Assessment of Disease Activity by Infrared Thermography in Patients with Rheumatoid Arthritis: A Comparative Cross-Sectional Study of Thermographic, Clinical and Ultrasound Assessments

DOROTHEE VINSON (✉ dorothee.vinson@gmail.com)
Assistance Publique Hopitaux de Marseille  https://orcid.org/0000-0002-9734-3522

Caroline paris
Assistance Publique Hopitaux de Marseille

Pierre Lafforgue
Assistance Publique Hopitaux de Marseille

Christophe Richez
Centre Hospitalier Universitaire de Bordeaux

Vincent Pradel
Assistance Publique Hopitaux de Marseille

Thao Pham
Assistance Publique Hopitaux de Marseille

Research article

Keywords: Rheumatoid Arthritis, thermal imaging, thermography, Ultrasound, clinical assessment

DOI: https://doi.org/10.21203/rs.3.rs-34703/v1

License: © This work is licensed under a Creative Commons Attribution 4.0 International License. Read Full License
Abstract

OBJECTIVES: To compare RA activity evaluation by thermal imaging with a camera adjustable to cellphones, standard clinical examination and ultrasound.

MATERIALS AND METHODS:

Monocentric study with 3 independent evaluations of RA activity: 1) tender (TJC) and swollen joints count (SJC) of wrists, MCP and PIP; 2) Ultrasound (US) examination with mode B and Power Doppler (PDUS); 3) thermographic assessment using infrared thermal cellphone camera FLIR One®. Thermal images analysis with (a) software detecting 10 regions of interest (ROI) corresponding to the studied joints and (b) by color reading (arthritis yes/no).

For each ROI, temperature difference measurement “ΔT-joint” (ΔTj) compared to the ipsilateral forearm (reference area) and comparison of ΔTj to a) TJC and SJC; b) US synovitis in B mode or c) PDUS grade (0,1,2,3); d) synovitis in visual detection on thermographic image. T-tests and ANOVA were performed.

RESULTS: 53 patients (43 women) with a mean (SD) age of 61.6 (12.3) years, totaling 921 examined joints. Mean disease duration was 17.6 (11.1) years. RA status was 81% ACPA+, 58% erosive, mean DAS28 score was 4.0 (1.6).

Mean ΔTj was higher in tender (p<0.001), swollen (p=0.066) joints and in US synovitis in B mode (p=0.021). Mean ΔTj was not associated with PDUS category (p-ANOVA=0.072). Synovitis detected with thermal image reading was associated with PDUS grade 3 (p<0.001).

CONCLUSION: Our results did not show the ability of thermal imaging to assess RA activity in small joints. However, our results are encouraging as temperature variation were observed in inflammatory joints.

Key Message

What is already known about this subject?

► Several studies have evaluated infrared thermography and its capacity of assessing arthritis in patients with RA, mainly on large joints, through cutaneous temperature variation.

► Recently, miniaturized thermal cameras, adaptable to smartphones, have been developed. Some studies have already assessed RA activity, in particular in small joints, by infrared thermography through the use of miniaturized thermal cameras, but with discordant results.

► No study has compared thermography to ultrasound to date.
What does this study add?

► Our study did not show the ability of thermal imaging to assess RA activity in small joints.

► However, our results are encouraging with temperature variation observed in inflammatory joints.

How might this impact on clinical practice?

► The emergence of more precise and sensitive cameras could open new perspectives.

► Direct visual reading of thermal imaging could be used without needing the use of a software. This strengthens the thermal camera as a quick and easy tool to be used in ambulatory practice if its ability to assess RA activity is demonstrated in the future.

Introduction

Regular evaluation of the activity of rheumatoid arthritis (RA) allows a strict control of the disease and treatment adaptation, to prevent joint destruction, impairment of quality of life and reduction of life expectancy (1–4). RA activity can be evaluated by composite scores such as the Disease Activity Score 28 (DAS28), or imaging tools including ultrasound (US) or magnetic resonance imaging (MRI) (5–7). Numerous composite scores include assessing the number of joints with active synovitis. However, evaluation of tender joint count (TJC) and swollen joint count (SJC) is poorly reproducible (8–10).

