



OPEN Comparison of the maximum standardized uptake value and magnetic resonance imaging characteristics between temporomandibular joint osteoarthritis and osteoarthritis

Jae-Young Kim^{1,2}, Chaeyeon Lee², Jae-Hoon Lee^{3,4}, Young Hoon Ryu^{3,4}, Min-Jun Kang^{1,2}, Hye-Sun Kim^{1,2} & Jong-Ki Huh^{1,2}✉

Osteoarthritis (OAI) and osteoarthritis (OAO) are subsets of degenerative joint diseases affecting the temporomandibular joint (TMJ), distinguished by the presence of joint pain. However, clinical diagnosis based on pain alone is challenging. This study aimed to differentiate OAI from OAO using imaging modalities, including single-photon emission computed tomography (SPECT-CT) and magnetic resonance imaging (MRI). Data from 65 patients (98 joints) who underwent MRI and SPECT-CT between January 2017 and December 2022 at Gangnam Severance Hospital were retrospectively analyzed. Patients were divided into the OAI and OAO groups based on the presence of TMJ pain and bony changes on MRI. Univariate and multivariate binary logistic regression analyses were performed to identify significant risk factors for two diseases. The maximum standardized uptake value (SUVmax) on SPECT-CT and disc shape on MRI were significantly different between the groups. Combining these two variables provided the highest diagnostic accuracy (area under the curve [AUC] = 0.889) compared with SUVmax or disc shape alone (AUC = 0.846 and AUC = 0.752, respectively). There was significant difference in AUC between disc shape and SUVmax + disc shape ($p = 0.023$). These findings suggest that the combination of SPECT-CT and MRI findings improves the differentiation between OAI and OAO.

Keywords Osteoarthritis, Osteoarthritis, Temporomandibular joint, Degenerative joint disease, MRI, SPECT-CT

Osteoarthritis (OAI) and osteoarthritis (OAO) are subsets of degenerative joint diseases (DJD) affecting the temporomandibular joint (TMJ) that are distinguished by the presence of joint pain. However, the sensitivity and specificity of clinical criteria alone for diagnosing TMJ OAI are low^{1,2}. In 2014, a group comprising several prominent researchers published improved diagnostic criteria for the temporomandibular joint (DC/TMD) based on the existing research diagnostic criteria for temporomandibular disorder³. However, precise diagnostic criteria for distinguishing OAI from OAO have not been established.

DJD is diagnosed based on morphological changes such as flattening, sclerosis, erosion, or osteophyte formation in the mandibular condyle or the presence of subcortical bone cysts on imaging studies such as computed tomography (CT), cone-beam CT, and magnetic resonance imaging (MRI)^{4–6}. Among patients with DJD findings on imaging studies, those with and without arthralgia, are diagnosed with OAI and OAO, respectively³.

Wahaj et al.⁵ reported that bone marrow edema observed on MRI is helpful for diagnosing OA. However, other researchers have reported that cone-beam CT is an effective examination method that is cost-effective

¹Department of Oral and Maxillofacial Surgery, Yonsei University College of Dentistry, Seoul, Republic of Korea.

²Department of Oral and Maxillofacial Surgery, Yonsei University Gangnam Severance Hospital, Seoul, Republic of Korea. ³Department of Nuclear Medicine, Yonsei University College of Medicine, Seoul, Republic of Korea.

⁴Department of Nuclear Medicine, Yonsei University Gangnam Severance Hospital, Seoul, Republic of Korea. ✉email: OMSHUH@yuhs.ac

compared to CT and is more appropriate than MRI for evaluating bony changes^{7,8}. Thus, identifying a single imaging study that is effective for TMJ OA diagnosis is difficult. Recently, efforts have been made to diagnose TMJ-OA using nuclear medicine^{9,10}. Seo et al. (2016)¹¹ reported that the use of the maximum standardized uptake value (SUVmax) in single-photon emission computed tomography (SPECT)-CT can be helpful in the diagnosis of arthralgic TMJ.

This study aimed to evaluate the usefulness of SPECT-CT and MRI for differentiating between OAI and OAO.

Materials and methods

Participants

Patients with chief complaints of pain or discomfort in the TMJ area who visited the Department of Oral and Maxillofacial Surgery, Gangnam Severance Hospital, Yonsei University (Seoul, Korea) between January 2017 and December 2022 were included in this retrospective study. MRI and SPECT-CT were performed at the Department of Radiology and Nuclear Medicine of the same hospital after clinical evaluation. OAO and OAI were diagnosed based on previous studies, including the DC/TMD classification and the clinical features of Wilkes classification stage IV or stage V^{3,12–14}. The OAI and OAO groups included patients with bony changes on MRI with and without TMJ pain based on palpation of joint, respectively. That is, if there was pain during joint palpation, it was diagnosed as OAI, and if there was no pain during joint palpation or referral pain during masticatory muscle palpation, it was diagnosed as OAO.

The exclusion criteria were as follows: (1) interval between MRI and SPECT-CT > 6 months; (2) history of radiation therapy to the head and neck; (3) diagnosis of rheumatoid arthritis; (4) history of maxillofacial trauma or surgery, including the TMJ; and (4) bone changes on MRI without pain or with pain in the masticatory muscles rather than the joint area.

