

Predicting outcome of repair of medial meniscus posterior root tear with early osteoarthritis using bone single-photon emission computed tomography/computed tomography

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Abstract

Repair of medial meniscus posterior root tear (MMPRT) is considered as an effective early intervention strategy for osteoarthritis. We aimed at evaluating whether or not single-photon emission computed tomography/computed tomography (SPECT/CT) could predict the treatment outcome.

Eleven patients with MMPRT who underwent preoperative SPECT/CT were retrospectively enrolled. Clinical symptoms were evaluated based on the knee injury and osteoarthritis outcome score (KOOS) and visual analogue scale (VAS) for pain. The uptake pattern of the medial tibial plateau (MTP) on SPECT/CT was visually assessed. Additionally, the maximum lesion-to-cortical counts ratio (LCR_{max}) for the anterior and posterior aspects of MTP and anterior-posterior MTP ratio (APR) were quantitatively assessed. Spearman correlation analyses were performed between the change in clinical symptom scores and preoperative SPECT/CT patterns.

All patients showed increased radiotracer uptake in MTP. Among them, 8 (73%) showed dominant uptake in the anterior aspect of MTP. The rest 3 (27%) showed posterior-dominant uptake. Patients with anterior-dominant patterns tended to show better outcomes in terms of the postoperative KOOS score ($P = .07$). Anterior MTP LCR_{max} showed a negative correlation with the change in VAS ($\rho = -0.664$, $P < .03$). APR showed a correlation with the change in the KOOS score ($\rho = 0.655$, $P < .03$).

Patients with MMPRT with relatively higher uptake in the anterior aspect of MTP could have better clinical outcomes after the repair. The preoperative SPECT/CT pattern may have a predictive value in selecting patients with good postoperative outcomes.

Abbreviations: APR = anterior-posterior MTP counts ratio, CT = computed tomography, KOOS = knee injury and osteoarthritis outcome score, LCR_{max} = maximum lesion-to-cortical counts ratio, MM = medial meniscus, MMPRT = medial meniscus posterior root tear, MRI = magnetic resonance imaging, MTP = medial tibial plateau, SPECT = single-photon emission computed tomography, VAS = visual analogue scale.

Keywords: bone scan, medial meniscus posterior root tear, meniscal root repair, osteoarthritis, single-photon emission computed tomography/computed tomography

Editor: Gaurav Malhotra.

WW and J-YP contributed equally to this work.

This research was supported by a grant of the Korea Health Technology R&D Project through the Korea Health Industry Development Institute (KHIDI), funded by the Ministry of Health & Welfare, Republic of Korea (HI19C0339).

The authors have no conflicts of interest to disclose.

The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request. The datasets generated during and/or analyzed during the current study are not publicly available, but are available from the corresponding author on reasonable request.

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How to cite this article: Whi W, Park JY, Choi H, Paeng JC, Cheon GJ, Kang KW, Lee DS, Han HS. Predicting outcome of repair of medial meniscus posterior root tear with early osteoarthritis using bone single-photon emission computed tomography/computed tomography. *Medicine* 2020;99:27(e21047).

Received: 2 March 2020 / Received in final form: 17 May 2020 / Accepted: 1 June 2020

<http://dx.doi.org/10.1097/MD.00000000000021047>

1. Introduction

Medial meniscus posterior root tear (MMPRT) profoundly affects the meniscal biomechanics and kinematics, leading to accelerated degenerative changes of the knee joint.^[1–4] It is associated with clinically significant meniscal extrusion, which can affect impairment of hoop stress force transmission causing accelerated degenerative articular wear.^[5] A biomechanical study compared the peak tibiofemoral contact pressure of MMPRT as similar to a total medial meniscectomized knee.^[6] In this regard, the treatment of meniscal root tears has recently evolved into various repair strategies to restore meniscal function both biomechanically and clinically, thus preventing degenerative changes of the knee.^[7]

However, the effect of MMPRT repair is debatable, particularly in terms of the prognostic outcome after the treatment. Although arthroscopic pull-out repair of the MMPRT has shown favorable clinical and radiographic results,^[8,9] results tend to vary among individuals, particularly at long-term follow-ups.^[10] An explainable cause of variability in the effect of MMPRT repair is the heterogeneity of early osteoarthritis. For instance, varus alignment and chondral lesions were prone to inferior outcomes after MMPRT repair.^[11] Meniscus extrusion is associated with poor results after conservative treatment for MMPRT.^[12] Nonetheless, evidence of baseline characteristics predicting the future outcome of the MMPRT repair has been limited. Therefore, appropriate selection of patients who would benefit from the treatment by using functional characteristics could be a critical issue in the efficacy of MMPRT repair.

