

Morphological evaluation and diagnosis of medial type osteoarthritis of the knee using ultrasound

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Abstract

Objective The aim of this study was to diagnose osteoarthritis (OA) of the knee joint using ultrasound (US).

Methods The study subjects included 27 males and 54 females (131 knees), who had a mean age of 62.8 years. US was used to evaluate the medial joint space of both knees in complete extension with and without weight-bearing. In each patient, the medial radial displacement of the medial meniscus (MRD), the peripheral joint space (PJS) and the number of osteophytes were evaluated. The subjects were divided into five groups based on the KL grade (0–4), and then each value was compared. Additionally, the subjects were divided into two groups: KL grade 0 and 1 (non-OA group) and KL grade 2–4 (OA group). We classified patients who met the following criteria as having OA on the US assessment: <5 mm of PJS during weight-bearing, >5 mm of MRD during weight-bearing, and >2 mm of osteophytes. Then we examined the diagnostic accuracy of the radiographic diagnosis (non-OA or OA of the knee) using US assessment.

Results The PJS was significantly decreased and the MRD was significantly increased in the OA group compared to the non-OA group ($p < 0.001$). The percentage of radiographic OA of the knee that was correctly diagnosed by ultrasound was 90.8 % (sensitivity), with a specificity of 95.5 %. The positive predictive value was 97.5 % and the negative predictive value was 84.0 %.

Conclusions Our study therefore showed that US has both a high reliability and excellent diagnostic accuracy.

Introduction

Osteoarthritis (OA) is a major chronic disease among the elderly, and is an important cause of impairment and disability, with associated health care costs [1]. The knee is one of the most common joints involved in OA. In Japan, the ROAD study reported the estimated prevalence of symptomatic knee OA in adults over 65 years of age to be 26.2 % [2]. The diagnosis of knee OA is established based on clinical evaluations, usually supplemented by radiography. Radiographs are examined for the presence or absence of one or more signs of OA using the Kellgren–Lawrence (KL) scale. KL grade 2 is defined as osteophyte formation, and a KL score ≥ 2 is generally used as the standard diagnostic criterion for knee OA [3, 4].

Ultrasound (US) is used for the non-invasive assessment of musculoskeletal status. Recently, many studies have reported using US to evaluate the knee joint, and the US evaluation of the meniscal position under load-bearing has been discussed [5–8]. Kawaguchi et al. [9] evaluated the medial radial displacement (MRD) of the medial meniscus in osteoarthritic (OA) and normal knees with and without weight-bearing, using US. They found that the MRD of the medial meniscus increases with weight-bearing during follow-up, as OA progresses. However, few reports have described using US to make diagnoses of OA in knee joints.

The aim of this study was to investigate the correlation between the OA grade determined by radiography and that by US evaluation and to investigate the diagnostic accuracy of OA determined using US.

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Materials and methods

Case selection

This study was approved by the institutional review board of our institution. All participants, before giving their consent to participate in this study, were informed that their data would be published. The subjects were selected from among patients attending the outpatient Department of Orthopaedic Surgery at Gunma University, based on the following criteria: (1) no history of surgical treatment or trauma of the knee, (2) the presence of any knee pain in medial joint space, (3) patient age ≥ 40 years. The exclusion criteria were a history of avascular necrosis, rheumatoid or other inflammatory arthritis, periarticular fractures, Paget's disease, villonodular synovitis, joint infection, neuropathic arthropathy and gout or pseudogout. Using these criteria, we recruited 81 individuals with 131 knees (27 males and 54 females) with a mean age of 62.8 years (range 41–87 years).

Radiographic assessment

Anteroposterior weight-bearing radiographs of the knee were acquired with the knee fully extended and the subject in a standing position. Knee radiographs were read without knowledge of the participant's clinical status by a single well-experienced orthopedist using the KL scale. The KL radiographic grading system was used to measure the global radiographic severity of OA changes. According to this system: grade 0, normal (no osteophytes); grade 1, possible osteophytes; grade 2, definite osteophytes and possible joint space narrowing; grade 3, moderate/multiple osteophytes and definite joint space narrowing, some sclerosis and possible attrition; and grade 4, large osteophytes, marked joint space narrowing, severe sclerosis and definite attrition.