Osteoarticular US allows a good anatomical analysis in B mode and a vascular analysis in power Doppler US (PDUS) (11). Injected MRI is a reliable and sensitive tool to assess the inflammatory activity in RA (12–15). However, these tools have limitations for frequent use, mainly for reasons of availability and cost for MRI. Ultrasound is less expensive and more easily available than MRI but requires time and a qualified practitioner in osteoarticular US, with low intra and inter-observer reproducibility (16).

Thus, there is a need for an objective, rapid and low-cost measurement for an ambulatory evaluation of RA activity.

In the 1980s, several studies have evaluated infrared thermography and its capacity of assessing arthritis in patients with RA, mainly on large joints, through cutaneous temperature variation (17–20). The increase of cutaneous temperature reflects the joint’s temperature underneath. Thermography is a diagnostic imaging procedure that detects, records and produces a thermal image of the skin's surface temperature of the patient (21). Thermography does not involve ionizing radiation, venous access nor any other invasive procedure (21). There are currently two recognized methods of clinical thermographic imaging: electronic infrared thermography and liquid crystal thermography. The infrared thermography has the advantage of detecting contactless temperatures.

Mathematical formulas have been developed to represent temperature distribution on a thermal image. In 1982, Salisbury et al. used the Heat Distribution Index (HDI) from temperature's results of the thermal
image to identify thermal synovitis (18). The HDI corresponded to ±1 standard deviation (SD) of the heat distribution following a Gaussian distribution. In 2008, Spalding et al. measured the temperature of two ROI in patients’ hands and compared them to the measurement of joint volume (22). Even though they have shown the usefulness of thermography in identifying inflamed joints, these thermal imaging cameras were large size and fixed devices, thus limiting their use in current practice.

Recently, miniaturized thermal cameras have been developed, with technical capabilities similar to those of the previously cited studies. These devices can measure the temperatures ranging from 10 °C to 40 °C with a sensitivity of 0.1 °C. These miniature thermal cameras, adaptable to smartphones, have been largely marketed with no medical purpose but to detect leaks in buildings (23).

Some studies have already assessed RA activity, in particular in small joints, by infrared thermography through the use of miniaturized thermal cameras, but with discordant results (22, 24). No study has compared thermography to ultrasound to date.

The aim of our study was therefore to compare the evaluation of RA activity by thermal imaging through miniaturized thermal cameras with clinical and ultrasound evaluation.

**Materials And Methods**

**Design of study**

We carried out a monocentric cross-sectional study from January to October 2019 in the Rheumatology Department of the University Hospital of Sainte Marguerite in Marseille, France. Inclusion criteria were patients suffering from RA (2010 ACR/EULAR criteria (25)), aged from 18 to 90 years old. The exclusion criteria were (a) the presence of Raynaud's syndrome, (b) a severe deformity of hands/wrist, (c) a recent surgery of wrist/fingers within the 3 months preceding their inclusion, or (d) fever during clinical examination.

**RA Activity Evaluation**

Upon their arrival in the Rheumatology Department, each patient underwent an interview. The interview lasted about 10 minutes, in a standardized room, thus allowing the hands to rest. Then, the patient had 3 independent evaluations: first, a thermal image was taken with the FLIR One® camera, then a clinical examination was performed by a second evaluator, and finally an ultrasound evaluation was done by a third evaluator. Each evaluator was unaware of the other assessments.

Thermal images were taken before physical examination and ultrasound evaluation to avoid measurement errors due to hand manipulation or the use of ultrasounds that could potentially modify the skin temperature.
In total, each patient had 3 independent assessments of joint disease activity of each hand (wrists, metacarpophalangeal (MCP) and proximal interphalangeal (PIP) joints excluding thumbs): thermal evaluation, physical and US examination.

1. Clinical Evaluation

The following data were collected during the interview: patient age, body weight and height, medical history, current and previous treatments. RA history data were collected: disease duration, date of diagnosis, serological (rheumatoid factor (RF) and anti-CCP) and erosive status. The patient had then a full physical examination.

The examiner evaluated for each joint if they were painful (yes(Y)/ no(N)) and swollen (Y/N). The activity of the disease was evaluated with the overall Visual Analogue Scale (VAS), Tender Joints Counts (TJC), Swollen Joints Counts (SJC) and biological results (ESR (mm) and CRP (mg/L)).