This study was approved by the Institutional Review Board of Gangnam Severance Hospital (approval no. #3-2024-0273), and the requirement for written informed consent was waived. This study complied with the tenets of the Declaration of Helsinki.

MRI Parameters.

TMJ MRI was performed using a 3.0-T Magnetom scanner (Achieva; Philips Medical Systems, Best, The Netherlands) with 3-inch surface coils. MRI conditions were identical to those in our previous study¹⁵. Briefly, for T1-weighted imaging, the following parameters were used: repetition time, 450 ms; echo time, 20 ms; slice thickness, 3 mm; field of view, 120 mm; and acquisition matrix size, 240 × 240. The parameters for T2-weighted imaging were as follows: repetition time, 2900 ms; and echo time, 90 ms.

MRI Evaluation.

The disc morphology, relationship between the disc and condyle, bone marrow signal, fluid collection, and joint space were analyzed using MRI based on a previous study¹⁵. MRI findings were interpreted by the consensus of two oral and maxillofacial surgeons (J.Y. Kim and J.K. Huh) with 15 and 30 years of experience, respectively.

Disc shape

The disc shape on closed-mouth images was categorized as biconcave, folded, flattened, eyeglass, or amorphous (Fig. 1). A “biconcave” disk was defined as a disk with structure and position within normal limits (WNL). Discs with a cap or cup shape, (∩- or U-shaped) without shortening in length on the anterior band, intermediate zone, and posterior band, were classified as a “folded”. Discs with a biplanar shape and loss of voluminous configuration of the anterior band, posterior band, or both were classified as “flattened”. Discs with anteroposterior shortening were classified as having an “eyeglass” shape. Deformed discs in which the configuration could not be distinguished were classified as “amorphous.” The higher category was recorded for discs with anterolateral or anteromedial displacement and those with more than two shapes^{16,17}.

Relationship between the disc and condyle

The positional relationship between the disc and condyle was classified into the following three types (Fig. 2): normal, anterior disc displacement with reduction, and anterior disc displacement without reduction.

Bone marrow signal

Bone marrow signal (BMS) was classified as “WNL” or “Low” compared to that of the ipsilateral ramus or body of the mandible based on the signal intensity on T1-weighted images. (Fig. 3)

Joint effusion

Joint effusion was evaluated on T2-weighted images. Based on previous studies, it was classified into three types according to the amount of fluid collected (Fig. 4): G0, no fluid collection or only a thin line of high signal intensity;¹⁸ G1, fluid collection within the boundary of the disc; G2, moderate to large amount of fluid collection beyond the disc boundary or capsular expansion^{15,19}.

Joint space

The joint space was classified into three categories: “normal,” “narrowed,” and “bone-to-bone contact.” (Fig. 5) Narrowing was defined as insufficient space for the disc between the condyle and fossa. Bone-to-bone contact was defined as complete or almost complete contact between the cortices of the condyle and fossa with no space between them on a closed-mouth image.

