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Radiological evaluation of joint space width in medial knee osteoarthritis

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Background. Although joint space width on weight-bearing radiographs of the knee is critical for early diagnosis and grading knee osteoarthritis, the optimal method with which to accurately measure this value remains controversial. The purpose of this study was to investigate and quantify the effects of the radiographic technique on joint space width in medial knee osteoarthritis.
Materials and Methods. We compared maximum plateau gaps and minimum joint space widths on bilateral weight-bearing plain radiographs acquired using three different methods in 31 patients with medial knee osteoarthritis (56 knee joints): standing with the knee extended (standard imaging); SynaFlexer method; and Rosenberg method. Measured values were compared statistically, with values of $P < 0.05$ considered significant.
Results. Maximum plateau gap in the medial compartment was significantly lower with the SynaFlexer method (3.2 ± 1.5 mm) and Rosenberg method (2.2 ± 1.2 mm) than with standard imaging (4.7 ± 2.2 mm; $P < 0.05$ each). Minimum width of the medial joint space was also significantly lower with the SynaFlexer method (3.1 ± 1.4 mm) and Rosenberg method (2.3 ± 1.4 mm) than with standard imaging (4.1 ± 1.4 mm; $P < 0.05$ each).
Conclusion. The Rosenberg method appears beneficial for diagnosing early knee osteoarthritis, while the SynaFlexer method seems more appropriate for assessing disease severity or progression in patients with painful intermediate to severe knee osteoarthritis.

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Key words: Radiograph; Osteoarthritis; Knee; Joint space width

Introduction

Knee osteoarthritis (OA) is one of the most common musculoskeletal disorders and represents a major cause of debilitation in affected individuals, particularly among the elderly [1-3]. Recent evidence has shown increases in the incidence of two risk factors for knee OA among younger patients – traumatic knee injury [4] and obesity [5]. Early diagnosis and strict evaluation of the severity of knee OA is therefore indispensable for applying appropriate treatments.

The diagnosis and classification of knee OA rely on the history and physical examination findings, and are often confirmed from radiological evaluation. One of the most critical pieces of radiological evidence is precise measurement of the thickness of the articular cartilage, along with identification of bone spurs (osteophytes), bony deformities and bone cysts [6]. Measuring joint space width (JSW) from weight-bearing radiographs can indirectly reflect total articular cartilage thickness of the knee joint and has been accepted as the primary structural outcome measure for the clinical setting

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of knee OA for decades [7]. However, multi-center trials have verified that the reproducibility of JSW acquired in the traditional weight-bearing position with full knee extension is inadequate [8,9]. Optimal alignment for measuring JSW is generally characterized by superimposition of the anterior and posterior margins of the tibial plateau [10]. In addition, the most obviously thinned region of articular cartilage is in the 30–60° posterior aspect of the femoral condyle, which is difficult to appropriately reflect on standard weight-bearing radiographs [11,12]. A critical need has thus emerged for accurate and precise radiographic quantitation.

Rosenberg et al. proposed taking radiographs in 45° of knee flexion as the most sensitive for evaluating the amount of cartilage loss [11]. However, the Rosenberg posture is difficult to maintain, especially for elderly patients with serious muscle weakness and knee joint pain. The plexiglass SynaFlexer frame allows reproducible positioning of the knee, with the patient only needing to place the feet in the foot supports and to touch the thighs to the vertical platform anteriorly (Figure 1)[10,13]. However, the accuracy and precision for JSW assessment with these methods have rarely been evaluated quantitatively.

The present study aimed to compare measured values derived from plain weight-bearing radiographs of the knee acquired using three different methods, and to investigate individually targeted optimal radiographic quantitation to evaluate knee OA.

Figure 1. SynaFlexer™
The plexiglass frame for standardizing knee and foot positions.

Materials and Methods

A total of 31 patients (56 knee joints) with primary medial knee OA qualified for inclusion based on clinical and radiographic evidence of chronic knee pain classified as Osteoarthritis Research Society International grade 1 or 2 [14]. Radiographic evidence, such as bone spurs (osteophytes), bony deformities and bone cysts, and thickness of the articular cartilage were evaluated for patients in standing images using standard methods. Exclusion criteria included evidence of other types of arthritis, such as previous trauma, surgical intervention, or treatment with corticosteroids. Participants included 23 female patients (40 knee joints) and 8 male patients (16 knee joints), and mean age was 67.3 years (range: 41–84 years) (Table 1). All patients were seronegative for rheumatoid factor and had erythrocyte sedimentation rates within the normal range.