2. Ultrasound Evaluation

Ultrasound scans were performed on a MyLab60® device from Esaote Biomedica, Genoa, Italy, with a probe of 4–13 MHz frequency scale. A pool of five trained evaluators (CP, ST, JS, EF and MG) was able to perform the ultrasound evaluation. For each patient, one of the five evaluators performed the US examination, while being unaware of the results of clinical examination and thermal images. A bilateral assessment was carried out systematically of MCP 2–5, PIP 2–5 and radiocarpal joint on the dorsal side, first in B mode and then in Power Doppler (PDUS). For each joint, it was collected if there was a synovial hypertrophy (Y/N) in B mode, and then its PDUS grade, rated from 0 to 3, according to the classification of OMERACT(26).

3. Thermal evaluation with FLIR One® camera

An independent evaluator (DV) realized one thermal image per patient that included both hands.

Thermal images were analyzed in two different ways: (1) an automatic detection of the temperature in 10 ROI, through the software Gips Vision, and (2) a direct visual analysis of the thermal image.

Condition of acquisition of thermal images

Thermal images were obtained with a FLIR One® infrared camera adjustable to smartphones, FLIR T300 model. This camera has a 0.1 °C sensitivity and is originally used to detect leaks in buildings (23). Several settings of the camera had to be selected before taking thermal images, and we standardized the picture conditions in our routine (Supplementary Data 1).

Analysis of thermal images

Thermal images were analyzed in two different ways: (1) an automatic detection of temperature of 10 predetermined ROI, and (2) an analysis by direct visual detection using color reading of the thermal image (arthritis Y/N).
1. Automatic detection of Region of Interest (ROI)’s temperature

To have an automatic reading of the thermal images taken, we have developed, with the company GipsVision®, a software allowing an automated reading of these images obtained with the FLIR One® camera. The software automatically detects 10 ROI corresponding to the joints studied for each hand (wrist, MCP 2–5, PIP 2–5, and forearm) and reads the average ROI temperature. To build the ROIs, the GipsVision software delimits the hand. With the delimitation of the hand, the software automatically positioned the end of the fingers, the inflection of the wrist, the axis of the forearm and the center of the carpus. Thanks to these markings, ROI of MCP and PIP were automatically fixed on the thermal image (Supplementary Data 2). It was not possible to reposition ROI manually.

The FLIR One® camera produces a color image in a scale from dark blue to light yellow. These colors are arbitrary, depending on the color palette used. Each color does not correspond to a fixed temperature. The software developed by GipsVision converts this color to a numeric value on a linear scale from 0 to 256, and then calibrate the correspondence between the converted values to actual temperatures in degrees Celsius (°C). For each ROI, the software produces the average temperature of all measures detected inside the ROI.

In the absence of standard of cutaneous temperature, it was impossible to define a normal range of joint temperature for our measurements. Therefore, for each ROI we calculated the temperature difference \( \Delta T_j \) compared to the ipsilateral forearm, that was used as a normal reference temperature of the body \( \Delta T_j = \text{Temperature of joint} - \text{Temperature of ipsilateral forearm} \). Thus, the patient was considered as its own reference, and for each patient, we calculated the median of \( \Delta T \) of all their joints.

2. Direct Visual Reading of the Thermal Image

After the automatic detection of ROIs temperature with the GipsVision® software, a second evaluation was made through a direct visual reading of the thermal image (Fig. 1). Indeed, this time the evaluator had to assess whether, in his opinion, there was an arthritis for each joint of interest by visual reading of the image. The thermal image was a color image in a scale from dark blue (for colder temperatures) to light yellow (for higher temperatures). Thus, arthritis was spotted in lighter yellow in comparison with other joints of the same and contralateral hand.