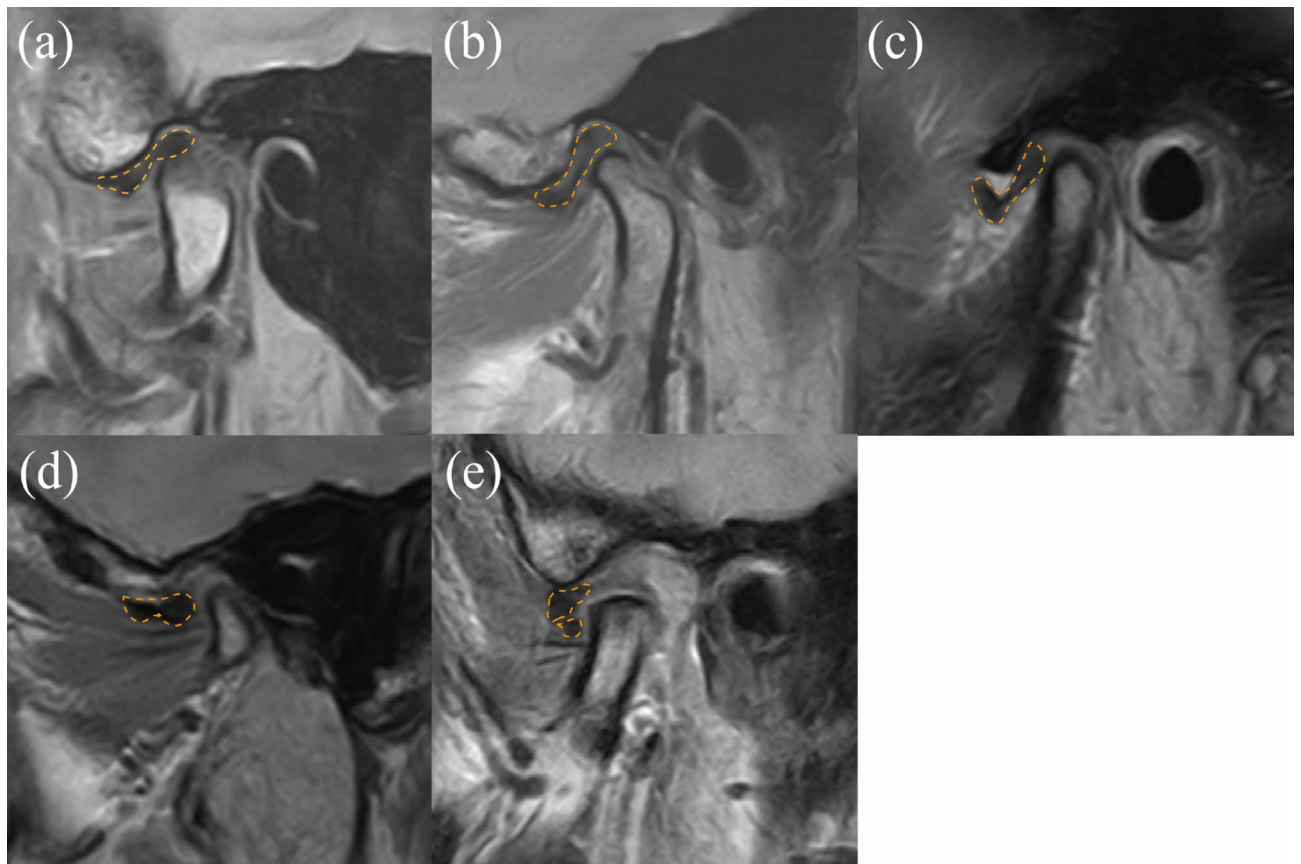


Fig. 1. Disc shapes (dotted lines) (a) Biconcave; (b) Flattened; (c) Folded; (d) Sunglass; (e) Amorphous.

SPECT-CT parameters

The parameters of SPECT-CT was based on our previous study²⁰. SPECT-CT was conducted using the Symbia Intevo16 system (Siemens Healthineers, Erlangen, Germany). The scan covered the area from the top of the head to the lung apex, performed 3 h after administering 740 MBq of ^{99m}Tc-hydroxydiphosphonate. The imaging parameters included a 3° rotation per step, 20 s of acquisition time per projection, and a 512 × 512 matrix size. For the CT scan, low-dose images were acquired with settings of 110 kV and 120 mA, incorporating adaptive dose modulation. The reconstructed images were processed using xSPECT Quant and xSPECT Bone software (Siemens Healthineers, Erlangen, Germany) for high-resolution analysis and quantification²⁰.

For each participant, regions of interest (ROIs) were manually delineated on the CT component of fused SPECT/CT images to quantify radiotracer uptake in TMJ. A spherical ROI of a 30-mm diameter was placed at the center of the mandibular condyle, carefully adjusted on axial and coronal CT images to include all relevant anatomical structures of the TMJ. The ROI was optimized to sufficiently cover the area with the highest radiotracer uptake while avoiding surrounding non-target tissues. The standardized uptake value (SUV) was calculated as follows: $SUV = (\text{decay-corrected activity [kBq/mL]} / (\text{injected activity [kBq]} / \text{body weight [g]}))$. SUVmax was defined as the highest voxel value within each ROI. Two nuclear medicine physicians (J.H. Lee and Y.H. Ryu) independently measured SUVmax for both left and right TMJs using the open-source software LIFEx (version 7.4.6; LIFEx, RRID: SCR_025284, www.lifexsoft.org²¹). Any discrepancies between the observers were resolved by consensus through a joint review of the images. Half of the patients were randomly selected to calculate inter-observer agreement.

Statistical analysis

The data were analyzed using SAS ver 9.4 (SAS Institute, Cary, NC, USA), SPSS (version 27.0; SPSS Inc., Chicago, IL, USA) and the R Statistical Package version 4.4.2 (Institute for Statistics and Mathematics, Vienna, Austria; www.R-project.org). Intraclass correlation coefficient was analyzed. Cut-off value for SUVmax was calculated using the Youden Index, and the receiver operating characteristic (ROC) curves were constructed, and the areas under the curves (AUC), sensitivity, specificity, accuracy, PPV, and NPV was calculated. Number of joints between OAI and OAO based on SUVmax cut-off value was analyzed using chi-square test. Univariate and multivariate binary logistic regression analyses were performed to identify the risk factors for OAI and OAO. Multivariate regression analysis was conducted in a stepwise manner. AUC were compared with multiple comparison by Bonferroni correction. Statistical significance was set at $p < 0.05$.

