JMeXFRI

Journal of the Mexican Federation of Radiology and Imaging

Check for updates

FULL RESEARCH ARTICLE

Standing knee US versus knee MRI for evaluating medial meniscal extrusion

*I.F. Alejandro Lopez-Beltran and Osiris G. Salazar-Lopez**

Department of Radiology and Imaging, Hospital de Especialidades Num. 2, Unidad Medica de Alta Especialidad, Centro Medico Nacional del Noroeste "Lic. Luis Donaldo Colosio Murrieta", Instituto Mexicano del Seguro Social, Ciudad Obregon, Sonora, Mexico

ABSTRACT

Introduction: *A weight-bearing (WB) knee ultrasound (US) represents a conceptual shift from static morphological to functional assessment. This study aimed to compare the ability of magnetic resonance imaging (MRI), non-weight-bearing US (NWB-US), and WB-US for diagnosing medial meniscal extrusion and to determine the prevalence of minor and major extrusion grades.* **Material and methods:** *Findings were categorized as normal medial meniscus, minor, and major medial meniscal extrusion. Cochran's Q test and McNemar's test with Holm-Bonferroni correction were used for statistical analyses.* **Results:** *This study included 50 adult patients (14 women and 36 men, mean age 37.8 ± 10.1 years) with knee pain. MRI classified more knees as normal (n = 40, 80.0%) compared to NWB-US (n = 20, 40.0%) and WB-US (n = 7, 14.0%) (p < 0.001). WB-US identified minor (n = 20, 40.0%) and major (n = 23, 46.0%, p < 0.001) medial meniscal extrusion more frequently. NWB-US identified 17 (34.0%) minor and 13 (26.0%) major cases. MRI identified 4 (8.0%) and 6 (12.0%) minor and major medial cases, respectively. There was a trend toward greater medial meniscal extrusion with increasing patient age across all three imaging methods. The effect of BMI depended on the imaging modality: extrusion frequency increased with MRI and WB-US as BMI increased, while medial meniscal extrusion decreased with increasing BMI in NWB-US.* **Conclusion:** *WB-US was more useful than MRI and NWB-US for diagnosing minor and major grades of medial meniscal extrusion. Increasing age was the most significant factor, with BMI affecting results depending on the imaging modality used.*

Keywords: *Meniscal. Weight-bearing. Ultrasound. Magnetic Resonance Imaging.*

INTRODUCTION

Meniscal extrusion has recently been recognized as a hallmark of meniscus dysfunction. The medial meniscus covers 50-75% of the medial tibial plateau and is attached circumferentially to the capsule[1]. Meniscal extrusion compromises the weight-bearing surface area and predisposes the knee to injury. It can manifest as osteoarthritis, osteophytosis, chondral lesions, further meniscal tearing, and cartilage loss[1]. Meniscal extrusion is the displacement of the meniscus, ranging from a minimal physiologic extrusion to more than 10 mm[2]. Knee magnetic resonance imaging (MRI) focuses predominantly on structural anatomy at rest[1,3]. However, its accuracy in detecting medial meniscal extrusion under static, non-weight-bearing conditions is limited[4-6] due to the dynamic nature of meniscal biomechanics, which are subject to axial and rotational forces during weight-bearing[4-8].

Ultrasound (US) is a modality that allows multiplanar and dynamic imaging of the meniscus and other knee structures. It has excellent sensitivity and specificity in detecting extrusion, along with reliable quantitative

***Corresponding author:**
Osiris G. Salazar-Lopez
E-mail: osiris.salazar@gmail.com

Received for publication: 13-07-2025
Accepted for publication: 18-09-2025
DOI: 10.24875/JMEXFRI.M25000115

Available online: 15-01-2026
J Mex Fed Radiol Imaging. 2025;4(4):233-242
www.JMeXFRI.com

extrusion assessment[5,9] US evaluation can be performed in two ways: non-weight-bearing (NWB-US) with the patient supine or weight-bearing (WB-US) with the patient standing, allowing evaluation under axial loading on the examined extremity[10].