Statistical Analysis

As described before, in the absence of standard of cutaneous temperature, we took the patient as its own reference: for each ROI we calculated the temperature difference \( \Delta T \)-joint \( \Delta T_j \) between each joint and ipsilateral forearm, the latter being considered as representative of the body temperature, and for each patient, we calculated the median of \( \Delta T \) of all their joints, thereafter named “\( \Delta T \)-patient” \( \Delta T_p \). Therefore, we calculated means and standard deviation (SD) of \( \Delta T_p \) at the patient level, and of \( \Delta T_j \) at the joint level.
At the joint level, we assessed the evaluation performances of clinical, ultrasound, and thermographic measures: we compared $\Delta T_j$, acquired from automatic detection of ROI using the GipsVision® software, according to a) presence or absence of pain or swelling; b) US synovitis in B mode or c) in PDUS mode (0,1,2,3); and d) synovitis in direct visual detection on thermographic image. T-tests for binary variables and ANOVA for characteristics with more than 2 categories were performed.

We also conducted a secondary analysis at the patient level. Without reference normal values of $\Delta T$, we compared $\Delta T_p$ across categories of DAS28 status ($< 2.6; [2.6–5.1]; >5.1$) by 1-way ANOVA and the CRP status (CRP $< 5$ or $\geq 5$ mg/L) with a Student t-test.

All computations were performed using IBM® SPSS® version 20. All statistical tests were 2-sided and $p < 0.05$ was considered significant.

**Ethical Approval Information**

This study did not involve invasive evaluation on human participants as RA patients were included when coming to the Rheumatology Department for RA diagnosis or follow-up. There were no additional exams than those usually done as part of their regular follow-up. Therefore, this study did not justify the approval of Ethics Committee.

All participants received information and gave informed consent.

**Results**

**Population characteristics**

53 patients (43 women, 10 men) were included in our study, totaling 954 joints. Thirty-three joints, from 4 patients, had missing temperature data due to technical detection problem of ROI from the GipsVision® software. Therefore, a total of 921 joints were included in the analysis. The main population characteristics are presented in Table 1. Mean age (SD) was 61.6 (12.3) years, and mean disease activity of RA was moderate (mean DAS28 = 4.0), extending from 1.1 to 7.3.

**Clinical examination vs. Automatic ROI thermal imaging**

We compared clinical assessments of joint (presence or absence of pain or swelling) to the $\Delta T_j$ acquired from automatic detection of ROI in thermal image. Of the 921 included joints, 268 were tender and 173 were swollen according to physical examination. The mean of $\Delta T_j$ was significantly lower in non-tender joints than in tender joints ($\Delta T_j= -0.30 ^\circ C \pm 0.84$ vs $-0.06 ^\circ C \pm 0.70$, $p < 0.001$) and the same trend was observed, not at a significant level, between non-swollen and swollen joints ($p = 0.066$) (Table 2).

**Ultrasound Assessment vs. Automatic ROI Thermal Imaging**

We assessed the evaluation performances of US (mode B and PDUS) measures with the automatic ROI thermal imaging. In B mode, 235 joints had synovitis. The mean of $\Delta T_j$ was significantly lower in joints
without synovitis compared to those with synovitis (\(-0.26 \, ^\circ\text{C} \pm 0.84 \) vs \(-0.13 \, ^\circ\text{C} \pm 0.69\), \(p = 0.021\), Table 2). 782 joints were PDUS-0, 42 PDUS-1, 55 PDUS-2 and 42 PDUS-3. Mean \(\Delta Tj\) was higher in presence of PDUS hyperemia (mean \(\Delta Tj = + 0.54 \, ^\circ\text{C} \pm 0.51\) in the group PDUS-3, versus mean \(\Delta Tj= -0.25 \, ^\circ\text{C} \pm 0.83\) in the group PDUS-0), although the intergroup ANOVA across 4 Doppler categories did not reach statistical significance at the conventional level (\(p = 0.072\)), neither did the comparison after grouping categories PDUS 0–1 versus PDUS 2–3 (\(p = 0.086\)) (Table 2).

**Ultrasound Assessment vs. Direct Visual Reading of the Thermal Image**

After assessing thermal image through automatic detection of ROI, we then assessed the evaluation performances of thermal image through direct visual reading of the thermal image and compared it with US measurements. We compared the results of US assessment (synovitis (Y/N) in B mode and PDUS category (0-1-2-3)) to the direct visual reading of thermal image (thermal synovitis (Y/N)).