Bilateral standing femorotibial radiographs were taken using a high-voltage KXO-80G system (Toshiba, Tokyo, Japan) and a beam-limiting device (TF-6TL-6; Toshiba) under the following conditions: tube voltage, 50 kV; tube current, 100 mA; exposure time, 0.1 s; and image distance (roentgen beam-cassette distance), 100 cm. All imaging was performed by the same radiology technician under uniform conditions. Three different radiographic methods were adopted for imaging: standardized radiographic method (standard imaging group) and two semi-flexed techniques, comprising the SynaFlexer method (SynaFlexer group) and the Rosenberg method (Rosenberg group). Standard imaging was performed with the patient standing upright with knees fully extended and feet parallel. The X-ray beam was focused antero-posteriorly directly over the midpoint of the femorotibial joint and directed horizontally (Figure 2a). In the SynaFlexer group, semi-flexed posteroanterior (PA) radiographs were taken with the SynaFlexer™ (Synarc, San Francisco, CA), a commercially available plexiglass frame to standardize knee flexion and foot positioning [10,13]. This frame allows convenient, reproducible positioning of the knee for serial examinations without a need for creation and storage of foot maps. The feet were externally rotated 10°, and the thighs touched the vertical platform anteriorly, resulting in a fixed knee flexion of approximately 20°. The X-ray beam was angled 10° caudally (Figure 2b). In the Rosenberg group, PA radiographs were taken basically according to the original Rosenberg method [11]. Both knees were radiographed with weight equally distributed, and knees flexed 45° (Figure 2c). The patellae were touching the radiation cassette and the radiograph beam was centered at the level of the inferior poles of the patellae. In the original Rosenberg method, the X-ray beam was directed 10° caudad.

We finely adjusted X-ray beam angles with reference to the angle between the axis of the fibula and the medial tibial plateau in the lateral view of the knee. All images acquired from the three different radiographic methods were converted to Digital Imaging and Communications in Medicine format. After delineating the contours of the medial and lateral compartments of the femur and tibial plateaus, maximum plateau gap (distance between the anterior and posterior margins of the tibial plateau) and minimum JSW between opposing weight-bearing subchondral cortical surfaces were measured using image analyzing software (POP-Net Essential, version 4.2C; image ONE, Tokyo, Japan) (Figure 3). Three observers evaluated radiographs from each patient twice at a minimal interval of 2 weeks. Intra-observer reliability was assessed based on evaluations by the first author, and inter-observer reliability was assessed based on evaluations between the first and second authors. Readers were blinded to initial measurements, and mean values were taken as the measured values.

Reproducibility and intra-observer reliability of measurements were estimated using the intra-class correlation coefficient and Pearson's correlation coefficient. Parameters (plateau gap and JSW) were compared among the three methods using one-way analysis of variance and Tukey-Kramer and Bonferroni/Dunn post-hoc multiple comparison tests. Significance was defined at the $P < 0.05$ level.

This study was approved by the ethics review board of Wajinkai Hospital (approval no. 2017-2301), and the objectives of the investigation were explained in detail in writing and verbally to all participants. Informed consent was obtained from each patient prior to enrolment and all agreed with having their data published.

Table 1 Physical characteristics of the study participants

	Male	Female
Age	62.6 (41 - 74)	69.0 (50 - 84)
Hight (cm)	167.1 (160 - 176)	154.7 (145 - 162)
Body weight (kg)	70.8 (57 - 100)	62.6 (48 - 115)
BMI (Body Mass Index) (kg/m^2)	25.2 (19.7 - 32.4)	26.0 (21.4 - 44.0)

a b c

Figure 2. Acquisition of radiographs
Standard imaging method (a), SynaFlexer method (b) and Rosenberg method (c).
X-ray beam was directed anteroposteriorly in the standard imaging method, and posteroanteriorly in the SynaFlexer and Rosenberg methods.

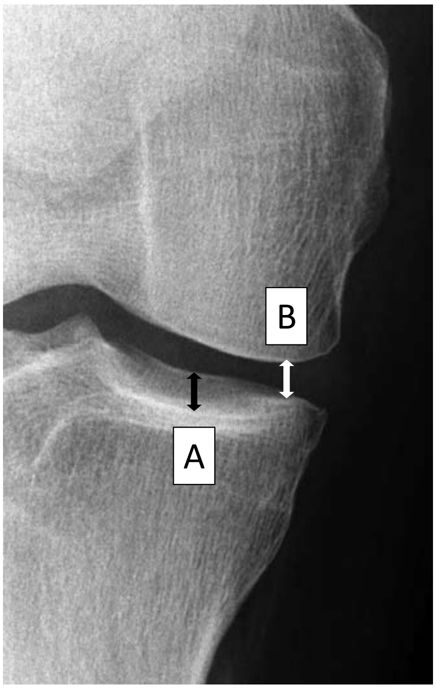


Figure 3. Methods of measuring plateau gap and joint space width Maximum plateau gap (A) and minimum joint space width (B). Both values are measured parallel to the tibial axis.

