brace longitudinally may cause patients to change their gait motion pattern and/or mechanical stress in other joints. Furthermore, Winter and Sienko (1988) suggested that hip moment was also affected by trunk and pelvis motion, supporting the idea that compensatory motion of the trunk or pelvis should be considered to prevent an increased mechanical stress to other joints in patients with long-term bracing. Further investigation is needed into the biomechanical changes that could occur with long-term treatment of knee OA with bracing.

There are several limitations in this study. First, the patients showed varying degrees of OA severity including bilateral OA. Liikavainio et al. (2007) reported that bilateral OA patients with no pain in either knee joint showed no asymmetry in kinematic or kinetic variables in level walking. In the current study, patients had unilateral pain and the more symptomatic knee joint could show changes in kinematic and kinetics. Compensatory changes in the gait of patients with knee OA is related to the OA severity (Huang et al., 2008), and in this study, most patients with bracing showed changed motion on walking despite the different severities of OA. This might indicate that bracing affects the motion of knee OA patients in spite of the OA grades. Further studies should investigate whether patients with the same severity of OA show compensatory walking motions with bracing.

Second, although hip abductors play a role in hip joint moments in the frontal plane (Chang et al., 2005), the muscle strength of the hip abductors was not measured in this study. However, previous studies indicated that gluteus medius muscle activity is not relevant to the hip joint moment in the frontal plane during gait (Rutherford and Hubley-Kozey, 2009), and strengthening the hip did not induce biomechanical changes in the hip or knee (Bennell et al., 2010). Thus, hip muscle strength could not change hip and knee kinematics and kinetics.

Third, walking speed was not prescribed in this study and patients walked at a self-selected velocity. A previous study showed that when subjects walked at faster speeds, the joint moments were increased (Lelas et al., 2003). In the present study, although patients walked faster and at higher cadence with bracing, external knee adduction moment was reduced. Thus, future research should investigate the effects of bracing on walking at the same speed and cadence. In addition, Kito et al. (2010) reported that knee OA patients walked with increased knee adduction moment impulse during initial double stance and single limb support, and that sustained increased cadence also increased net load on the knee due to the increased frequency of initial stance and mid-stance phase. It is therefore necessary to investigate the long-term effects on daily activity in patients using braces.

5. Conclusion

This study investigated the effects of unloading bracing on the involved and contralateral knee and hip joints of knee OA patients during the stance phase. External adduction moment in the involved knee decreased with bracing, while ipsilateral hip kinematics and kinetics, and contralateral knee and hip kinetics, also changed. When treating patients with knee OA using a brace, it is important to consider the effects on both the involved and contralateral lower limb joints.

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ORIGINAL ARTICLE

Comparison of MRI-based assessment systems for osteoarthritic knees: the irregularity index system and WORMS

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Abstract

Purpose Several MRI-based evaluation systems for osteoarthritis (OA) of the knee have been developed. Among them the whole-organ magnetic resonance imaging score (WORMS), which evaluates the status of the entire knee joint, appears to be representative. We developed an irregularity index system to measure irregularities of the contours of the femoral condyle on MRI. Only the contour of the condyle was assessed by the irregularity index, whereas several items comprising the knee joint were taken into account by WORMS. This study compared the irregularity index and WORMS in terms of their correlations with clinical scores.

Methods Thirty-one medial-type OA knees were studied. Kellgren-Lawrence grading was used for X-ray grading: 8 were grade II, 11 were grade III, and 12 were grade IV. Japanese Orthopaedic Association scores and Japanese knee osteoarthritis measure scores were used for clinical assessments. We determined the correlations between MRI-based assessment scores and clinical scores.

Results Both the irregularity index and WORMS exhibited positive correlations with these clinical scores. The irregularity index was associated with bone cysts of the medial compartment and menisci in the articular features of WORMS.

Conclusions These MRI-based methods are useful for evaluating OA severity. However, the irregularity index may have advantages over WORMS because of its semi-automatic features.

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Introduction

Osteoarthritis (OA) of the knee joint is a common musculoskeletal problem in the elderly population and adversely affects their quality of life. In an aging society, proper treatment systems are sought in terms of better quality of life and from a socioeconomic standpoint. For these purposes, evaluating the severity of affected joints is essential.