The presence of synovitis in thermal image coincided in US mode B in 37.6%, whereas US mode B synovitis was not found by thermal image in 62.4%. Comparing thermal image and PDUS, PDUS grade 3 was associated with an absence of synovitis on thermal image in 41.9%, whereas for PDUS grade 0 the presence of synovitis was found on thermal image in 12.2% (\(p < 0.001\)).

Evaluation's results at the patient level are presented in Supplementary Data 3.

**Discussion**

Our study compared the evaluation of RA activity by thermal imaging, through miniaturized thermal cameras, with clinical and ultrasound evaluation. Using an automatic detection of the ROI temperature, thermal imaging was correlated to tender joint count and US mode B results, but was not able to discriminate RA activity at the joint level for more relevant parameters of inflammation markers, i.e. swollen joints and PDUS.

Using direct visual identification of synovitis, thermal imaging showed only limited concordance with US measurements (mode B and PDUS).

There are few studies comparing clinical evaluation with thermal imaging from miniaturized thermal cameras, and their results are discordant.

In 2018, Jones et al. (24) compared thermal imaging of the hand joints of patients with RA to those of healthy volunteers. Their patients’ characteristics were similar to ours. Thermographic analysis of joint temperature was not associated with clinical measures of disease activity. The calibration of their camera, the computer software, and the temperature assessment were not specified (24). The authors suggest that the clinical examination may lack sensitivity and that it would be interesting to compare it with US assessment.
Tan et al. (27) recently compared thermal imaging with US and clinical evaluation. Their sample was smaller (n = 37) with patients whose RA was more recent, but with the same activity as our population. They reported a significant association between thermal imaging and US data, but not with clinical examination. However, they performed assessment on all MCP and PIP joints, including thumbs. In our study, we made the choice to exclude thumbs as we wanted to avoid the bias of spotting thermal arthritis that could be either attributed to RA flare or to trapezo-metacarpal osteoarthritis which is common on this joint. Neither the thermal camera used in Tan’s study, nor the way of spotting joints and measuring their temperature, were described thus preventing detailed comparison with our study.

Despite the validity of our results, our study had several limitations. First, there was a lack of statistical power. Although including a large number of patients, the number of joints with the highest markers of RA activity was small compared to the number of joints with low activity (173 swollen joints vs 748 non-swollen, and 42 PDUS grade 3 joints vs 782 PDUS grade 0 joints). To increase the power of the study, it would require a greater number of active joints (swollen joints and PDUS grade 2–3 joints).

Another concern was the potential bias in PDUS evaluation. Five evaluators performed the ultrasound evaluation as our work was a daily practice observational study. We did not assess the intra and inter-reproducibility of the ultrasound evaluation.

The sensitivity of the thermal camera was also a potential limit. Indeed, the model used had a sensitivity of 0.1 °C (23). More recent cameras have been marketed since the start of our study, with a finer sensitivity (< 0.06 °C) (23). A new study with the use of a more sensitive thermal camera would be needed to better assess thermal arthritis, particularly those clinically swollen or presenting PDUS grade 2–3.

The methods used in the different studies to assess the presence of thermal synovitis from temperature data were heterogeneous, as HDI was used for Salisbury (18), ΔT in our study and Tan’s (27), or not mentioned for Jones (24). A consensus on standardized measures would be required in future works.

Although our results did not show significant results on inflammation markers used for RA activity’s evaluation (swollen-joint and PDUS-3), we observed a numerical trend for these parameters. Indeed, the temperature difference of joints with PDUS-3 was higher, meaning clinically “hotter”, than those without doppler signal (PDUS-0). This trend was also found between the group with doppler signal (PDUS 2–3) and those without PD (PDUS 0–1). This was also the case for clinically swollen joints versus non-swollen joints.

Finally, thermal images were analyzed through automatic and direct visual detection. The results of both analyses were consistent, indicating that direct visual reading could be used without needing the software. This strengthens the thermal camera as a quick and easy tool to be used in ambulatory practice.

**Conclusion**
Our results did not show the ability of thermal imaging to assess RA activity in small joints. However, our results are encouraging with temperature variation observed in inflammatory joints. The emergence of more precise and sensitive cameras could open new perspectives.

