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The accuracy of infrared thermal imaging and ultrasound in evaluating knee osteoarthritis dysfunction

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▶ ***Original article***

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ABSTRACT

***Background*:** To explore the accuracy of infrared thermal imaging and ultrasound in evaluating knee osteoarthritis (KOA) dysfunction. ***Materials and Methods*:** From November 2021 to June 2022, 50 KOA patients diagnosed by our hospital were selected. According to the results of ultrasound examination, the subjects were separated into mild group (30 cases) as well as moderate to severe group (20 cases). Pain as well as dysfunction was assessed using the visual analog Scale (VAS) and Western Ontario and McMaster osteoarthritis index (WOMAC). The forward-looking infrared (FLIR) thermal imager was used for infrared thermal imaging on the day of treatment as well as 1 month later. ***Results*:** The degree of cartilage wear detected by ultrasound was strongly correlated with the pain of knee osteoarthritis ($r=0.674$, $P<0.05$) and WOMAC osteoarthritis index ($r=0.643$, $P<0.05$). The knee temperature in the moderate to severe group was higher relative to the mild group ($P<0.05$, figure 2). The reliability and repeatability of the two infrared thermal imaging tests in knee were good (ICC=0.78). The knee temperature was positively correlated with the degree of cartilage wear under ultrasound ($r=0.426$, $P<0.05$, table 2). The knee temperature was positively related to pain ($r=0.403$, $P<0.05$) and WOMAC osteoarthritis index ($r=0.382$, $P<0.05$). ***Conclusion*:** Combined application of infrared thermal imaging and ultrasound in the evaluation process of knee osteoarthritis can assess the pain and dysfunction of knee osteoarthritis to a certain extent.

INTRODUCTION

Knee osteoarthritis (KOA) is a common disease among the elderly and is very common among people over 50 years old [1]. With an aging population, KOA may become the fourth leading cause of disability by 2020 [2]. KOA belongs to a degenerative disease featured by progressive destruction of articular cartilage along with substantial abnormalities of subchondral bones, ligaments, synovium, joint capsule, and periarticular muscles [3]. Patients with KOA often experience pain, stiffness, and swelling of the knee joint, which can occasionally lead to severe limb deformity [4]. Its diagnostic methods mainly rely on the above clinical manifestations, accompanied by corresponding radiological modification [5]. Studies have revealed that KOA patients possess a higher risk of fracture relative to those without osteoarthritis, and chronic inflammation associated with KOA increases the risk of cardiovascular disease, diabetes, and cancers [6]. Therefore, KOA is an important factor in elderly knee function loss and disability, and the pain and dysfunction caused by it seriously affect people's life [7].

Currently, the commonly used clinical imaging examinations of KOA contain X-ray, computed tomography (CT), as well as magnetic resonance imaging (MRI) [8]. X-ray is able to detect the skeletal characteristics and joint space width of KOA, but it lacks sensitivity and specificity to evaluate the joint tissue injury of KOA, and cannot directly observe the joint structure [9]. CT can be used to determine whether there are fractures and osteophytes, but it is not suitable for multiple examinations due to its high radiation [10]. MRI can be used to determine KOA with meniscus injury and joint effusion, but it is expensive and cannot be used routinely [11]. Recently, with the improvement of musculoskeletal ultrasonography, increasing studies have been conducted to observe the relationship between anatomical lesions and KOA pain [12]. Of note, the examination such as X-ray, CT, MRI and ultrasound can provide information for knee joint anatomy pathological changes, belongs to the structural imaging examination, such inspection cannot be used to judge the KOA physiology and function change [13]. Imaging methods that enable physiological and functional examination of lesions are called functional imaging and can provide physiological and functional information, such as bone scans and infrared thermography [14]. Infrared thermography provides the heat, metabolism, and corresponding changes of blood vessels of the human body by measuring the surface temperature changes of the body, which can reflect the physiological and functional changes of tissues, and belongs to the category of functional imaging (15). The skin temperature of healthy human is symmetrically distributed. Asymmetrical skin temperature distribution indicates an abnormality in the body (16). Therefore, infrared thermal imaging can be used as a research tool to study thermoregulation and temperature-related pain disorders (17). At present, infrared thermal imaging of knee joint is mostly applied to knee lesions caused by inflammatory arthritis, but there are few relevant studies for evaluating KOA.