Radiographic examination has been the gold standard to diagnose and evaluate the OA knee [1, 2], although disparities between the severity of radiographic findings and patients' symptoms are often observed. Therefore, we can use radiography as a reference for severity evaluation or for selecting treatment options, but we cannot rely solely on it. Establishing other objective assessment systems for determining the severity of the OA knee would be of great help in treatment selection, as well as in assessing the efficacy of treatment. Unfortunately, no good biomarkers that serve this purpose have yet been established; imaging of the involved joint is remains essential.

Recently, magnetic resonance imaging (MRI) has begun to be used for OA severity evaluations. Several studies have argued for the relationships between pain severity and changes in specific tissue lesions on MRI, such as articular cartilage [3, 4], bone attrition [5–7], bone edema [6, 8–11], synovitis [8, 11, 12], and meniscal tears [4, 6]. However, the clinical importance of these findings has not been confirmed [13, 14]. More recently, MRI-based, semiquantitative whole organ assessments have been proposed [15–17].

Among them, the whole-organ magnetic resonance imaging score (WORMS) appears to be representative. It evaluates the entire knee joint's status and has been reported to be a reliable evaluation method for knee OA. Peterfy et al. [15] showed that WORMS had a high inter-observer agreement among trained readers. Eckstein et al. [18] reported that MRI-based measurements, such as WORMS, were useful for elucidating the pathophysiology of various tissues, identifying risk factors for OA, and combating OA with new and better therapies.

In our previous study, we developed a new method, the irregularity index system, to semi-automatically measure irregularities of the contours of the femoral condyle using standard, sagittal, proton-density-weighted MR images and demonstrated that the irregularity index could reflect the severity of knee OA [19].

However, a comparison of this system with other MRI-based assessments still needs to be made. The purpose of this study was to compare image-based grading of knee OA, including X-ray grading, WORMS, and the irregularity index, in terms of their correlations with clinical scores.

Materials and methods

Patients and clinical assessments

This study was conducted in accordance with the rules and regulations of the local research committee for use of humans in research studies. The subjects were recruited from the patients who visited our hospital for treatments of OA knees. All patients had an antero-posterior, weight-bearing X-ray at their first visit, and they were graded according to the Kellgren/Lawrence (K/L) grading system [1]. The inclusion criterion was medial-type OA knees with ≥grade II by K/L grading. The exclusion criteria were prior surgical treatment for the knee, history of knee trauma, and inflammatory joint diseases. A total of 31 patients (31 knees) who consented to participate in this study were enrolled. Twenty-two patients had bilateral involvement, and knees with more severe symptoms were assessed in the present study. The subjects included 18 females and 13 males with a mean age of 69 years (range 56–81 years).

They were also clinically examined and were scored using the Japanese Orthopaedic Association OA knee score (JOA score) [20, 21] and the Japanese knee osteoarthritis measure (JKOM) [22]. A JOA score was comprised of four items: (1) pain on walking, (2) pain on ascending or descending stairs, (3) range of motion (ROM), and (4) joint effusion. Each item receives 0–30, 0–25, 0–35, and 0–10 points at 5-point intervals, respectively, according to morbidity; total sum of four scores (0–100) is generally used for evaluating OA knees in Japan. JKOM is a self-administered, disease-specific measure and a counterpart of WOMAC that was developed for assessing Japanese OA patients by taking Japanese lifestyles into account. It has proved to be as good as or better than WOMAC or SF-36 in terms of its reliability and validity [22]. This score is composed of 25 questionnaires related to pain and stiffness, condition in daily life, general activities, and health conditions. For each questionnaire patients are asked to reply according to a 5-point scale from none to extreme according to their status where none receives 1 point and extreme 5 points. Total sum of scores is used for OA knee evaluation.

MRI acquisition

All patients underwent an MRI of their affected knee within 2 weeks of their first visit. MRI was performed with a 1.5-T scanner (Signa, GE Medical Systems) equipped with a knee surface coil. The sequence for the irregularity index was according to Ochiai et al. [19]. The sequences for WORMS were according to Peterfy et al. [15].