**Abbreviations**

- ACR
- American College of Rheumatology
- DAS28
- Disease Activity Score 28

**Declarations**

**Acknowledgements:** We are grateful to company GipsVision, and especially Frederic Equoy with whom we have developed a software allowing an automated reading of the thermal images obtained with the FLIR One® camera.

**Contributorship:** DV: contributed to the conception of the study, the data collection, the thermal imaging collection and evaluation, the data analysis, the results interpretation and the manuscript writing and approval. CP: contributed to the conception of the study, the development of the condition of use of the thermal camera FLIR One®, the data collection. CP, ST, MG, EF: contributed to the ultrasound examination of RA patients. All rheumatologist from the Department of the University Hospital of Sainte Marguerite (Marseille, France): contributed to the clinical examination of RA patients. TP: contributed to the conception of the study, results interpretation and manuscript approval. PL and CR: contributed to the results interpretation and manuscript approval. VP: was in charge of the statistical analyses. All authors take responsibility for the integrity of the work as a whole, from inception to published article, and they should indicate that they had full access to all the data in the study and take responsibility for the integrity of the data and the accuracy of the data analysis. They give permission to reproduce published material, report sensitive personal information, to use illustrations of identifiable persons or to name persons for their contributions.

**Funding** This study was supported by the CRI (Club des Rhumatismes et Inflammation) The authors have not declared a specific grant for this research from any funding agency in the public or commercial sectors.

**Competing interests** None declared.

**Patient and Public Involvement** was not appropriate in our study.

**Patient consent:** obtained.

**Ethical approval information:** This study did not involve invasive evaluation on human participants as RA patients were included when coming to the Department of the University Hospital of Sainte Marguerite
(Marseille, France) for RA diagnosis or follow-up. There were no additional exams than those usually done as part of their regular follow-up. Therefore, this study did not justify the approval of Ethics Committee. All participants received information on the study protocol and gave informed consent.

**Data sharing statement** All data (clinical, US and thermal imaging) concerning RA patients and data analysis are available upon request in the Department of the University Hospital of Sainte Marguerite (Marseille, France).

**References**

1. Minaur NJ, Jacoby RK, Cosh JA, Taylor G, Rasker JJ. Outcome after 40 years with rheumatoid arthritis: a prospective study of function, disease activity, and mortality. J Rheumatol Suppl. 2004 Mar;69:3–8.
2. Pincus T, Sokka T. Mortality in rheumatic diseases. Introduction. Clin Exp Rheumatol. 2008 Oct;26(5 Suppl 51):S1-4.
3. Toledano E, Candelas G, Rosales Z, Martínez Prada C, León L, Abásolo L, et al. A meta-analysis of mortality in rheumatic diseases. Reumatol Clin. 2012 Dec;8(6):334–41.
4. Dadoun S, Zeboulon-Ktorza N, Combescure C, Elhai M, Rozenberg S, Gossec L, et al. Mortality in rheumatoid arthritis over the last fifty years: systematic review and meta-analysis. Jt Bone Spine Rev Rhum. 2013 Jan;80(1):29–33.
5. Gaujoux-Viala C, Gossec L, Cantagrel A, Dougados M, Fautrel B, Mariette X, et al. Recommendations of the French Society for Rheumatology for managing rheumatoid arthritis. Jt Bone Spine Rev Rhum. 2014 Jul;81(4):287–97.
6. Smolen JS, Landewé R, Breedveld FC, Buch M, Burmester G, Dougados M, et al. EULAR recommendations for the management of rheumatoid arthritis with synthetic and biological disease-modifying antirheumatic drugs: 2013 update. Ann Rheum Dis. 2014 Mar;73(3):492–509.
7. Bykerk VP, Massarotti EM. The new ACR/EULAR classification criteria for RA: how are the new criteria performing in the clinic? Rheumatol Oxf Engl. 2012 Dec;51(Suppl 6):vi10–15.
8. Bird P, Lassere M, Shnier R, Edmonds J. Computerized measurement of magnetic resonance imaging erosion volumes in patients with rheumatoid arthritis: a comparison with existing magnetic resonance imaging scoring systems and standard clinical outcome measures. Arthritis Rheum. 2003 Mar;48(3):614–24.
9. Guzmán J, Burgos-Vargas R, Duarte-Salazar C, Gómez-Mora P. Reliability of the articular examination in children with juvenile rheumatoid arthritis: interobserver agreement and sources of disagreement. J Rheumatol. 1995 Dec;22(12):2331–6.
10. Hernández-Cruz B, Cardiel MH. Intra-observer reliability of commonly used outcome measures in rheumatoid arthritis. Clin Exp Rheumatol. 1998 Aug;16(4):459–62.
11. Szkudlarek M, Court-Payen M, Jacobsen S, Klarlund M, Thomsen HS, Østergaard M. Interobserver agreement in ultrasonography of the finger and toe joints in rheumatoid arthritis. Arthritis Rheum.
12. Ostergaard M, Hansen M, Stoltenberg M, Lorenzen I. Quantitative assessment of the synovial membrane in the rheumatoid wrist: an easily obtained MRI score reflects the synovial volume. Br J Rheumatol. 1996 Oct;35(10):965–71.