In this research, we used both infrared thermal imaging and ultrasound to evaluate the accuracy of KOA dysfunction. Our study found that the combined application of infrared thermal imaging and ultrasound could assess the pain and dysfunction of KOA to a certain extent.

MATERIALS AND METHODS

General data

From November 2021 to June 2022, 50 KOA patients diagnosed by our hospital were selected, among which, 10 men and 40 women were contained, the mean age was (62.53±6.46) years old, and the average body mass index (BMI) was (23.73±2.25) kg/ m^2. The diagnosis of all patients was in line with the diagnostic criteria of the Chinese Association of Rheumatology for KOA. Exclusion criteria: (1) Patients had a history of knee surgery. (2) Patients with severe primary diseases of cardiovascular, liver, kidney, hematopoietic system as well as mental illness. (3) Other diseases affecting the knee joint, such as knee tumor, rheumatoid arthritis, gout, etc. (4) Pregnant or lactating women. (5) Patients with severe artery stenosis of lower extremity.

Ultrasound examination and grouping of knee joint

Color Doppler ultrasound diagnostic instrument (Philips IE33, Netherlands) was used to examine the knee cartilage. The probe frequency ranges from 9 to 12 MHz. The patient was instructed to take the supine position with the knee flexion of 30° to 45°. The probe was put on the upper edge of the patella and transverse and longitudinal scanning was performed in four directions: anterior, posterior, internal and external. The patient was instructed to take the prone position, straighten the knee joint, and perform popliteal scan. During the scan, the Angle of the probe was adjusted continuously to obtain better quality images.

The degree of cartilage wear was determined by relevant literature criteria: 0 (normal), the cartilage site had uniform low echo area. Grade 1 (mild), cartilaginous interface roughness and/or increased local cartilaginous echo. Grade 2a (moderate), in addition to the above changes, local cartilage thinning (less than 50%) was observed. Grade 2b (moderate), local cartilage thinned 50% to 100%. Grade 3, degenerative change (severe), local cartilage thinned up to 100%. According to the degree and grade of cartilage wear detected by ultrasound, the subjects were separated into mild group as well as moderate and severe group, among which grade 2a, 2b and 3 were moderate and severe group, and grade 0 and 1 were mild group. In this paper, a total of 40 bilateral KOA patients were studied, and the side with more severe cartilage wear was used as the observation side. The left side was selected as the observation side for the patients with one knee joint grade. The typical ultrasound images of normal cartilage and KOA patient's cartilage were demonstrated in figures 1 and 2.

Figure 1. Typical ultrasound image of normal cartilage.

Figure 2. Typical ultrasound image of KOA patient's cartilage.

Observation indexes

(1) Visual analog scale (VAS) (18): the scale of 0-10 CM was used to divide the pain into 10 grades. The larger the number, the greater the pain intensity was. Before use, explain the use method to the patient, and the patient marks the location of the scale of perceived pain severity.

(2) Western Ontario and McMaster osteoarthritis index (WOMAC) score (19): The osteoarthritis scoring system was implemented to evaluate the knee pain, stiffness as well as function of the subjects in the past week, and the total score was recorded.

Infrared thermal imaging examination

Equipment and environment requirements

Forward-looking infrared (FLIR) thermal imager (FLIR SC620, FLIR Systems Inc, USA) was adopted to

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collect thermal maps of the tested joints, and its performance fully met the requirements of thermal sensitivity, time and spatial resolution of medical thermal imaging. The temperature resolution was 0.05 K, the temperature measurement range was 10 ~ 40°C, and the minimum analytical temperature difference was 0.01°C. At the same time, all tests were conducted in a standardized medical thermal imaging environment, where the ambient temperature and humidity could be controlled to 25°C±1°C and 50% ±10%, respectively.

Inspection method

Infrared thermal imaging was performed twice on the same day and 1 month later. 72 h before the examination, the subject has no external drugs or patches on his knee joint. Before the examination, the patient will rest in the test room and expose his legs for 20 min to ensure that the thermophysiological state of the human body reaches a relatively stable balance. The subject took a standing position, adjusted the camera parallel to the knee height of the subject, and set the focal length to 72 cm. The anterior knee joint of the patient was collected by infrared imaging twice, and the interval of each image was 5 s. Image analysis was performed using the infrared thermal imaging instrument's own procedures.