Calculation of the irregularity index

Three sagittal slices that represented the center of the medial femoral condyle (MFC) were selected for calculating the irregularity index by two orthopaedic surgeons who reached a consensus without knowledge of the patient's age and sex. The contour irregularity of the femoral condyle was calculated by a custom-made program for MATLAB 6.5J (The Mathworks, Natick, MA). The methods for calculating the irregularity index were described in a previous study [19]. In brief, Digital Imaging and Communications in Medicine (DICOM) data of the selected images were incorporated directly into the software (Fig. 1a). The image was converted into a black-and-white image (Fig. 1b). Then the contours of the MFC were extracted (Fig. 1c), which led to making two lines by tracing the upper surface and the lower surface of the extracted contours (Fig. 1e). Based on these two lines, contour thickness was measured at each pixel, and the standard deviation of contour thickness (SDC) was calculated and used as the irregularity index.

Scoring for WORMS

WORMS was scored for each patient by a single surgeon according to the method introduced by Peterfy et al. [15]. Briefly, this method divides the entire knee into 15

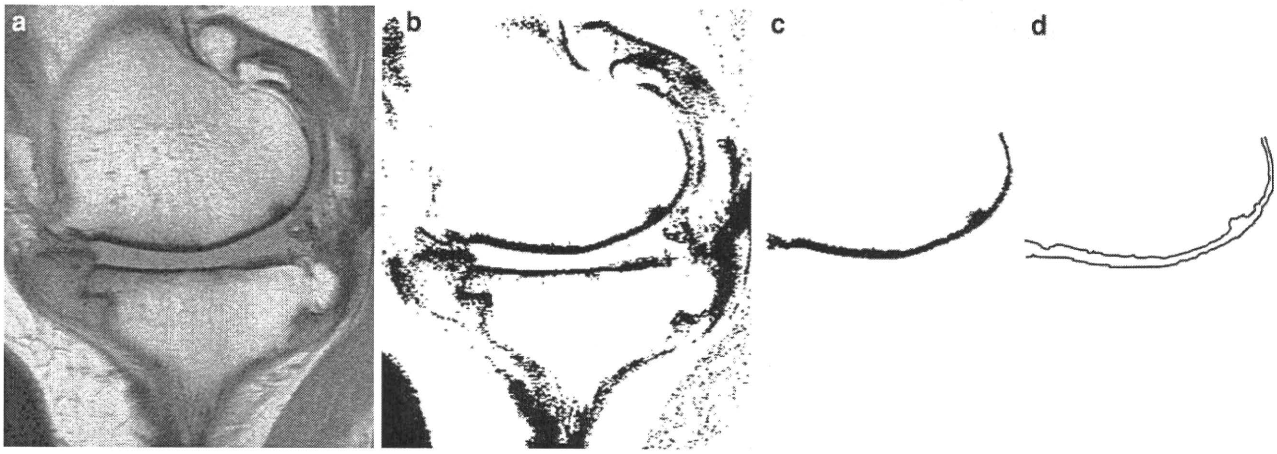

Fig. 1 Irregularity index. DICOM data of sagittal images of the medial compartment were incorporated into a computer (**a**) and converted into a black and white image (**b**). Then the contour of the medial femoral condyle was extracted (**c**), and the upper and the lower surface were automatically traced (**d**). Based on these two lines, contour thickness was measured at each pixel, and the standard deviation of contour thickness (SDC) was used as the irregularity index

different regions by anatomical landmarks and scores each of these regions with respect to 8 independent articular features, such as cartilage morphology, marrow abnormality, bone cysts, bone attrition, osteophytes, meniscal integrity, ligament integrity, and synovitis. The maximum score is 332, and the minimum score is 0 when there are no findings.

Statistical analysis

Comparisons of clinical scores (JOA, JKOM) among K/L grades were made by one-way analysis of variance (ANOVA) and a post hoc Tukey-Kramer test. Correlations between SDC or WORMS, and the clinical scores were evaluated by Pearson's correlation coefficient. Relationships between the articular features from WORMS and SDC with the clinical scores were analyzed by regression analysis. Statistical significance was defined as $p < 0.05$. All statistical analyses were performed with Statview 5.0 (SAS Institute Inc., Cary, NC).