13. Ostergaard M, Stoltenberg M, Løvgreen-Nielsen P, Volck B, Sonne-Holm S, Lorenzen I. Quantification of synovitis by MRI: correlation between dynamic and static gadolinium-enhanced magnetic resonance imaging and microscopic and macroscopic signs of synovial inflammation. Magn Reson Imaging. 1998 Sep;16(7):743–54.

14. Szkudlarek M, Court-Payen M, Strandberg C, Klärlund M, Klausen T, Ostergaard M. Power Doppler ultrasonography for assessment of synovitis in the metacarpophalangeal joints of patients with rheumatoid arthritis: a comparison with dynamic magnetic resonance imaging. Arthritis Rheum. 2001 Sep;44(9):2018–23.

15. Colebatch AN, Edwards CJ, Østergaard M, van der Heijde D, Balint PV, D'Agostino M-A, et al. EULAR recommendations for the use of imaging of the joints in the clinical management of rheumatoid arthritis. Ann Rheum Dis. 2013 Jun;72(6):804–14.

16. 10.1002/acr.20102
Cheung. Reliability of ultrasonography to detect synovitis in rheumatoid arthritis: A systematic literature review of 35 studies (1,415 patients) [Internet]. Arthritis Care & Research - Wiley Online Library. 2010 [cited 2020 Mar 9]. Available from: https://onlinelibrary.wiley.com/doi/full/10.1002/acr.20102.

17. Rajapakse C, Grennan DM, Jones C, Wilkinson L, Jayson M. Thermography in the assessment of peripheral joint inflammation—a re-evaluation. Rheumatol Rehabil. 1981 May;20(2):81–7.

18. Salisbury RS, Parr G, De Silva M, Hazleman BL, Page-Thomas DP. Heat distribution over normal and abnormal joints: thermal pattern and quantification. Ann Rheum Dis. 1983 Oct;42(5):494–9.

19. Devereaux MD, Parr GR, Thomas DP, Hazleman BL. Disease activity indexes in rheumatoid arthritis; a prospective, comparative study with thermography. Ann Rheum Dis. 1985 Jul;44(7):434–7.

20. Ring EF, Collins AJ, Bacon PA, Cosh JA. Quantitation of thermography in arthritis using multi-isothermal analysis. II. Effect of nonsteroidal anti-inflammatory therapy on the thermographic index. Ann Rheum Dis. 1974 Jul;33(4):353–6.

21. Thermography Guidelines. Standards and protocols. [Internet]. [cited 2020 Jan 27]. Available from: http://www.iact-org.org/professionals/thermog-guidelines.html.

22. Spalding SJ, Kwoh CK, Boudreau R, Enama J, Lunich J, Huber D, et al. Three-dimensional and thermal surface imaging produces reliable measures of joint shape and temperature: a potential tool for quantifying arthritis. Arthritis Res Ther. 2008;10(1):R10.

