillard, F. and Rivière, D., *Sport et arthrose fémorotibiale*, Sci Sports, Vol. 15 (2000), pp.125-157.

(6) Gozlan, G., Bensoussan, L., Coudreuse, J.M., Fondarai, J., Gremeaux, V. and Viton, J.M., *Mesure de la force des muscles rotateurs de l'épaule chez des sportifs sains de haut niveau (notation, volley-ball, tennis) par dynamométre isocinétique : comparaison entre épaule dominante et non dominante*, Ann Readap Med Phys, Vol. 49 (2005), pp. 8-15.

(7) Roos, E.M. and Dahlberg, L., *Positive effects of moderate exercise on glycosaminoglycan content in knee cartilage: a four-month, randomized, controlled trial in patients at risk of osteoarthritis*, Arthritis Rheum, Vol. 52 (2005), pp. 3507-3521.

(8) Sharma, L. and Chang, A., *Advancing our understanding of its impact on the knee and the hip*, Ann Rheum Dis, Vol. 66 (2007), pp. 141-143.

(9) Gabay, O., Hall, D.J., Berenbaum, F., Henrotin, Y. and Sanchez, C., *Arthrose et obésité: modèles expérimentaux Osteoarthritis and obesity: Experimental models*, Revue du Rhumatisme, Vol. 75 (2008), pp. 1215-1219.

(10) Daniel, D.M., Stone, M.L., Sachs, R. and Malcom, L., *Instrumented measurements of anterior knee laxity in patients with acute Anterior Cruciate Ligament disruption*, Am J Sports Med, Vol. 13 (1985), pp. 401-408.

(11) Markolf, K.L., Kochan, A. and Amstutz. H.C., *Measurement of knee stiffness and laxity in patients with documented absence of ACL*, J Bone Joint Surg, Vol. 66(A) (1984), pp. 242-295.

(12) Wiertsema, S.H., Van Hoff, H.J.A., Migchelsen, L.A.A. and Steultjens, M.P.M., *Reliability of the KT-1000 and the Lachman test in patients with ACL rupture*, The Knee, Vol. 15 (2008), pp. 107-117.

(13) Schuster, A.J., McNicholas, M.J., Wachtl, S.W., McGurty, D.W. and Jacob, R.P., *A new mechanical testing device for measuring anteroposterior knee laxity*., Am J Sports Med, Vol. 32 (2004), pp. 1731-1736.

(14) Albert, S.M., Glickman, M. and Kallish, M., *Thermography inorthopedics*, Ann N Y Acad Sci, Vol. 70 (1964), pp.121-157.

(15) Horvath, S.M. and Hollander, J.L., *Intra-articular temperature as a measure of joint reaction*, J Clin Invest, Vol. 73 (1949), pp. 441-469.

(16) Bacon, P.A., Collins, A.J., Ring, F.J. and Cosh, J., *Thermography in the assessment of inflammatory arthritis*, Clin Rheum Dis, Vol. 2 (1976), pp. 51-65.

(17) Devereaux, M.D., Parr, G.R., Lachmann, S.M., Thomas, D.P. and Hazleman, B.L., *Thermographic diagnosis in athletes with patellofemoral arthralgia*, Journal of Bone and Joint Surgery British Volume, Vol. 68-B(1) (1986), pp. 42-44.

(18) Ben-Eliyahu, D.J., *Infrared Thermography and the Sports Injury Practice*, Dynamic Chiropractic, Vol. 10(7) (1992), pp 7-17.

(19) Mangine, R.E., Siqueland, K.A. and Noyes, F.R., *The Use of Thermography for the Diagnosis and Management of Patellar Tendinitis*, JOSPT, Vol. 9(4) (1987), pp. 132-140.

(20) Ben-Eliyahu, D.J., *Infrared thermographic imaging in the detection of sympathetic dysfunction in patients with patellofemoral pain syndrome*, J Manipulative Physiol Ther., Vol. 15(3) (1992), pp.164-70.

(21) Selfe, J. , Sutton, C., Hardaker, N.J., Greenhalgh, S., Karki, A. and Dey, P., *Anterior knee pain and cold knees: A possible association in women*, The Knee, Vol. 17 (2010), pp.319-323.

(22) Maly, M.R., Culham, E.G. and Costigan, P.A., *Static and dynamic biomechanics of foot osteoarthritis in people with medial compartment knee osteoarthritis*, Clinical Biomechanics, Vol. 17 (2002), pp. 603-610.

(23) Darton, K. and Black, C.M., *The use of infra-red thermography in a rheumatology unit*, Br J Rheumatol, Vol. 29 (1990), pp. 291-293.

(24) Huygen, F.J., Niehof, S., Klein, J. and Zijlstra, F.J., *Computer-assisted skin videothermography is a highly sensitive quality tool in the diagnosis and monitoring of complex regional pain syndrome type I*, Eur J Appl Physiol, Vol. 91 (2004), pp. 516-540.

(25) Varju, G., Pieper, C.F., Renner, J.B. and Kraus, V.B., *Assessment of hand osteoarthritis: correlation between thermographic and radiographic methods*, Rheumatology, Vol. 43 (2004), pp. 915-924.

(26) Zaproudina, N., Varmavuo, V., Airaksinen, O. and Narhi, M., *Reproducibility of infrared thermography measurements in healthy individuals*, Physiol Meas, Vol. 29 (2008), pp. 515-539.