Statistical analysis

SPSS 23.0 software (International Business Machines Corporation, USA) was implemented for statistical analysis. Spearman rank correlation was implemented to analyze the correlation between the degree of cartilage wear detected by ultrasound and the temperature, VAS score and WOMAC osteoarthritis index in 5 regions, and the correlation between temperature and VAS score and WOMAC osteoarthritis index in 5 regions. Age, BMI, and knee temperature were compared between groups using an independent *t-test*. Intra-group correlation coefficient (ICC) was applied to evaluate the reliability and repeatability of temperature measurements by two infrared thermal imaging.

RESULTS

Comparison of age as well as BMI of patients with different degrees of cartilage wear

Ultrasonic examination showed that there were 30 cases with mild cartilage wear, including 14 cases of grade 0 and 16 cases of grade 1. In the moderate to severe group, there were 20 cases, including 8 cases of grade 2a, 9 cases of grade 2b as well as 3 cases of grade 3. No significant difference was discovered in age and BMI of KOA patients between both groups (P>0.05, figure 3).

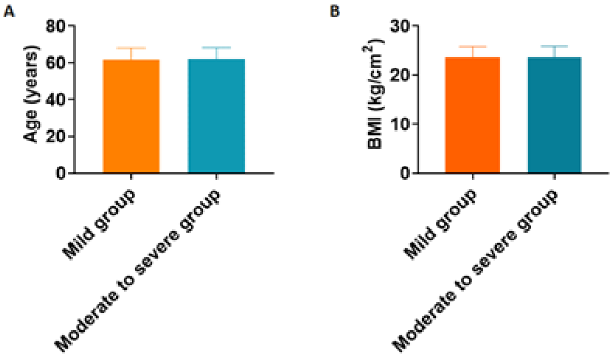

Figure 3. Comparison of age and BMI of patients with different degrees of cartilage wear. **(A)** Comparison of age and BMI of patients with different degrees of cartilage wear. **(B)** Comparison of BMI of patients with different degrees of cartilage wear. BMI: body mass index.

Ultrasonography of the relationship between cartilage wear and pain and WOMAC osteoarthritis index

The average VAS score of KOA patients was 5.13±2.24 and the average WOMAC of KOA patients was 71.89±25.63. Grade 0, grade 1, grade 2a, grade 2b along with grade 3 cartilage wear detected by ultrasound were assigned as 0, 1, 2, 3 and 4 respectively. Spearman rank correlation analysis showed that the degree of cartilage wear detected by ultrasound was strongly related to the pain (r=0.674, P<0.05) and WOMAC osteoarthritis index (r=0.643, P <0.05).

Table 1. Ultrasonography of the relationship between cartilage wear and pain and WOMAC osteoarthritis index.

Position	Grade	VAS	WOMAC
Knee cartilage evaluation	0 (n=14)	r=0.674 P<0.05	r=0.643 P <0.05
	1 (n=16)		
	2a (n=8)		
	2b (n=9)		
	3 (n=3)		

Note: VAS: visual analog Scale. WOMAC: Western Ontario and McMaster osteoarthritis index.

Infrared thermal imaging of knee temperature

Based on infrared thermal imaging, the knee temperature of KOA patients in the moderate to severe group was higher relative to the mild group (P<0.05, figure 4).

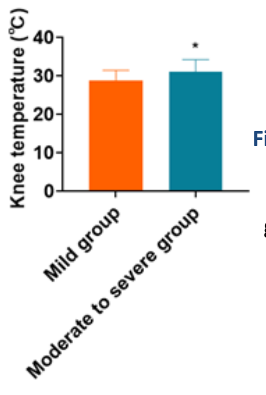

Figure 4. Infrared thermal imaging of knee temperature in both groups. *P<0.05 compared with the mild group, and P values were obtained by t-test.

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Correlation between the degree of cartilage wear shown by infrared thermal imaging and ultrasonic examination

The reliability and repeatability of the two infrared thermal imaging tests in knee were good (ICC=0.78). The knee temperature was positively correlated with the degree of cartilage wear under ultrasound (r=0.426, P<0.05, table 2).

Correlation between infrared thermal imaging and pain

It was displayed in table 2 that, the knee temperature was positively related to VAS score (r=0.403, P<0.05) and WOMAC osteoarthritis index (r=0.382, P<0.05).

Table 2. Correlation between knee temperature and grading of cartilage wear, pain and WOMAC osteoarthritis index.