Results

For plateau gap, the intra-class correlation coefficient and Pearson's correlation coefficient were 0.894 and 0.874 – 0.948, respectively. For JSW, the intra-class correlation coefficient and Pearson's correlation coefficient were 0.914 and 0.876 – 0.945, respectively. Table 2 shows mean values and standard deviations of maximum plateau gaps and minimum JSWs for each method. Mean plateau gaps in the medial compartment were significantly smaller for the SynaFlexer group (3.2 ± 1.5 mm) and Rosenberg group (2.2 ± 1.2 mm) than for the standard imaging group (4.7 ± 2.2 mm, P = 0.004 and P = 0.002, respectively). In particular, the Rosenberg group showed the lowest value among the three groups (P = 0.036). Meanwhile, JSW of the medial compartment was significantly smaller for both semi-flexed groups (SynaFlexer group, 3.1 ± 1.4 mm; Rosenberg group, 2.3 ± 1.4 mm) than for the standard imaging group (4.1 ± 1.4 mm, P = 0.002 and P = 0.001, respectively). JSW was also smaller in the Rosenberg group than in the SynaFlexer group (P = 0.034). On the other hand, no significant differences in plateau gap or JSW were seen in the lateral compartment of the knee joint among the three groups.

Discussion

For the diagnosis of early knee OA or the assessment of disease severity, accurate and precise values of articular cartilage thickness are critical. Magnetic resonance imaging can directly visualize joint cartilage and provide accurate measurements of cartilage volume, thickness, and surface area [15, 16]. However, magnetic resonance imaging requires a large accommodation space and specially dedicated technicians, and may cause distress in claustrophobic patients. JSW from plain X-ray is therefore generally accepted as the most reliable value of articular cartilage thickness [7]. Several studies, however, have verified that the reproducibility of JSWs obtained from traditional weight-bearing radiographs in full knee extension is inadequate [9, 17], because of the separation between anterior and posterior margins of the tibial plateau [10]. Moreover, a pathological study by Messieh et al. [18] indicated that most OA cartilage destruction occurs in posterior sites of the femoral condyle. JSW in patients with knee OA might thus be much smaller on radiographs acquired with the knee in various degrees of flexion [18, 19].

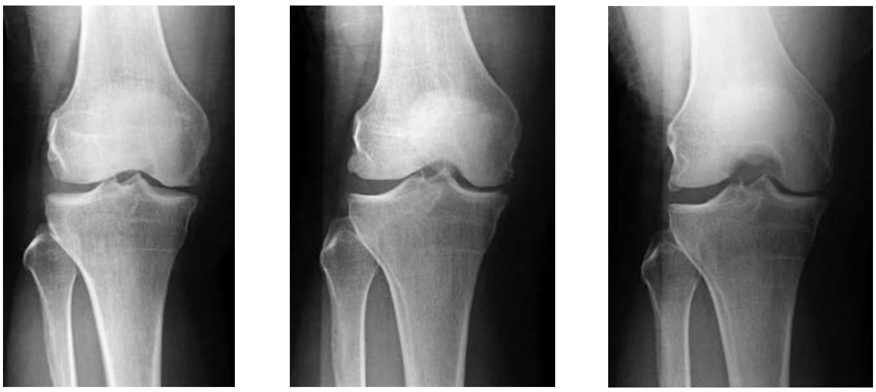
The present study assessed femorotibial JSW in patients with knee OA and investigated discrepancies among three radiographic methods. Plateau gap and JSW were significantly smaller in the same patients with medial knee OA assessed using the SynaFlexer and Rosenberg methods than with the standard imaging method (Figure 4). An increased plateau

Table 2 Comparisons of plateau gap and joint space width among the three methods
[a] $P < 0.05$ compared to the standard imaging group
[b] $P < 0.05$ compared to the SynaFlexer group

(mm)		Standard imaging	SynaFlexer	Rosenberg
Plateau gap	medial	4.7 ± 2.2	3.2 ± 1.5[a]	2.2 ± 1.2[a,b]
	lateral	2.0 ± 1.9	1.4 ± 1.3	1.2 ± 1.0
Joint space width	medial	4.1 ± 1.4	3.1 ± 1.4[a]	2.3 ± 1.4[a,b]
	lateral	4.4 ± 1.8	4.2 ± 1.2	4.0 ± 1.6