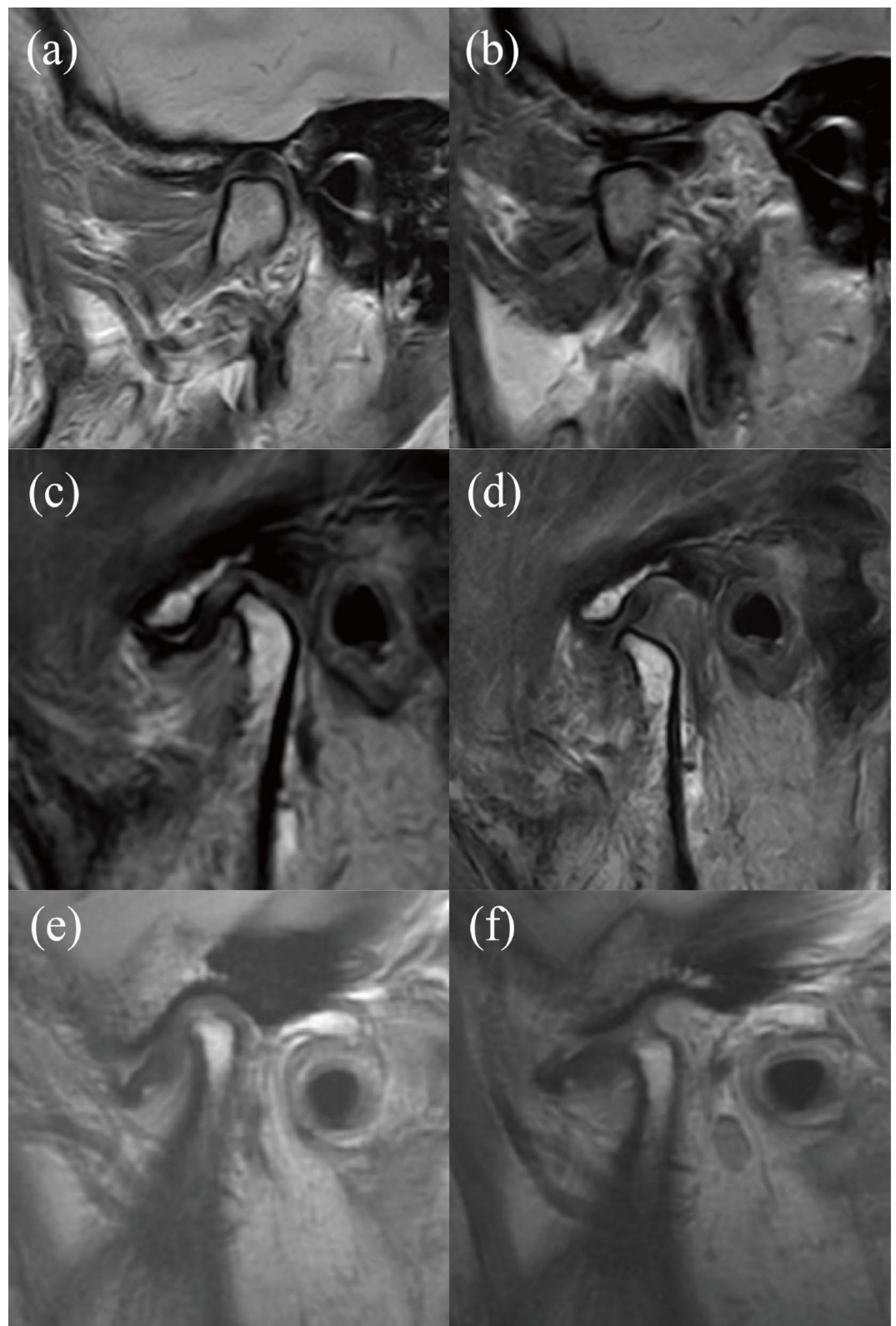


Fig. 2. Relationship between the disc and condyle. (a, b) Normal disc position; (c, d) Anterior disc displacement with reduction; (e, f) Anterior disc displacement without reduction.