US assessment

US was used to examine both knees to diagnose the MRD and the peripheral joint space (PJS) using the LOGIQ e device (GE Health Care, USA) with linear-array probes at 12 MHz. All US examinations were performed by one experienced knee joint surgeon who was blinded to the other items included in the evaluation. The US evaluations were performed with both knees in complete extension in both the standing and supine positions. The MRD and PJS were measured on longitudinal US images at the site at which the medial collateral ligament (MCL) was most clearly visualized. Normal MCLs are observed to be hyperechoic, covering the medial femoral condyle, the outer margin of the medial meniscus and the medial tibial

plateau. The MRD was measured as the distance from the outermost edge of the medial meniscus to a line connecting the femoral and tibial cortices. The PJS was measured as the distance from the peripheral femoral to the peripheral tibial cortices.

Marginal osteophytes were defined as those more than 2 mm from the femoral and tibial cortices. When marginal osteophytes were present in the femur and tibia, the MRD and PJS were measured on the clearly visualized normal cortical bone continuous with the femoral and tibial marginal osteophytes [5–9]. The distances were measured using electronic calipers (to an accuracy of 0.1 mm). We defined the supine position MRD and PJS as the non-weight-bearing medial radial displacement (NWMRD) and non-weight-bearing peripheral joint space (NWPJS), respectively, and the standing position MRD and PJS as the weight-bearing medial radial displacement (WMRD) and weight-bearing peripheral joint space (WPJS), respectively (Fig. 1). The intra-observer agreements were analyzed using kappa statistics. The intra-observer intraclass correlation coefficient (ICC) was 0.929 ($p < 0.001$) for the distance measurement of the PJS and was 0.961 ($p < 0.001$) for the distance measurement of the MRD. The ICC was 0.956 for presence or absence of the osteophyte ($p < 0.001$).

The subjects were divided into five groups according to the KL grade determined using knee radiographs. Because a KL grade ≥ 2 is generally considered to be the standard diagnostic criterion for knee OA [3, 4], the subjects were divided into two groups: KL grade 0 and grade 1 (non-OA group) and KL grades 2 and higher (OA group). Furthermore, we were seeking to make diagnoses of OA of the knee joints. Since radiographic OA is diagnosed in the standing position, we used the US findings from the patients in the weight-bearing position for the comparisons. We classified patients who met at least two criteria (WPJS < 5 mm, WMRD > 5 mm and osteophytes > 2 mm) as

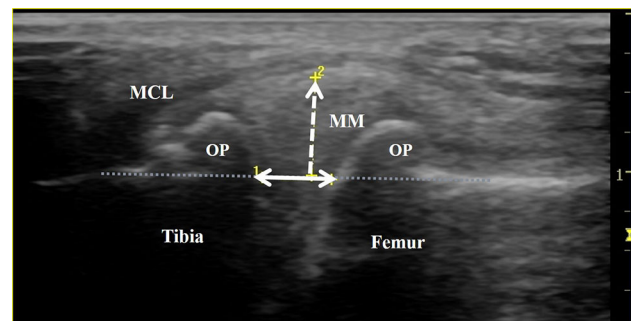


Fig. 1 The MRD and PJS were measured on longitudinal US images at the site at which the medial collateral ligament (MCL) was most clearly visualized. *OP* osteophyte, *MM* medial meniscus, *MCL* medial collateral ligament, *double-sided arrow* peripheral joint space, *Upside dotted arrow* medial radial displacement of the medial meniscus

having radiographic OA on the US assessment. We examined the diagnostic accuracy of the radiographic non-OA or OA of the knee using the US assessment.

Statistical analysis

Each group, divided according to the KL grade, was compared using a one-way ANOVA. Student's *t*-test and the chi-square test were used to calculate the statistical significance of differences between the unpaired groups. All statistical analyses were conducted using the IBM SPSS Statistics 19 software program (IBM Japan, Ltd., Tokyo, Japan), and the critical value for significance was set at $p < 0.05$.

Results

The characteristics of the patients are presented in Table 1. Significant differences were found in the patient age between the KL grade 0 knees and the other grades. The mean (SD) values for the MRD and PJS in the supine and standing positions were compared according to the KL grade. No significant differences were noted in the MRD (with or without weight-bearing) between the KL grade 0 and KL grade 1 knees, but the MRD was significantly higher in KL grade 2 or more severe grade knees compared to the grade 0/1 knees ($p < 0.001$). With regard to NWPJS, no significant differences were noted between the KL grade 0 and KL grade 2 knees, but NWPJS value was

significantly different between the KL grade 0/1/2 knees and the KL grade 3 or 4 knees. No significant differences were noted in WPJS values between the KL grade 0 and KL grade 1 knees, but the WPJS values were significantly different between the KL grade 0/1 knees and the knees with KL grade 2 or more severe grade ($p < 0.001$). The proportion of osteophytes was 0 % in KL grade 0, 4.0 % in KL grade 1, 92.6 % in KL grade 2, 100 % in KL grade 3 and 100 % in KL grade 4 knees. The proportion of osteophytes was significantly different between the KL grade 0/1 knees and the knees with KL grade 2 or more severe grade ($p < 0.001$) (Table 2).