The purpose of this study was to evaluate whether or not preoperative single-photon emission computed tomography (SPECT)/computed tomography (CT) findings could predict the outcome of MMPRT repair. Bone scanning is the gold-standard modality for assessing skeletal disorders, particularly with its advancements through SPECT/CT. In contrast to magnetic resonance imaging (MRI), SPECT/CT as a hybrid imaging modality can provide information on osseous physiology and metabolism as well as structural abnormalities.^[13] SPECT/CT can theoretically demonstrate an abnormality before a morphologic change is detectable with other anatomical imaging modalities.^[14] As functional information provided by bone SPECT/CT may be associated with the heterogeneity of osteoarthritis, a specific type of osteoarthritis identified by the SPECT/CT pattern could be related to the outcome of MMPRT.

2. Methods

2.1. Subjects

As an observational study, we retrospectively enrolled patients with early osteoarthritis who had undergone MMPRT repair. Patients diagnosed with acute or chronic MMPRT on MRI were initially treated with non-surgical methods for 3 months. MMPRT was diagnosed on MRI and defined as radial tear within 5 mm of the posterior bony attachment of the medial meniscus.^[15] Conservative therapy consisted of activity modification, which prohibited patients from squatting or climbing stairs, applying an ice pack, taking anti-inflammatory drugs or analgesics, and controlling weight. If pain and functional disability decreased after 3 months of conservative treatment, the patient was consistently followed-up without surgery. However, if the patient's pain persisted with an increased functional disability after 3 months of conservative treatment,

arthroscopic meniscectomy or meniscus repair was performed according to the reparability of the meniscus. Contraindications of MMPRT repair included a Kellgren–Lawrence grade of 3 or more on plain radiographs and asymmetric varus alignment (hip–knee–ankle angle of more than 5°) on long cassette radiographs.

For MMPRT repair, a single experienced surgeon performed arthroscopic transosseous pullout suture repair for all patients at a single institution. The rehabilitation protocol applied for all patients was as follows: restriction of the range of motion within 90° with toe-touch weight-bearing and isometric quadriceps contraction in extension for 4 weeks, followed by a further range of motion exercise and weight-bearing after 4 weeks. Clinical results were evaluated using the pre- and post-operative knee injury and osteoarthritis outcome scores (KOOSs) and visual analog scale (VAS) for pain. The temporal variation in scores was recorded.

Between April 2014 and November 2016, 20 patients diagnosed with MMPRT underwent preoperative SPECT/CT and MMPRT repair. Among them, 11 patients (all women, 59.6 ± 5.2 years) underwent pre- and postoperative clinical evaluations for 12 months or more.

2.2. Imaging

Bone planar imaging was acquired 3 hours after an intravenous injection of 740 MBq (20 mCi) of ^{99m}Tc-3,3-diphosphono-1,2-propanedicarboxylic acid, followed by SPECT/CT of the distal femoral shaft to the proximal tibial shaft. SPECT/CT acquisition was performed on a hybrid dual-head gamma camera and 16-slice CT scanner (Discovery NM/CT 670, GE Healthcare, Waukesha, WI, US). SPECT scans were acquired using a low-energy high resolution collimator with 360° orbit, 120 steps (20/s/step), and 128 × 128 matrix, while the CT part of SPECT/CT used 16-detector row helical CT with 120 kVp, 40 mAs, 1 s gantry rotation, and reconstructed section thickness of 3.75 mm.

2.3. Image analysis

The tracer uptake was visually assessed for the anterior and posterior aspects of the medial tibial plateau (MTP). More specifically, more than 2 experienced nuclear medicine physicians visually reviewed the uptake pattern of the anterior and posterior aspects of MTP. The anterior and posterior aspects of MTPs were divided by a hypothetical line based on the tibial eminence. Accordingly, patients were divided into 2 groups based on the aspect of MTP with dominant uptake: anterior and posterior.