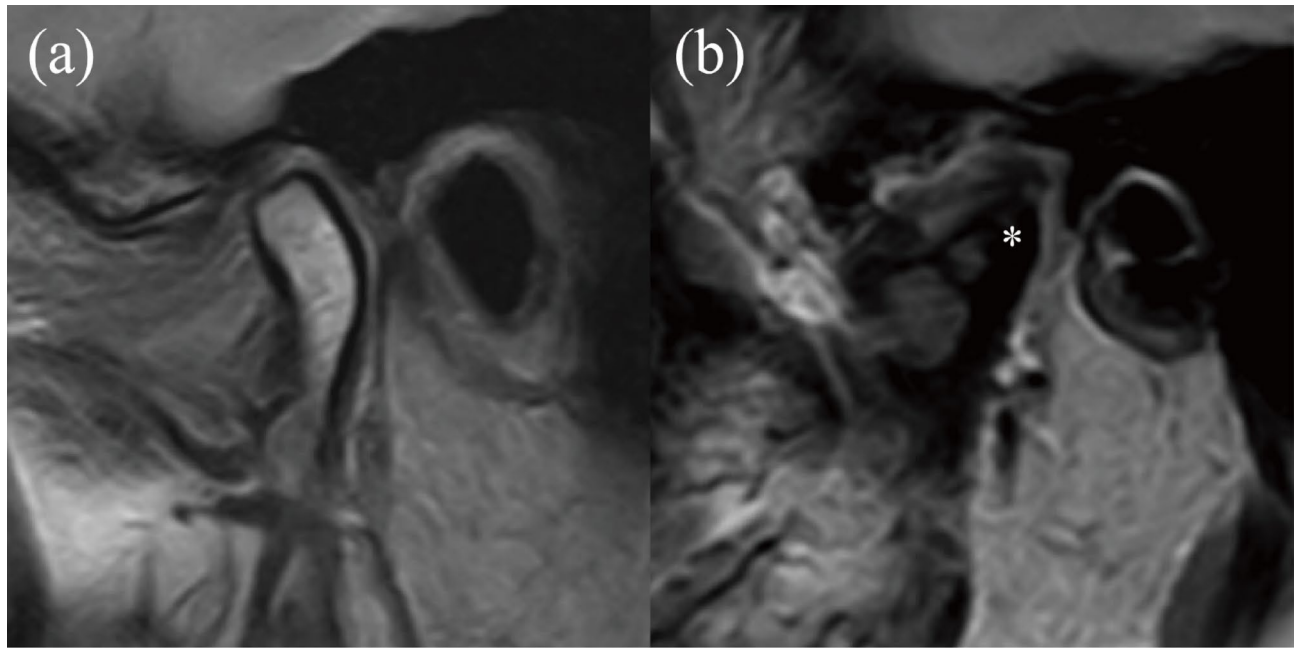


Fig. 3. BMS¹⁵ (a) The signal intensity of the condyle is similar that of the ramus, indicating normal BMS; (b) the asterisk indicates low BMS. BMS Bone marrow signal.

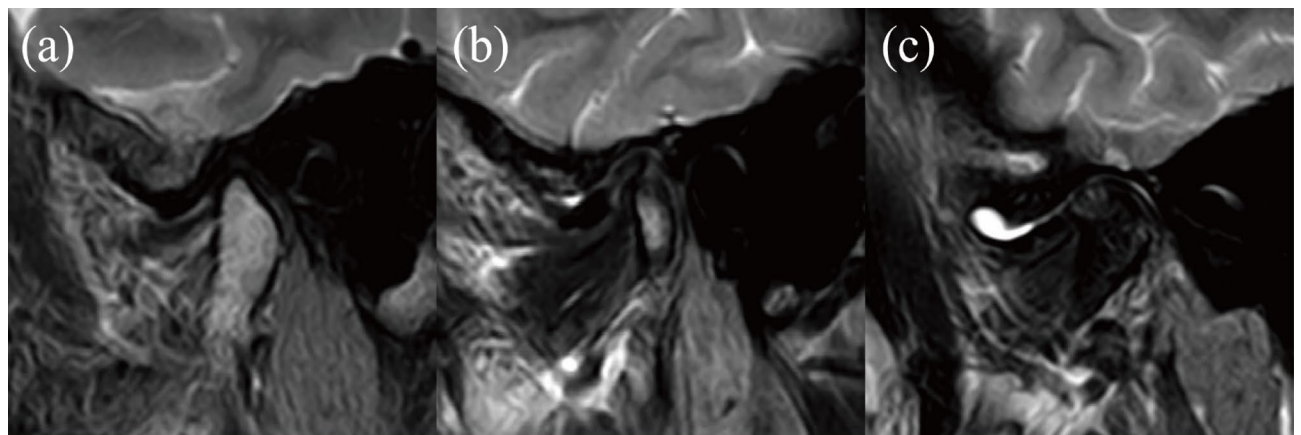


Fig. 4. Fluid collection. (a) No fluid collection (G0); (b) Small amount of fluid collection is observed within the boundary of the disc (G1); (c) Moderate to large amount of fluid collection beyond disc boundary with capsular expansion (G2).

Results

This study included 65 patients (98 joints). The OAI and OAO groups included 62 joints (51 patients; 5 men and 46 women; age, 45.96 ± 17.35 years) and 36 joints (28 patients; 2 men and 26 women; age, 45.00 ± 17.32 years), respectively. Sixteen patients were diagnosed with OAI on one side and OAO on the other; therefore, they were included in both groups. Table 1 presents a comparison of the clinical characteristics between the groups. The inter-observer agreement for SUVmax measurements was excellent, showing an intraclass correlation coefficient of 0.973 (95% CI: 0.956–0.983).

The optimal cut-off based on SUVmax to distinguish OAI and OAO was 5.64. The AUC was 0.850 (95% confidence interval (CI) 0.770–0.920) with sensitivity, 0.66 (95% CI 0.54–0.78); specificity, 0.94 (95% CI 0.87–1.00); accuracy, 0.77 (95% CI 0.68–0.85); positive predictive value (PPV), 0.95 (0.89–1.00); and negative predictive value (NPV), 0.62 (95% CI 0.49–0.75). There thirty-four out of 36 (94.44%) whose SUVmax was under 5.64 in OAO group, whereas 41 out of 62 (66.13%) patients whose SUVmax was over 5.64 in OAI group ($p < 0.001$). They are summarized in Table 2.