Results

Eight knees were grade II based on the K/L grading system (5 females and 3 males with a mean age of 67 years), 11 knees were grade III (6 females and 5 males with a mean age of 66 years), and 12 knees were grade IV (7 females and 5 males with a mean age of 74 years). As the K/L grade rose, the JOA score significantly decreased ($p <$ 0.0001), and the JKOM significantly increased ($p = 0.007$). There were significant differences between all grades based on JOA scores and between grades II and III and grades II and IV based on JKOM scores (Table 1).

Table 1 Kellgren–Lawrence grades and clinical scores

	JOA (mean ± SD)	JKOM (mean ± SD)
KL II	75.6 ± 4.2	60.0 ± 8.8
KL III	68.2 ± 4.6*	75.6 ± 21.2*
KL IV	50.8 ± 7.1*,†	83.6 ± 10.9*

KL Kellgren-Lawrence grading, *JOA* Japanese Orthopaedic Association scores, *JKOM* Japanese knee osteoarthritis measure scores

* $p < 0.05$ compared with K/L II, † $p < 0.05$ compared with K/L III

Both the irregularity index and WORMS exhibited strong negative correlations with JOA scores ($r = -0.77$, $p < 0.0001$; $r = -0.81$, $p < 0.0001$, respectively; Fig. 2), and moderate positive correlations with JKOM scores ($r = 0.41$, $p = 0.04$; $r = 0.49$, $p = 0.007$, respectively; Fig. 3).

WORMS and the irregularity index were positively correlated ($r = 0.70, p < 0.0001$, Fig. 4). Among the items comprising WORMS, the irregularity index showed statistically significant associations with bone cysts in the medial femorotibial joint (MFTJ), cysts in the tibial spine (S), and menisci (Table 2). MFTJ cartilage and bone cysts of the patello-femoral joint (PF) tended to be related to the irregularity index (Table 2).

Discussion

In order to evaluate the status of the OA knee, radiographic examination has played an important role up to now. However, several problems should be pointed out with the use of radiographic examination. Radiographic grading systems, including the K/L grading scale, frequently show

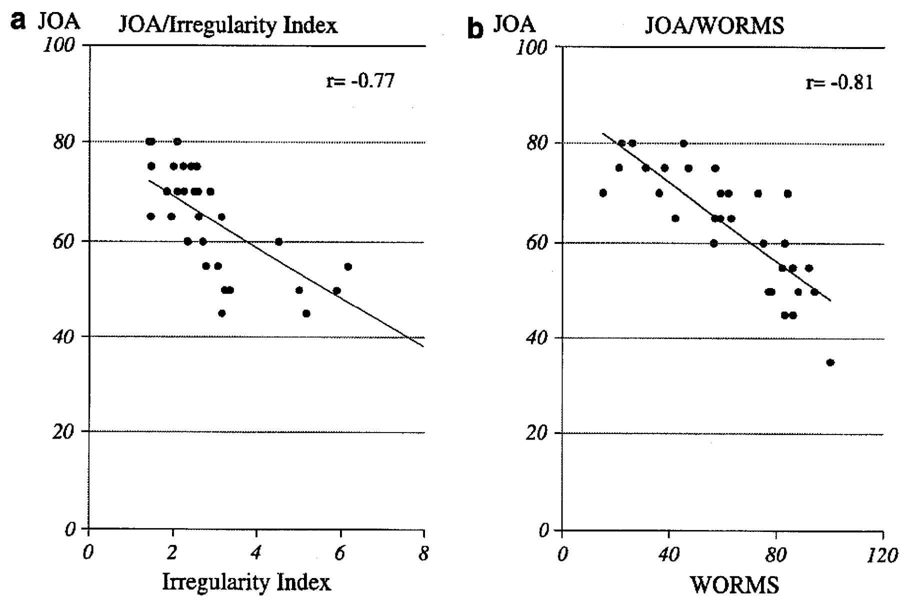

Fig. 2 Correlations between MRI scores and JOA scores. **a** Irregularity index scores and JOA scores. **b** WORMS and JOA scores. Both the irregularity index and WORMS had strong negative correlations with JOA scores. *JOA* Japanese Orthopaedic Association OA knee score