For quantitative analyses, the reference tracer uptake was measured in the cortex of the femoral diaphysis by using manually drawn volume-of-interests (VOIs). Subsequently, the maximum lesion-to-cortical count ratio (LCR_{max}) for both anterior and posterior MTPs was calculated. VOIs were drawn for the anterior and posterior aspects of MTP considering the hypothetical line based on the tibial eminence aforementioned. As another parameter, the anterior–posterior MTP LCR_{max} ratio (APR) was also assessed. Quantitative and visual analyses were performed with an imaging analysis software package (Syngo, via, Siemens Healthcare, Erlangen, Germany).

2.4. Statistical analysis

Spearman correlation analyses were performed to evaluate the association between changes in the clinical symptom score and

SPECT parameters, including LCR_{max} and APR. A P -value $< .05$ was considered significantly different. All statistical calculations were performed using MedCalc Statistical Software version 19.0.5 (MedCalc Software bvba, Ostend, Belgium; <https://www.medcalc.org>; 2019).

2.5. Ethics approval and consent to participate

All procedures in this study that involved human participants were performed in accordance with the ethical standards of the institutional and/or national research committee and complied with tenets of the 1964 Helsinki Declaration and its later amendments or comparable ethical standards (SNUH IRB No. 1908-083-1054).

3. Results

Visual analyses revealed that all 11 (100%) patients showed increased tracer uptake in MTP on the injured side of the knee. Among them, 8 (73%) showed dominant uptake in the anterior aspect of MTP (Fig. 1a). The rest 3 (27%) showed dominant

uptake in the posterior aspect of MTP (Fig. 1b). Table 1 summarizes the uptake pattern, whether anterior- or posterior-dominant uptake, in MTP. The group with anterior-dominant uptake tended to show better outcomes in terms of the postoperative change in the KOOS score, although without statistical significance (Fig. 1c, median: 127 vs 65.5, respectively; $P = .07$).

We also performed a quantitative analysis for evaluating whether a pattern of preoperative SPECT finding was associated with postoperative outcome. The LCR_{max} of anterior MTP showed a significant negative correlation with the postoperative change in VAS ($\rho = -0.664, P < .03$) (Fig. 2). LCR_{max} of anterior MTP and the postoperative change in the KOOS score tended to show a positive correlation, although without statistical significance ($\rho = 0.418, P = .20$). The LCR_{max} of posterior MTP showed no correlation with either of the clinical symptom scores. As another quantitative value representing the ratio of the anterior uptake to the posterior uptake, APR showed a significant correlation with the postoperative change in the KOOS score ($\rho = 0.655, P < .03$) but not with the VAS score ($\rho = -0.464, P = .15$) (Fig. 3).