In the univariate logistic regression analyses, all variables except BMS showed significant differences between the OAO and OAI groups. In multivariate logistic regression analysis ($R^2 = 0.562$), SUVmax and disc shape were

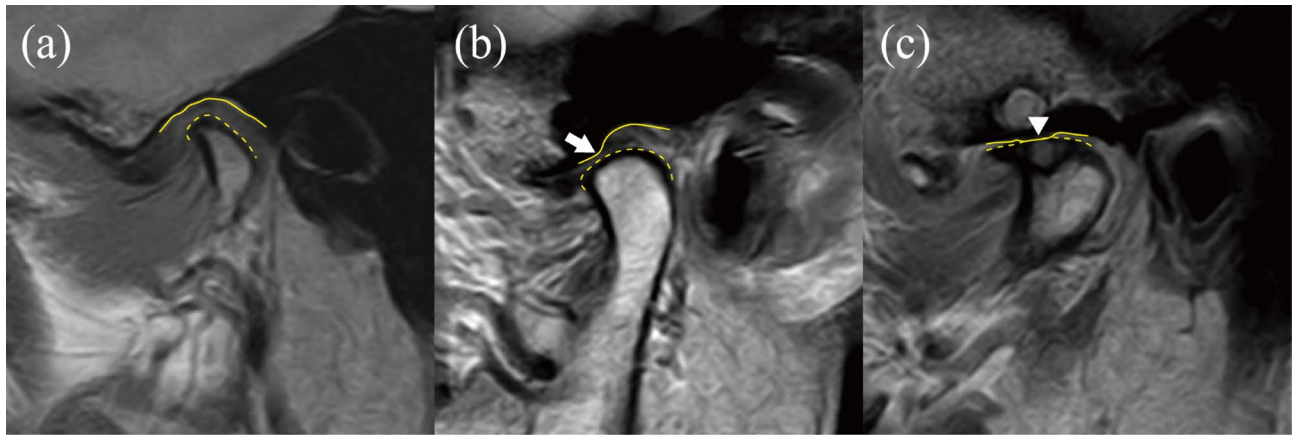


Fig. 5. Joint space¹⁵. (a) Normal; (b) Narrowed (white arrow); (c) Bone to bone contact (white arrowhead). The dotted and solid yellow lines indicate the condyle and temporal bone, respectively.

risk factors for OAI but not for OAO. Particularly, a 1-point increase in SUVmax increased the risk of OAI by 2.11 times. (Table 3)

The AUC for the disc shape was the lowest (0.752; range, 0.651–0.854), and the AUC for SUVmax was 0.846 (range, 0.771–0.921). However, the AUC was the highest (0.889; range, 0.825–0.952) when SUVmax and disc shape were considered simultaneously (SUVmax + disc shape). AUCs were not significantly different between disc shape and SUVmax ($p=0.391$) and between SUVmax and SUVmax + disc shape ($p=0.125$). However, there was significant difference in AUC between disc shape and SUVmax + disc shape ($p=0.023$). (Fig. 6)

Discussion

In the DC/TMD published in 2014, OAO and OAI were classified separately as subsets of DJD³. The two diseases are distinguished by the presence of arthralgia; nonetheless, some studies use the two terms interchangeably, and the distinction is ambiguous even in the field of orthopedics²². Furthermore, a complaint of pain can cause confusion in diagnosis.

In this study, disc shape alone had the lowest predictive power (0.752; range, 0.651–0.854), whereas SUVmax had a slightly higher power (0.846; range, 0.771–0.921). The highest predictive power (0.889; range, 0.825–0.952) was achieved when SUVmax and disc shape were considered simultaneously. Nuclear imaging study itself is a good modality for diagnosis of osteoarthritis^{20,23}. Therefore, when considering the AUC value, it is thought that using the SUVmax value in SPECT-CT would be helpful to distinguish between OAI and OAO. The optimal SUVmax cut-off for differentiating OAI and OAO was 5.64. In particular, 34 out of 36 joints diagnosed with OAO showed SUVmax values below 5.64. Therefore, cases diagnosed below the cut-off value are interpreted as having a higher possibility of osteoarthritis than osteoarthritis. In addition, we suppose that a combination of SUVmax on SPECT-CT and disc shape on MRI is more effective than a single imaging test. This is consistent with the results of Hussain et al. (2008)⁸ that using multiple tests comprehensively, rather than a single imaging test, is more accurate for diagnosing erosion and osteophytes.

Several studies have investigated the relationship between TMJ pain and MRI findings. Although some studies have reported a correlation between MRI features and TMJ pain^{24,25}, others have shown that MRI signs of OAI do not always coincide with the cause of pain^{26,27}. Higuchi et al. (2020)²⁸ reported a significant correlation between reduced anterior disc displacement and joint effusion, and TMJ pain, which is similar to our results. However, MRI alone has several limitations in diagnosing TMJ-OA. Particularly, differentiating between OAI and OAO, which are diagnosed based on pain, is difficult. Toshima et al.²⁶ analyzed several characteristics of patients with OAO with bone changes on MRI. In this study, TMJ pain was not significantly correlated with bone changes. Thus, determining the presence of TMJ pain based on bone changes alone was difficult, and other tests were necessary.

Nuclear medicine can be used to evaluate active lesions relatively early because it reflects the bone metabolism. Among various nuclear medicine examinations, SPECT-CT using ^{99m}Tc methylene diphosphonate is useful for evaluating the local osteometabolic activity²⁹. In addition, it is helpful for diagnosing arthralgic condyles¹¹. In particular, if it exceeds 5.64 and the disc shape is amorphous, the possibility of osteoarthritis is much higher. However, the extent of bony changes on imaging studies and pain are not necessarily correlated³⁰. Therefore, we believe that a more objective examination is needed to distinguish OAI from OAO and that using multiple imaging modalities in combination is necessary.