Position	Grading of cartilage wear by ultrasound examination	VAS score	WOMAC osteoarthritis index	ICC
Knee temperature	r=0.426	r=0.403	r=0.382	0.78
P value	<0.05	<0.05	<0.05	

Note: VAS: visual analog Scale. WOMAC: Western Ontario and McMaster osteoarthritis index. ICC: Intra-group correlation coefficient.

DISCUSSION

Currently, imaging methods for knee joint evaluation can be roughly divided into structural imaging evaluation and functional imaging evaluation [20]. Structural imaging assessment refers to the assessment of the structures involved in the disease, including X-ray, CT, MRI and ultrasound [21]. Functional imaging assessment can provide physiological changes and functional information of the disease, such as infrared thermal imaging and radionuclide bone scan [22]. This study combined infrared thermal imaging and ultrasound to assess the accuracy in assessing dysfunction in patients with KOA.

Ultrasound is a safe, radiation-free, simple and inexpensive method [23]. In our study, ultrasound was used to assess the degree of cartilage wear to determine the severity of KOA. The results showed that the degree of cartilage wear measured by ultrasound was strongly associated with pain and WOMAC osteoarthritis index. Consistently, literatures have also shown that the degree of cartilage wear measured by ultrasound is related to pain and WOMAC osteoarthritis index [24]. These results indicate that the degree of cartilage wear detected by ultrasound can indirectly reflect the degree of pain of patients.

ICC analysis on the day of presentation and 1 month later showed reproducibility of infrared thermal imaging in evaluating KOA. The results of our study exhibited that the knee temperature of patients with moderate and severe KOA was elevated relative to patients with mild KOA, suggesting that there may be an inflammatory reaction process in KOA, which was consistent with former studies [25]. In our study, the correlation between the severity of KOA detected by infrared thermal imaging and ultrasound was studied, indicating that infrared thermal imaging and ultrasound could evaluate not only moderate and severe KOA, but also mild KOA, which was in line with former studies [26, 27].

As a functional imaging, infrared thermal imaging can detect the changes of diseases in the early stage. The outcomes of this study presented that the knee temperature was positively correlated with pain as well as WOMAC osteoarthritis index, suggesting that changes in the knee temperature could be used to determine pain and dysfunction. It was also suggested that infrared thermal imaging can show physiological changes of the knee joint before structural changes, and therefore can be used for pre-treatment evaluation.

In conclusion, the combination of ultrasound and infrared thermal imaging can assess the pain and dysfunction of KOA to a certain extent, which is valuable for promotion.

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Author Contributions: Bo Zhang, Xiaoxiong Zhao and Tong Chen participated in the study design and the literature search. Bo Zhang, Xiaoxiong Zhao and Shixiang Ren collected the data and wrote the manuscript. Bo Zhang, Xiaoxiong Zhao, Tong Chen, Shixiang Ren and Yuan Lin revised the manuscript. All authors read and approved the final manuscript.

REFERENCES

1. Michael JW, Schlüter-Brust KU, Eysel P (2010) The epidemiology, etiology, diagnosis, and treatment of osteoarthritis of the knee. *Dtsch Arztebl Int, **107**(9): 152-62.*
2. Benner RW, Shelbourne KD, Bauman SN, *et al.* (2019) Knee Osteoarthritis: Alternative Range of Motion Treatment. *Orthop Clin North Am, **50**(4): 425-32.*
3. Sharma L (2021) Osteoarthritis of the Knee. *N Engl J Med, **384**(1): 51-9.*
4. Mahmoudian A, Lohmander LS, Mobasheri A, *et al.* (2021) Early-stage symptomatic osteoarthritis of the knee - time for action. *Nat Rev Rheumatol, **17**(10): 621-32.*
5. Yeoh PSQ, Lai KW, Goh SL, *et al.* (2021) Emergence of Deep Learning in Knee Osteoarthritis Diagnosis. *Comput Intell Neurosci, **2021**: 4931437.*
6. Turkiewicz A, Díaz Y, Duarte-Salles T, *et al.* (2022) Knee and hip osteoarthritis and risk of nine cancers in a large real-world matched cohort study. *Rheumatology (Oxford), **61**(6): 2325-34.*
7. Sinatti P, Sánchez Romero EA, Martínez-Pozas O, *et al.* (2022) Effects of Patient Education on Pain and Function and Its Impact on

[DOI: 10.61186/ijrr.21.3.447]