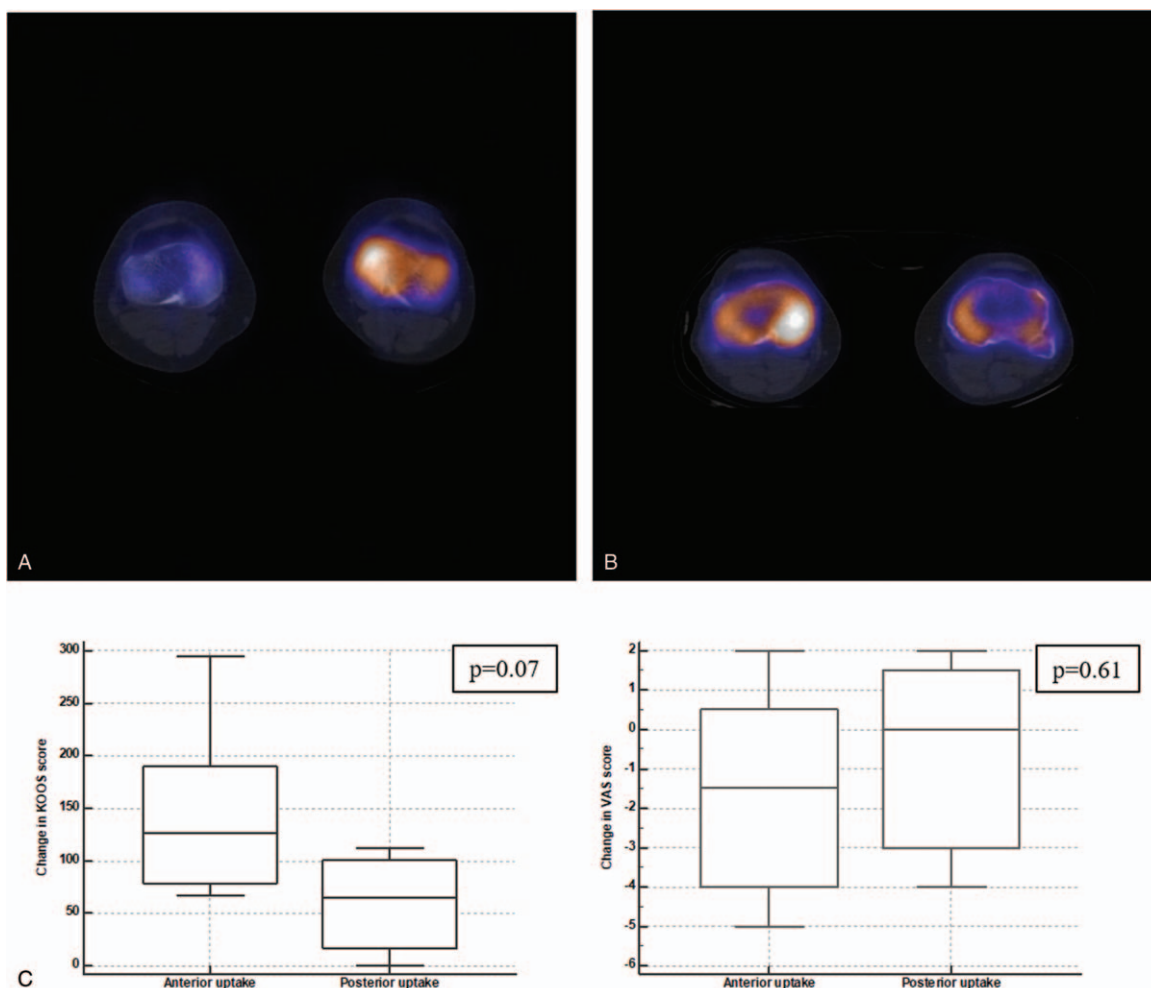


Figure 1. Visual patterns of single-photon emission computed tomography/computed tomography (SPECT/CT) and postoperative symptom improvement. a, b. Representative SPECT/CT images of the anterior- and posterior-dominant pattern of uptake in the medial tibial plateau. c. The group with anterior-dominant patterns tended to show better outcomes in terms of changes in the postoperative knee injury and osteoarthritis outcome score, although without statistical significance. The visual analogue scale did not show any noticeable correlation with the uptake pattern.

Table 1
Baseline characteristics and qualitative results of patients.

No.	Age	Sex	Right/Left	BMI	HKA angle	SPECT pattern	KOOS			VAS		
							Pre	Post	Change	Pre	Post	Change
1	58	F	Left	24.03	2.54	Anterior, diffuse	260	394	134	4	4	0
2	61	F	Left	28.05	3.53	Anterior, focal	249	318	69	9	5	-4
3	56	F	Left	25.63	2.14	Posterior, diffuse	207	319	112	7	3	-4
4	70	F	Right	23.31	2.91	Posterior, focal	330	331	1	2	4	2
5	56	F	Left	25.95	1.32	Anterior, diffuse	330	417	87	1	3	2
6	59	F	Left	27.63	1.28	Anterior, focal	241	472	231	5	0	-5
7	59	F	Right	33.73	1.20	Anterior, diffuse	258	406	148	6	2	-4
8	57	F	Left	29.56	3.25	Anterior, diffuse	264	384	120	2	3	1
9	70	F	Right	29.72	1.62	Anterior, diffuse	256	323	67	3	3	0
10	56	F	Left	27.59	1.64	Posterior, focal	232.5	298	65.5	3	3	0
11	54	F	Right	23.1	2.84	Anterior, diffuse	149	444	295	5	2	-3

BMI=body-mass-index, HKA=hip-knee-angle, KOOS=knee injury and osteoarthritis outcome Score, Post=postoperative, Pre=preoperative, SPECT=single photon emission computed tomography, VAS=visual analogue scale.

4. Discussion

The site of joint inflammation associated with bone uptake of radiotracers can be identified and anatomically localized by SPECT/CT, as it provides 3-dimensional localization of the lesion.^[16] As the accumulation of radiotracers is associated with osseous metabolism before anatomical changes, we expect that SPECT/CT can demonstrate the early degeneration patterns of osteoarthritis in terms of the degree and anatomical location of mechanical and biochemical stresses.^[17] Different patterns of radiotracer uptake were found in our study, and the patients divided on the basis of those patterns showed different clinical outcomes of the MMPRT repair. Despite the limited number of patients, this close association of the uptake pattern with the postoperative outcome not only supports the spatial heterogeneity of the osteoarthritic processes in the knees but also suggests its usefulness in predicting the prognosis using preoperative SPECT/CT.