This study had several limitations. First, since this study aimed to investigate SPECT-CT and MRI characteristics, clinical symptoms such as limited mouth opening and their correlation with imaging findings were not considered. Second, the classification was based on the history of pain. This is an inevitable choice because pain is the clinical diagnostic criterion for differentiating between OAO and OAI; however, pain can be subjective and pain in the joint area can originate from the surrounding soft tissues or masticatory muscles³¹. Third, age and sex were not considered during SPECT-CT evaluation. More accurate results can be obtained if these details were investigated in more patients. Fourth, the duration and severity were not considered. According

	Osteoarthrosis	Osteoarthritis
No. of joints (patients)	36 (28)	62(51)
Age	45.00 ± 17.32	45.96 ± 17.35
Sex – n (%)*		
Male	2 (7.1)	5 (9.8)
Female	26 (92.9)	46 (90.2)
SUVmax	3.74 ± 1.09	7.39 ± 3.66
Disc-Condyle relationship†		
Normal	9 (25.0)	5 (8.1)
ADcR	5 (13.9)	6 (9.7)
ADsR	22 (61.1)	51 (82.3)
Disc shape†		
Biconcave	14 (38.9)	2 (3.2)
Flattened	6 (13.9)	8 (12.9)
Folded	3 (8.3)	8 (12.9)
Sunglass	6 (16.7)	9 (14.5)
Amorphous	8 (22.2)	35 (56.5)
BMS†		
WNL	31 (86.1)	45 (72.6)
Weak	5 (13.9)	17 (27.4)
Joint Space†		
WNL	12 (33.3)	6 (9.7)
Narrowing	22 (61.0)	38 (61.3)
Bone to Bone contact	2 (5.6)	18 (29.0)
Joint Effusion†		
G0	30 (83.3)	29 (46.8)
G1	4 (11.1)	22 (35.5)
G2	2 (5.6)	11 (17.7)

Table 1. Clinical characteristics, SUVmax and MRI findings. SUVmax, maximum standardized uptake value; ADcR, anterior displacement with reduction; ADsR, anterior displacement without reduction; BMS, bone marrow signal; MRI, magnetic resonance imaging. * Number of patients is based on the number of patients. The number of disc–condyle relationships, disc shape, BMS, joint space, and joint effusion were based on the number of joints.

SUVmax	Group			p-value
	OAO (n = 36)	OAI (n = 62)	Total (n = 98)	
≤ 5.64	34(94.44)	21(33.87)	55(56.12)	<0.001
> 5.64	2(5.56)	41(66.13)	43(43.88)	

Table 2. Number of joints of OAI and OAO based on SUVmax cut-off value – Number of joints (%).

to the study of Jung³² the degree of bone marrow sclerosis varies depending on the duration of osteoarthritis. Accordingly, it is assumed that the SUV value of SPECT-CT may also be affected. Finally, the 95% confidence interval is wide in logistic regression analysis. This is thought to be because the number of joints included in some items is somewhat small. If the total number of joints increases, this phenomenon may be reduced, but this phenomenon has also been observed in some other papers comparing pathological and normal conditions¹⁵. Therefore, care must be taken in interpretation.

In conclusion, we suppose considering SUVmax on SPECT-CT is helpful for differentiating OAI from OAO. In addition, combination of both SUVmax on SPECT-CT and the disc shape on MRI would be more effective than using a single imaging method. Future studies using various examination modalities are warranted.

Variables	Univariate		Multivariate	
	OR (95% CI)	p-value	OR (95% CI)	p-value
SUVmax	2.195 (1.520–3.169)*	< 0.001	2.112 (1.425–3.130)*	< 0.001
Disc-Condyle relationship				
Normal	1			
ADcR	2.160 (0.430–10.845)	0.350		
ADsR	4.173 (1.254–13.883)*	0.020		
Disc shape				
Biconcave	1		1	
Flattened	11.200 (1.751–71.637)*	0.011	4.964 (0.601–41.015)	0.137
Folded	18.667 (2.554–136.409)*	0.004	17.909 (2.095–153.052)*	0.008
Sunglass	10.500 (1.725–63.913)*	0.011	8.420 (1.104–64.194)*	0.040
Amorphous	30.625 (5.772–162.498)*	< 0.001	11.464 (1.744–75.348)*	0.011
BMS				
WNL	1			
Weak	2.342 (0.782–7.016)	0.128		
Joint space				
WNL	1			
Narrowing	3.455 (1.136–10.501)*	0.029		
Bone to Bone contact	18.000 (3.100–104.532)*	0.001		
Joint effusion				
G0	1			
G1	5.690 (1.746–18.541)*	0.004		
G2	5.690 (1.159–27.921)*	0.032		

Table 3. Univariate and multivariate logistic regression analyses of factors for diagnosis of OAO and OAI. OAO osteoarthritis, OAI osteoarthritis, *SUVmax* maximum standardized uptake value, *ADcR* anterior displacement with reduction, *ADsR* anterior displacement without reduction, *BMS* bone marrow signal, *CI* confidence interval, *OR* odds ratio, *WNL* within normal limits. R^2 was 0.562 in multivariate logistic regression analysis. * $p < 0.05$.