gap might lead to reduced accuracy of JSW measurements [8, 10]. Superimposition or closing the distance between these two margins (small plateau gap) is thus indispensable for precise JSW measurements. Decreased JSW in the knee flexion methods is consistent with arthroscopic findings showing that OA cartilage destruction is evident at posterior sites of the femorotibial joint [11, 12]. Matsuda et al. [20] reported that the medial tibial plateau in the Japanese population is inclined posteriorly by approximately 10°. In the present study, plateau gap and JSW of the medial compartment were significantly smaller in the Rosenberg group than in the other groups. Piperno et al. [9] suggested that the Lyon schuss view, as a variant of the Rosenberg method, can also provide visualize evidence of osteophytosis, which is helpful for diagnosing early OA. For these reasons, images of a flexed knee (such as in the Rosenberg method) are currently considered more sensitive in screening for early knee OA and for evaluating the severity of pathology compared to traditional weight-bearing radiographs [9, 21]. However, several problems remain with the Rosenberg method. For example, most patients suffering from severe knee OA cannot flex the knees to 45°, and even if they can, knee pain often prevents maintenance of such a position for long enough to take adequate radiographic images [22]. The plexiglass SynaFlexer frame, on the other hand, standardizes knee flexion and foot positioning. Charles et al. [10] and Kothari et al. [13] reported that the SynaFlexer frame allows convenient, reproducible positioning of the knee and engagement of the most damaged femoral articular cartilage to produce images of similar quality to those from the Rosenberg view. The patient only needs to place the feet in the foot supports and touch the thighs to the vertical platform anteriorly to allow highly reproducible examinations even in elderly patients with joint contracture and pain. Although sensitivity was inferior to that from Rosenberg images, plateau gap and JSW of the medial compartment on SynaFlexer images in the present study were significantly smaller than those from traditional standard images. A small plateau gap means that the X-ray beam is aligned more parallel to the tibial plateau. The present findings indicate that the Rosenberg method is ideal to diagnose early knee OA in relatively young and mildly symptomatic patients, whereas the SynaFlexer method is more appropriate for assessing disease severity or progression in patients with painful intermediate to severe knee OA.

Several limitations must be considered when interpreting the results of the present study. No significant positive differences in plateau gap or JSW of the lateral femorotibial joint were identified. All patients included in this study were diagnosed with mild to intermediate medial knee OA (Osteoarthritis Research Society International grade 1 or 2), so further research that includes patients with Osteoarthritis Research Society International grade 3 or higher or lateral knee OA is warranted. In addition, multiple regression analysis could not be performed due to the small number of patients. A study of a larger cohort including patients with lateral knee OA should be performed in the future. Nonetheless, the present findings provide valuable information on measuring JSW using different imaging methods, and should have an impact on clinical approaches to the diagnosis and assessment of knee OA severity.



a b c

Figure 4. Representative X-rays from a 62-year-old woman acquired using the three methods
a) Standard imaging method: plateau gap: medial 4.4 mm, lateral 3.2 mm; joint space width; medial 3.5 mm, lateral 5.4 mm. b) SynaFlexer method: plateau gap; medial 3.2 mm, lateral 2.1 mm; joint space width; medial 3.1 mm, lateral 3.9 mm. c) Rosenberg method: plateau gap: medial 2.9 mm, lateral 1.2 mm; joint space width; medial 2.3 mm, lateral 3.8 mm.

Conclusions

We compared the plateau gap and JSW of 56 knees with medial knee OA on radiographs acquired using three different methods of bilateral weight-bearing radiography: standard imaging; SynaFlexer; and Rosenberg method. Maximum plateau gap and minimum JSW of the medial compartment were significantly lower using the SynaFlexer and Rosenberg methods, compared to standard imaging ($P < 0.05$). The Rosenberg method appears beneficial for diagnosing early knee OA, while the SynaFlexer method seems more appropriate for assessing disease severity or progression in patients with painful intermediate to severe knee OA.

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Declarations

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Conflict of interest / Competing interests

Yuta Nishiyama, Hironobu Koseki, Chieko Imai, Takayuki Shida, Shinya Sunagawa, Masanori Yamaguchi, Umi Matsumura, Hitoshi Iwanaga declare that they have no conflicts of interest or competing interests. All authors have not and will not receive benefits or funding from any commercial party directly or indirectly related to the subject of this article.

Availability of data and material

The authors do not wish to share the data because the dataset is part of ongoing study protocols.

Code availability

Not applicable.

Authors' contributions

All authors substantially contributed to this article. YN and HK conceived and designed the study. YN, HK, CI, TS, SS, MY, and UM participated in the experiments and gathered data. YN, CI, TS, and HI analyzed and interpreted the data. YN initially drafted the manuscript, and HK and HI statistically analyzed and ensured the accuracy of the data. All authors have read and approved the final version of the manuscript and affirm that the work has not been submitted or published elsewhere in whole or in part.

Ethics approval

All procedures in studies involving human participants were performed in accordance with the ethical standards of the institutional and/or national research committee and in line with the 1964 Declaration of Helsinki and its later amendments or comparable ethical standards. This study was approved by the ethics review board of Wajinkai Hospital (approval no. 2017-2301). The nature of the study was thoroughly explained to each patient, and all patients provided written, informed consent prior to participation.

Consent for publication

Not applicable.

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