Our results suggested that bone SPECT/CT could be a sensitive imaging modality for assessing patients with MMPRT, as shown

by positive tracer uptake at MTP in 100% of patients, although our study was primarily aimed at predicting the postoperative outcome using SPECT/CT. As mechanical stress causes osseous metabolic changes before causing anatomical changes, SPECT/CT could sensitively demonstrate the functional abnormality with the accurate location. It provides incremental values in the evaluation of knee pain over other radionuclide imaging, such as a planar bone scan or SPECT alone, and now increasingly used in patients who present with knee pain or considered the candidate of arthroplasty.^[18]

In this study, a trend of symptom improvement after the MMPRT repair was found when the tracer uptake was dominant in the anterior aspect of MTP. However, the trend of improvement after the repair was not definite in patients who showed a posterior-dominant pattern of uptake on SPECT/CT. Many previous studies have repeatedly shown that a posterior root tear results in the increased peak contact pressure and decreased contact area compared to an intact knee.^[1,6,19] These studies have suggested that a meniscus root repair could restore the effect of mechanical stress causing the progression of osteoarthritis to the level of a native knee joint. Notably, since

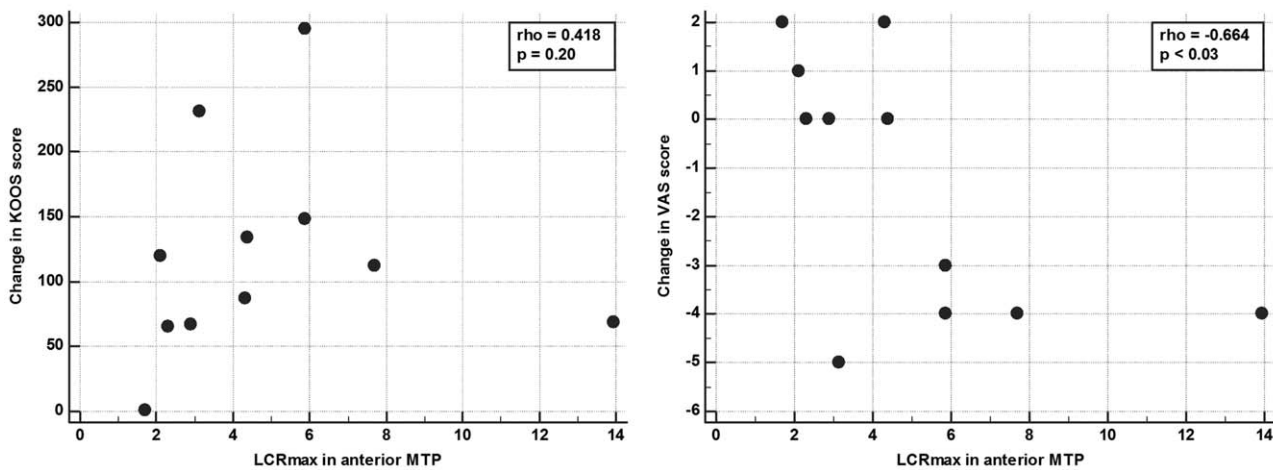


Figure 2. Correlation analysis of the maximum lesion to cortical count ratio (LCR_{max}) and postoperative symptom improvement. In the anterior medial tibial plateau, LCR_{max} showed a significant negative correlation with the postoperative change in visual analogue scale. The anterior LCR_{max} and change in the knee injury and osteoarthritis outcome score showed a positive correlation, although without statistical significance.