The non-OA group included 44 knees. The OA group included 87 knees. Significant differences were found between the two groups in patient age (52.2 ± 19.6 years in the non-OA group and 68.2 ± 12.0 years in the OA group, $p < 0.001$). The value of the NWMRD in the non-OA group was 2.40 ± 0.87 mm, while that in the OA group was 6.12 ± 2.57 mm. The value of the WMRD in the non-OA group was 2.95 ± 0.93 mm, while that in the OA group was 7.00 ± 2.65 mm. The NWMRD and WMRD values were significantly lower in the non-OA group than in the OA group ($p < 0.001$). The values of NWPJS and WPJS in the non-OA group were 6.05 ± 1.5 and 5.30 ± 1.04 mm, while those in the OA group were 3.52 ± 1.95 and 2.77 ± 1.54 mm, respectively. The NWPJS and WPJS values were both significantly higher in the non-OA group compared to the OA group ($p < 0.001$). The proportion of osteophytes was 2 % in the non-OA group, while that in the OA group was 98 % ($p < 0.001$) (Table 3).

As noted above, we defined patients who had two or more of the following as having OA on the US assessment: a WPJS < 5 mm, WMRD > 5 mm or osteophytes > 2 mm. A 2×2 contingency table showing the results of the ultrasonographic and radiographic evaluations of the OA of the knee is shown in Table 4. The percentage of the cases of radiographic OA of the knee that were correctly diagnosed by ultrasound was 90.8 % (sensitivity), with a specificity of 95.5 %. The positive predictive value was 97.5 % and the negative predictive value was 84.0 %.

Table 1 The characteristics of the patients divided by KL grade

KL grade	No. of subjects	Age mean \pm SD (years)
KL grade 0	19	43.9 ± 17.6
KL grade 1	25	63.6 ± 13.1
KL grade 2	27	61.0 ± 12.5
KL grade 3	30	71.0 ± 11.0
KL grade 4	30	70.8 ± 11.6

Table 2 The MRD and PJS values determined by ultra-sonographic evaluation of the knee in both the supine and standing positions according to KL grade

KL grade	NWMRD (mm) mean (95 % CI)	NWPJS (mm) mean (95 % CI)	WMRD (mm) mean (95 % CI)	WPJS (mm) mean (95 % CI)	Ratio of osteophytes
KL grade 0	2.05 (1.79–2.31)	6.23 (5.76–6.82)	2.54 (2.27–2.80)	5.73 (5.21–6.25)	0/19 (0 %)
KL grade 1	2.66 (2.25–3.06)	5.87 (5.38–6.36)	3.26 (2.83–3.69)	4.97 (4.60–5.34)	1/25 (4.0 %)
KL grade 2	3.58 (3.07–4.09)	5.19 (4.48–5.94)	4.27 (3.72–4.82)	4.46 (3.99–4.93)	25/27 (92.6 %)
KL grade 3	6.31 (5.62–7.01)	3.36 (2.79–3.94)	7.33 (6.65–8.02)	2.55 (2.17–2.94)	30/30 (100 %)
KL grade 4	8.21 (7.46–8.97)	2.18 (1.76–2.59)	9.13 (8.39–9.87)	1.47 (1.28–1.67)	30/30 (100 %)

CI confidence interval, NWMRD non-weight-bearing medial radial displacement, NWPJS non-weight-bearing peripheral joint space, WMRD weight-bearing medial radial displacement, WPJS weight-bearing peripheral joint space

Table 3 Comparison of the clinical findings of the radiographic non-OA and OA groups

	Non-OA group mean \pm SD (<i>n</i> = 44)	OA group mean \pm SD (<i>n</i> = 87)
Age (years)	52.2 \pm 19.6*	68.2 \pm 12.0
NWMRD (mm)	2.40 \pm 0.87*	6.12 \pm 2.57
NWPJS (mm)	6.05 \pm 1.16*	3.52 \pm 1.95
WMRD (mm)	2.95 \pm 0.93*	7.00 \pm 2.65
WPJS (mm)	5.30 \pm 1.04*	2.77 \pm 1.54
Ratio of osteophytes	1/44(2 %)	85/87(98 %)

NWMRD non-weight-bearing medial radial displacement, *NWPJS* non-weight-bearing peripheral joint space, *WMRD* weight-bearing medial radial displacement, *WPJS* weight-bearing peripheral joint space