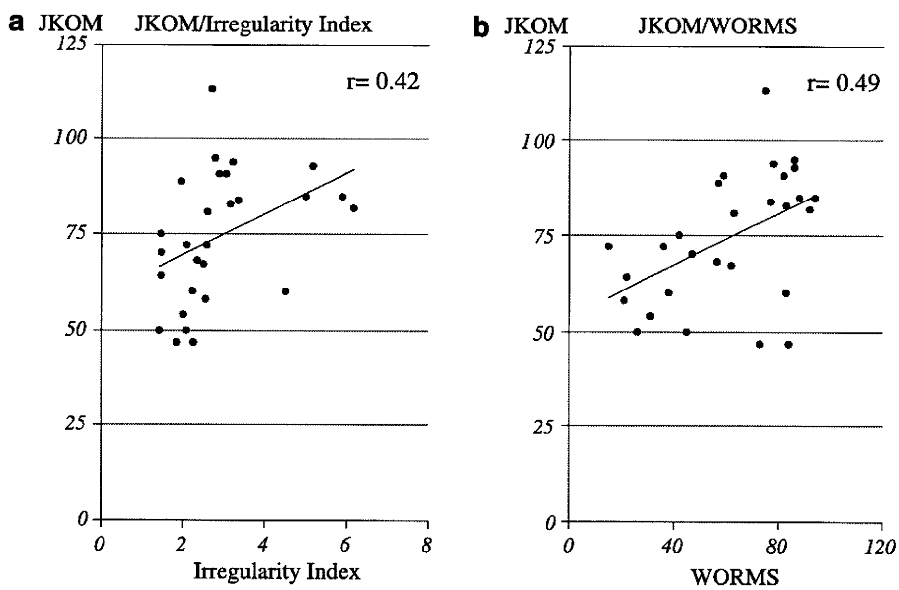

Fig. 3 Correlations between MRI scores and JKOM scores. **a** Irregularity index and scores JKOM scores. **b** WORMS and JKOM scores. Both the irregularity index and WORMS had moderate positive correlations with JKOM scores. *JKOM* Japanese knee osteoarthritis measure

discrepancies among observers [23–25]. Scott et al. reported inter- and intra- observer reliabilities, calculated using intraclass correlation coefficients, ranging from 0.63 to 0.83 and from 0.82 to 0.9 [5, 23], respectively, while Vilalta et al. [25] reported that the reliability among three observers was <0.5.

Another problem is the disparity between the severity of radiographic findings and patients' symptoms. This might be attributable to the fact that radiography cannot directly visualize non-ossified joint structures and that we are required to place all radiographs into 4 or 5 grades. In this study, although the K/L grades and the clinical scores showed significant differences between all grades based on JOA scores, we could not differentiate between grades III and IV based on JKOM scores. These results imply that a radiographic grading system, particularly in the severe K/L grades, would not reflect the clinical symptoms. Although it would not be easy to directly compare the results of X-ray grading and MRI scores, it appeared that the MRI scores were superior to X-ray grading, especially when monitoring the status of the knee joint over time and evaluating treatment efficacy, as they can detect small changes that have occurred in the knee joint. Both the irregularity index and WORMS would serve well for these purposes, as both of these are not simple grading systems and had good correlations with clinical scores.

Our main purpose in this study was to compare the irregularity index with WORMS, which has become recognized as one of the most reliable MRI systems to evaluate knee OA. Our results showed that the irregularity index had almost as good correlations as WORMS with both the JOA and the JKOM scoring systems. Thus, the irregularity index appeared to be as useful as WORMS for evaluating the OA knee.

Although both systems had similar correlations with clinical scores, the items or tissues to be assessed were quite different. Only the contour of the MFC was assessed with the irregularity index, whereas several tissues comprising the knee joint were taken into account by WORMS. In our previous study, an irregular contour of the MFC was found to correspond with histological changes that had occurred in subchondral bone [19]. Subchondral bone has become a current focus as an important factor for disease progression and as a possible source of pain in knee OA [26, 27]. Szebenyi et al. [2] reported an important relationship between pain and subchondral bone sclerosis. We have also focused on the relationship between the subchondral bone of the femoral condyle and clinical symptoms [28, 29]. Also, the histological changes that occurred in subchondral bone would not be independent of changes that occurred in overlying cartilage and adjoining bone marrow or menisci. Thus, the irregularity index could be representative of an involved compartment. The high correlation observed between the irregularity index and bone cysts of MFTJ and the menisci based on WORMS might support this idea. Dependence of items assessed in WORMS, such as high correlation between meniscal degeneration and cartilage degradation, might account for the unnecessity of assessing several tissues [30].