Conservative Treatment in Elderly Patients with Pain Related to Hip and Knee Osteoarthritis: A Systematic Review. *Int J Environ Res Public Health, **19**(10).*
8. Kijowski R, Demehri S, Roemer F, *et al.* (2020) Osteoarthritis year in review 2019: imaging. *Osteoarthritis Cartilage, **28**(3): 285-95.*
9. Oo WM, Linklater JM, Hunter DJ (2017) Imaging in knee osteoarthritis. *Curr Opin Rheumatol, **29**(1): 86-95.*
10. Jones IA, Togashi R, Wilson ML, *et al.* (2019) Intra-articular treatment options for knee osteoarthritis. *Nat Rev Rheumatol, **15**(2): 77-90.*
11. Dainese P, Wyngaert KV, De Mits S, *et al.* (2020) Association between knee inflammation and knee pain in patients with knee osteoarthritis: a systematic review. *Osteoarthritis Cartilage, **30**(4): 516-34.*
12. Kandemirli GC, Basaran M, Kandemirli S, *et al.* (2020) Assessment of knee osteoarthritis by ultrasonography and its association with knee pain. *J Back Musculoskelet Rehabil, **33**(4): 711-7.*
13. Hayashi D, Roemer FW, Guermazi A (2016) Imaging for osteoarthritis. *Ann Phys Rehabil Med, **59**(3): 161-9.*
14. Fokam D and Lehmann C (2018) Clinical assessment of arthritic knee pain by infrared thermography. *J Basic Clin Physiol Pharmacol, **30**(3).*
15. Verstockt J, Verspeek S, Thiessen F, *et al.* (2022) Skin Cancer Detection Using Infrared Thermography: Measurement Setup, Procedure and Equipment. *Sensors (Basel), **22**(9).*
16. Usamentiaga R, Venegas P, Guerediaga J, *et al.* (2014) Infrared thermography for temperature measurement and non-destructive testing. *Sensors (Basel), **14**(7): 12305-48.*
17. Barbosa JS, Amorim A, Arruda M, *et al.* (2020) Infrared thermography assessment of patients with temporomandibular disorders. *Dentomaxillofac Radiol, **49**(4): 20190392.*
18. Sung YT and Wu JS (2018) The visual analogue scale for rating, ranking and paired-comparison (VAS-RRP): A new technique for psychological measurement. *Behav Res Methods, **50**(4): 1694-715.*
19. García-Coronado JM, Martínez-Olvera L, Elizondo-Omaña RE, *et al.* (2019) Effect of collagen supplementation on osteoarthritis symptoms: a meta-analysis of randomized placebo-controlled trials. *Int Orthop, **43**(3): 531-8.*
20. Jogi SP, Thaha R, Rajan S, *et al.* (2022) Device for Assessing Knee Joint Dynamics During Magnetic Resonance Imaging. *J Magn Reson Imaging, **55**(3): 895-907.*
21. Katsurada T, Nishida M, Sakamoto N (2017) Imaging (X-ray - CT - MRI - ultrasound). *Nihon Rinsho, **75**(3): 387-91.*
22. Huang PH, Chen JW, Lin CP, *et al.* (2012) Far infra-red therapy promotes ischemia-induced angiogenesis in diabetic mice and restores high glucose-suppressed endothelial progenitor cell functions. *Cardiovasc Diabetol, **11**: 99.*
23. Paczesny Ł and Kruczyński J (2011) Ultrasound of the knee. *Semin Ultrasound CT MR, **32**(2): 114-24.*
24. Erhart-Hledik JC, Mahtani GB, Asay JL, *et al.* (2021) Changes in knee adduction moment wearing a variable-stiffness shoe correlate with changes in pain and mechanically stimulated cartilage oligomeric matrix levels. *J Orthop Res, **39**(3): 619-27.*
25. Denoble AE, Hall N, Pieper CF, *et al.* (2010) Patellar skin surface temperature by thermography reflects knee osteoarthritis severity. *Clin Med Insights Arthritis Musculoskelet Disord, **3**: 69-75.*
26. Oo WM, Linklater JM, Bennell KL, *et al.* (2021) Are OMERACT knee osteoarthritis ultrasound scores associated with pain severity, other symptoms, and radiographic and magnetic resonance imaging findings? *J Rheumatol, **48**(2): 270-8.*
27. Chopp-Hurley JN, Wiebenga EG, Bulbrook BD, *et al.* (2020) Evaluating the relationship between quadriceps muscle quality captured using ultrasound with clinical severity in women with knee osteoarthritis. *Clin Biomech (Bristol, Avon), **80**: 105165.*

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