* $p < 0.001$

Table 4 A 2 \times 2 contingency table showing the results of the ultrasonographic and radiographic evaluations of OA in the knee

	Positive ultrasound	Negative ultrasound	Total
Positive radiography	79	8	87
Negative radiography	2	42	44
Total	81	50	131

A total of 79 of the 87 cases of OA of the knee were correctly diagnosed by ultrasound

Discussion

Our results obtained for the US assessment showed that the NWMRD and WMRD increase with increasing OA grade. With regard to the MRD, our results were similar to the previous report by Kawaguchi et al. [9]. However, the PSJ values and osteophytes were not investigated in their study. In the present study, we found that the NWPJS and WPJS decreased with increasing OA grade, while the ratio of osteophytes increased with increasing OA grade.

The KL grade is simply a plain radiological diagnosis, and is commonly accepted by radiologists and clinicians as a standard grading system for knee joint osteoarthritis. However, the KL scale cannot characterize cartilage damage, including that of the meniscus, so the MRD cannot be detected by radiography, while it can be examined by US. This suggests that US can provide additional information about the severity of OA that cannot be provided by radiography.

MRI (magnetic resonance imaging) is used as a modality for evaluating intra-articular components and the position of the meniscus [10]. However, most images are obtained with the patient in a supine, non-weight-bearing position. In contrast, US can measure the meniscal subluxation under axial loading. In addition, MRI is

inconvenient, requiring considerable time to complete the test and very expensive instrumentation. Other advantages of US include its non-invasiveness, portability, and the ability to be repeated as often as necessary.

Recently, some studies evaluating the association of MRI-graded osteoarthritis with the KL grade have been reported [11–15]. Park et al. [14] reported a MR grading system for osteoarthritis of the knee joint, which correlated with the KL grade. However, no study has investigated the accuracy of US for diagnosing OA of the knee. When we defined patients as having OA who met two of the three criteria (WPJS $<$ 5 mm, WMRD $>$ 5 mm and osteophytes $>$ 2 mm), our results showed that the percentage of the cases of radiographic OA of the knee that were correctly diagnosed by US was 90.8 % (sensitivity), with a specificity of 95.5 %. Therefore, the results were highly reliable and accurate. This suggests that US may be useful for screening patients for OA.

Although radiography is the gold standard modality for diagnosing osteoarthritis, it is difficult to distinguish between KL grade 1 and 2 due to the fact that there are only slight differences between these conditions, and because they are defined exclusively by the presence of osteophytes. As a result, a patient with either joint space narrowing or some meniscal degeneration, but no associated osteophytes cannot be classified as having OA according to the KL system. This study shows that there were two knees that exhibited positive ultrasound findings and negative radiography findings; each knee was diagnosed with KL grade 1 on radiography. These knees demonstrated a WPJS of $<$ 5 mm and a WMRD of $>$ 5 mm on US. These results raise the possibility that these conditions may possibly represent a dysfunction of the meniscus without osteophytes. On the other hand, eight knees demonstrated negative ultrasound findings and positive radiography findings. These knees were diagnosed with KL grade 2 on radiography, although not all knees met the criteria because they displayed a WPJS of $>$ 5 mm and a WMRD of $<$ 5 mm on US. These results therefore raise the possibility that these conditions allow the meniscal function to be kept and thereby maintain the joint space. An evaluation of different conditions of patients who demonstrate the same KL grade is possible using US. Therefore, we think that US is a useful tool for diagnosing the presence of OA when used in addition to radiography.

This study is associated with several limitations that should be considered when interpreting the results. First, we examined only patients with medial OA, we did not evaluate patients with either lateral OA or patellofemoral OA. Second, we examined patients at only the level of the MCL, and the meniscal displacement, peripheral joint space and osteophytes in other directions were not estimated. Third, the US investigations were conducted under

static circumstances with the knee extended. Flexion of the knee can increase stress on the posterior segment of the meniscus and subsequently increase extrusion, so additional measurements may be necessary to confirm the presence of OA, especially early OA.

In summary, we found that there are characteristic changes associated with knee osteoarthritis in terms of the rate of PJS decrease and MRD and osteophyte increases as the KL grade increases in a morphological evaluation of the knee using US. Additionally, we were able to show a high reliability of the results and good diagnostic accuracy. Based on the findings of this study, we believe that US is able to accurately detect the early degeneration of the knee joint, and it is therefore a useful, affordable and non-invasive tool for assessing the knee joint.

Conflict of interest The authors declare that they have no conflict of interest.

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