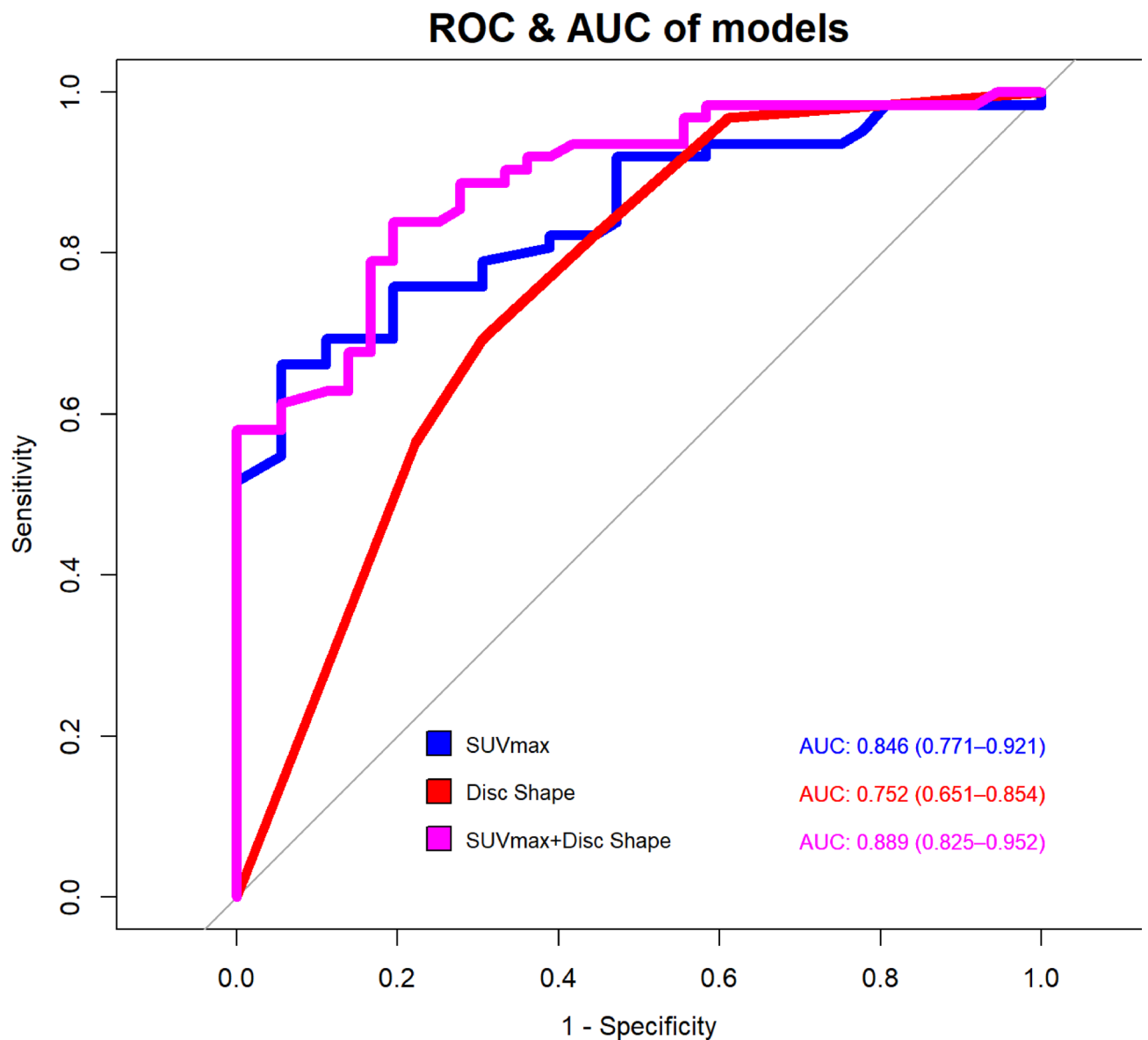


Fig. 6. ROC curves for disc shape (red line), SUVmax (blue line), and SUVmax + disc shape (pink line). ROC Receiver operating characteristic, AUC area under the curve, SUVmax maximum standard uptake value.

Data availability

The datasets used and/or analyzed during the current study available from the corresponding author on reasonable request.

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Author contributions

J.-Y. Kim and C. Lee wrote the original draft; J.-Y. Kim, J.-H. Lee, and J.-K. Huh designed the research; J.-Y. Kim, C. Lee, M.-J. Kang, J.-H. Lee, and Y.H. Ryu collected and analyzed the data. H.-S. Kim, J.-H. Lee and J.-K. Huh revised the manuscript and edited the manuscript; All authors reviewed the manuscript. All authors have read and agreed to the published version of the manuscript.

Declarations

Competing interests

The authors declare no competing interests.

Ethical approval

The study was approved by the institutional review board of Yonsei University Gangnam Severance Hospital approved this retrospective study (IRB No. 3-2024-0273), and waiver of written informed consent for this retrospective study. This study was also conducted according to the principles of the Declaration of Helsinki for research on humans.

Additional information

Correspondence and requests for materials should be addressed to J.-K.H.

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