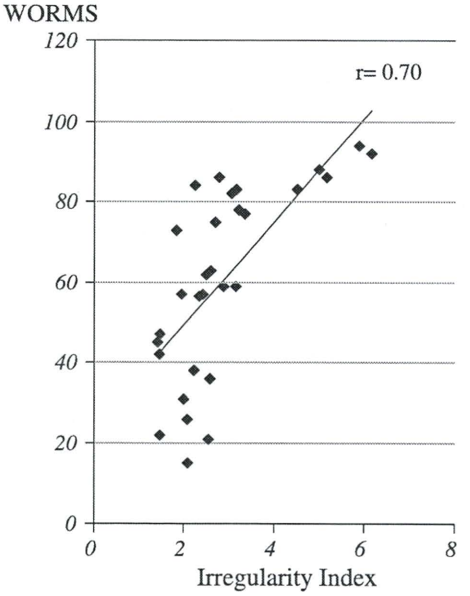

Fig. 4 Correlation between WORMS and the irregularity index. A good positive correlation was found between the two MRI-based evaluation systems

Comparing the two systems from a methodological standpoint, WORMS is a semi-quantitative method that is more complicated and less objective than the irregularity index because it scores 8 independent features in each of 15 different regions. In addition, WORMS requires specific MRI sequences to evaluate cartilage. Overall, the irregularity index system appears to have some advantages over WORMS. It is a quantitative method with semi-automatic computer calculations and can be used for evaluations using only sagittal fast spin echo (FSE) proton-density-weighted MR images, which are common in daily examinations.

Table 2 Irregularity index and items of WORMS (p values)

Items of WORMS	Irregularity index	Items of WORMS	Irregularity index
Cart_MFTJ	0.0973	Att_MFTJ	0.4803
Cart_LFTJ	0.4719	Att_LFTJ	0.3436
Cart_PF	0.1261	Att_PF	0.8892
Marrow_MFTJ	0.2337	Ost_MFTJ	0.522
Marrow_LFTJ	0.6084	Ost_LFTJ	0.5481
Marrow_PF	0.7026	Ost_PF	0.2071
Marrow_S	0.619	Menisci	0.0393*
Cyst_MFTJ	0.0036*	Ligaments	0.8248
Cyst_LFTJ	0.826	Synovitis	0.2876
Cyst_PF	0.0628		
Cyst_S	0.0021*		

Cart cartilage, *Marrow* marrow abnormality, *Cyst* bone cysts, *Att* bone attrition, *Ost* osteophytes, *MFTJ* medial femoro-tibial joint, *LFTJ* medial femoro-tibial joint, *PF* patello-femoral joint

* $p < 0.05$. Multiple regression analysis revealed that among the items of WORMS, bone cysts of the medial femorotibial joint (MFTJ), the tibial spine region (S), and menisci had statistically significant associations with the irregularity index ($p = 0.0036$, 0.0021 and 0.0393, respectively)

There are many methods for treating OA, from non-surgical treatments, such as non-steroidal anti-inflammatory drugs, disease-modifying OA drugs, rehabilitation, and insoles, to surgical treatments, including arthroscopic debridement, osteotomy, arthrodesis, and knee arthroplasty [31]. In order to assess the efficacy of these treatments, objective, reliable indices are required. MRI-based OA knee evaluations can potentially serve this purpose and will help to provide proper treatment options.

A few limitations should be pointed out concerning this study. Firstly, the number of knees assessed was too small, and a larger number of knees should be assessed for the above-mentioned purpose. Secondly, age-matched asymptomatic knees should be included to verify the meaning of MRI findings.

Conclusions

Both the irregularity index and WORMS had strong correlations with clinical scores. However, the irregularity index system may have advantages over WORMS because of its ease of implementation and its simplicity.

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Conflict of interest Authors do not have any conflict of interest with respect to the context of this paper.

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