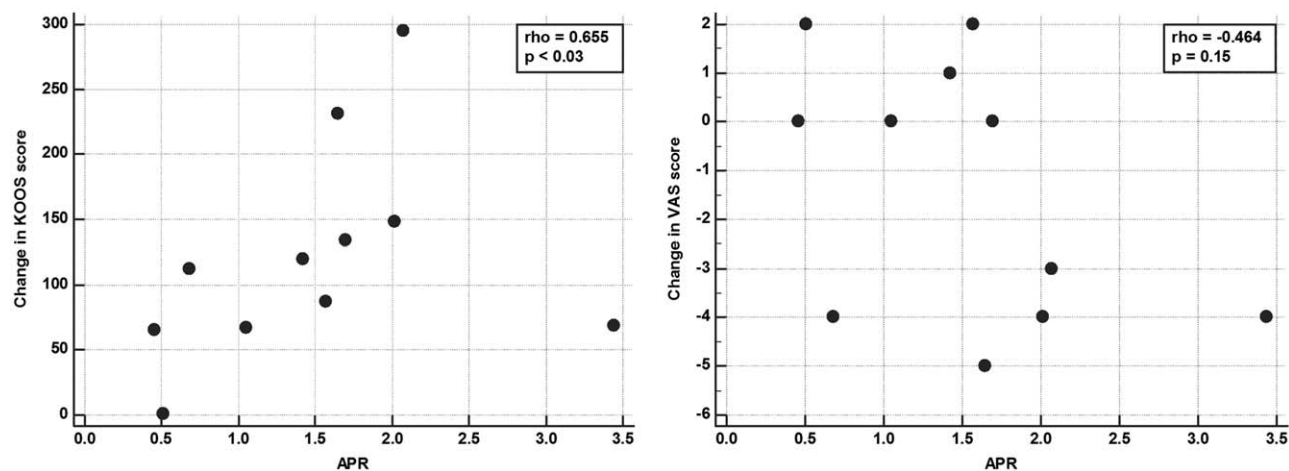


Figure 3. Correlation analysis of the ratio of anterior and posterior medial tibial plateau maximum lesion to cortical count ratio (APR) and postoperative symptom improvement. APR showed a significant correlation with the change in the knee injury and osteoarthritis outcome score ($\rho = 0.655$, $P < .03$) but not with the visual analogue scale score.

previous biomechanical studies were performed with cadaveric models, the variable uptake patterns identified by SPECT/CT may shed some light on the in vivo consequences of impaired biomechanics caused by a root tear. As part of the study that still needs further investigation, the reason why symptom improvement was seen in a patient with tracer uptake dominance in the anterior aspect of MTP is difficult to explain. A plausible explanation is that the inflammatory process dominant in the posterior aspect of MTP implies irreversible inflammatory or biomechanical change, which may hardly be improved by the repair of MMPRT. These assumptions can be further confirmed by correlating biomechanical studies, structural findings of knee MRI, such as anatomical variability in MM extrusion.^[20]

Despite the lack of biomechanical explanation, this study importantly revealed that quantitative parameters derived by SPECT/CT, LCR_{max} of the anterior MTP and APR, were associated with the improvement in clinical symptom scores after the MMPRT repair. According to our results, the anterior-dominant tracer uptake of MTP in preoperative SPECT/CT could be a positive prognostic factor of the MMPRT repair. Of note, this hardly means the other pattern of uptake is against the operation as the repair of MMPRT should be determined by considering various clinical factors, such as age and initial symptoms.

The study had some limitations. First, the number of subjects was too small to have a strong statistical power because subjective clinical symptom scores largely vary among individuals. Nonetheless, we found a significant correlation between symptom scores and quantitative values derived from SPECT/CT. Second, the clinical factor of whether or not the meniscus healed successfully with surgery was not included in the prediction analysis. Third, the clinical outcomes were obtained from a short-term clinical evaluation; therefore, more long-term outcome data should be studied in the future. Finally, as a retrospective study, postoperative SPECT/CT was not included in the analysis because SPECT/CT was not performed routinely in the postsurgical management. The uptake patterns in postoperative SPECT/CT could provide additional information related to clinical outcome as a future study.

5. Conclusion

Bone SPECT/CT is a sensitive imaging modality for evaluating MMPRT with early osteoarthritis and might have a predictive value for a postoperative outcome of the MMPRT repair. Patients with stronger tracer uptake in the anterior aspect of MTP and relatively lower uptake in the posterior aspect of MTP showed better clinical outcomes after the MMPRT repair. Our results suggest that the preoperative SPECT/CT pattern may be a predictive marker to select appropriate patients who would benefit from the MMPRT repair as an early intervention for osteoarthritis.

Acknowledgments

We thank our colleagues from Seoul National University Hospital, who provided insight and expertise that greatly assisted the research.

Author contributions

HC and HSH designed this study. WW and JYP performed data collection and analysis. JCP, GJC, KWK, and DSL supported the image interpretation and discussion. JYP and HSH performed clinical assessment. All authors interpreted data results, drafted and edited manuscript.

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