23. FLIR ONE | FLIR Systems [Internet]. [cited 2020 Jan 26]. Available from: https://www.flir.com/flir-one/.

24. Jones B, Hassan I, Tsuyuki RT, Dos Santos MF, Russell AS, Yacyshyn E. Hot joints: myth or reality? A thermographic joint assessment of inflammatory arthritis patients. Clin Rheumatol. 2018
25. Villeneuve E, Nam J, Emery P. 2010 ACR-EULAR classification criteria for rheumatoid arthritis. Rev Bras Reumatol. 2010 Oct;50(5):481–3.

26. Wakefield RJ, Balint PV, Szkudlarek M, Filippucci E, Backhaus M, D’Agostino M-A, et al. Musculoskeletal ultrasound including definitions for ultrasonographic pathology. J Rheumatol. 2005 Dec;32(12):2485–7.

27. York Kiat T, et al. Thermal Imaging in Rheumatoid Arthritis: A Comparative Analysis with Ultrasonography and Clinical Joint Assessment [Internet]. ACR Meeting Abstracts. [cited 2020 Jan 31]. Available from: https://acrabstracts.org/abstract/thermal-imaging-in-rheumatoid-arthritis-a-comparative-analysis-with-ultrasonography-and-clinical-joint-assessment/.

### Tables

| n= 53 patients | Mean (SD) or N (%) |
|----------------|--------------------|
| Age (y)       | 61.6 (12.3)        |
| BMI (kg/m2)   | 26.0 (6.1)         |
| Disease duration (y) | 17.5 (11.1)    |
| CRP (mg/L)    | 14.3 (25.1)        |
| DAS 28-CRP    | 4.0 (1.6)          |
| TJC total (0-28) | 7.6 (7.7)        |
| SJC total (0-28) | 3.8 (3.5)        |
| TJC hand/wrist (0-18*) | 5.3 (5.7)    |
| SJC hand/wrist (0-18*) | 3.4 (3.2)    |
| Sex ratio (% Female) | 43 (81.1%)  |
| RF positive (%) | 36 (67.9%)        |
| Anti-CCP positive (%) | 43 (81.1%)  |
| Erosive, yes (%) | 31 (58.5%)       |
| Remission: DAS 28 <2.6 | 16 (30.2%)  |
| Medium: DAS 28 [2.6-5.1] | 25 (47.2%) |
| High: DAS 28> 5.1 | 12 (22.6%)       |

*: exclusion of MCP1 and PIP1 on both hands
Table 2: Mean ΔT-joint according to clinical examination (tender and swollen joints) and to US examination (mode B and PDUS)

|                  | n     | Mean ΔTj       | p               |
|------------------|-------|----------------|-----------------|
| **TJC**          |       |                |                 |
| No tender joints | 653   | -0.30 °C ± 0.84| p < 0.001       |
| Tender joints    | 268   | -0.06 °C ± 0.70|                 |
| **SJC**          |       |                |                 |
| No swollen joints| 748   | -0.26 °C ± 0.82| p = 0.066       |
| Swollen joints   | 173   | -0.13 °C ± 0.72|                 |
| **US mode B**    |       |                |                 |
| Synovitis (N)    | 653   | -0.26 °C ± 0.84| p = 0.021       |
| Synovitis (Y)    | 268   | -0.13 °C ± 0.69|                 |
| **Power Doppler by category** | | | |
| PDUS 0           | 782   | -0.25 °C ± 0.83| p-ANOVA = 0.072 |
| PDUS 1           | 42    | -0.10 °C ± 0.62|                 |
| PDUS 2           | 55    | -0.25 °C ± 0.73|                 |
| PDUS 3           | 42    | +0.54 °C ± 0.51|                 |
| PDUS 0 and 1     | 824   | -0.24 °C ± 0.82| p = 0.086       |
| PDUS 2 and 3     | 97    | -0.12 °C ± 0.66|                 |

Figures
Figure 1: Analysis for each thermal image: automatic detection and direct visual reading

Legend:

(a) 1st thermal analysis: Automatic detection of ROI.
Detection of 10 ROI and calculation of ΔT = ROI temperature - Forearm temperature

(b) 2nd thermal analysis: Direct visual reading of the thermal image
Synovitis (yes/no). Here synovitis of both wrists, and right MCP 3 and 4

Figure 1

Analysis for each thermal image: automatic detection and direct visual reading

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- SupplementaryMaterialAll.docx