Medial meniscal extrusion is a marker of biomechanical alteration in the knee, with prognostic implications and potential utility in identifying patients at risk of developing or progressing to osteoarthritis[8]. Meniscal extrusion, a radial displacement of the meniscus greater than 3 mm, leads to altered knee biomechanics and accelerated knee joint degeneration[1]. It is graded as minor (2-3 mm) or major (> 3 mm), but reference values have not been standardized[3,7]. Static assessment in the supine position does not adequately reflect the magnitude of medial meniscal extrusion[6], and the usefulness of WB-US has not been sufficiently studied[5,8-13]. This study compared the ability of MRI, NWB-US, and WB-US to diagnose medial meniscal extrusion and determined the prevalence of minor and major medial meniscal extrusion.

MATERIAL AND METHODS

This cross-sectional study was conducted from June 2024 to January 2025 at the Department of Radiology and Imaging, Hospital de Especialidades No. 2, "Lic. Luis Donaldo Colosio Murrieta," Centro Medico Nacional del Noroeste del Instituto Mexicano del Seguro Social in Ciudad Obregon, Sonora, Mexico. Adult patients aged 18 years or older with knee pain referred by orthopedic physicians were consecutively enrolled. Patients were excluded if they had limitations for dynamic assessment in the standing position, a history of knee surgery, knee fractures, knee soft-tissue infections, obesity that prevented the use of the knee coil, or incomplete MRI examination. All participants provided informed consent. The research ethics committee and the research committee approved the study protocol.

Study design and variables

Age, sex, weight, height, body mass index (BMI), and the presence of posterior root tear were recorded. Patients were grouped based on MRI, NWB-US, and WB-US findings into normal medial meniscus examination, minor medial meniscal extrusion, and major medial meniscal extrusion according to Costa et al.[3]

Definitions

NWB-US[10]: imaging modality that evaluates knee structures with the patient supine with complete knee extension.

WB-US[10]: imaging modality that evaluates knee structures with the patient in a standing weight-bearing position with axial loading.

Medial meniscal extrusion: partial or complete displacement of the meniscus beyond the medial tibial plateau.

Minor medial meniscal extrusion[3]: partial or complete displacement of the meniscus beyond the medial tibial plateau greater than 2 mm but less than 3 mm.

Major medial meniscal extrusion[3]: partial or complete displacement of the meniscus greater than 3 mm.

Posterior root tear[13]: avulsion injury or radial tear occurring 10 mm of the posterior meniscal root bony attachment.

Imaging acquisition and analysis protocol

Knee MRI

MRI was performed on a Skyra 3.0T scanner (Siemens Healthineers, Erlangen, Germany) with high-resolution images. The imaging protocol used the Siemens Quiet Suite[14] in the axial, coronal, and sagittal planes. It included the following turbo spin-echo (TSE) sequences: proton density (PD)-weighted time repetition (TR)/time echo (TE) (3600/39 ms), fat-saturated PD-weighted (TR/TE, 4150/29 ms), and fat-saturated T2-weighted (TR/TE, 4200/63 ms).

Medial meniscal extrusion was measured as the distance from a horizontal line, extending from the outer margin of the medial meniscus to its intersection with a vertical line. Measurements were performed by drawing a vertical line through the peripheral margin of the medial tibial plateau and the medial femoral condyle. Osteophytes were not considered in determining the medial femoral or tibial cortical margin[3]. A radiologist with 15 years of experience (OSL) analyzed the MRI images.

Knee NWB-US and knee WB-US

Real-time grayscale US was performed with a GE LOGIQ F6 (General Electric HealthCare, Chicago, IL, USA) using a 7-13 MHz linear transducer.

NWB-US: involved scanning the medial meniscus with the patient supine and the knee joint fully extended, using the medial collateral ligament as an anatomical landmark.

WB-US: involved scanning the medial meniscus in the standing position with the knee fully extended, placing the transducer over the medial femoral and tibial cortical contours, using the medial collateral ligament as an anatomical reference[10].

A fourth-year radiology resident performed imaging examinations under the supervision of a radiologist (OSL) with 15 years of experience.

Statistical analysis

Univariate analysis with measures of central tendency and dispersion was performed for quantitative variables. Frequencies and percentages were evaluated for qualitative variables. Because medial meniscal extrusion measurements did not follow a normal distribution, the Friedman test was used. The Nemenyi post hot test was applied to statistically significant results[15]. The Friedman test was used to compare the three imaging modalities in three categories (normal meniscus, minor medial meniscal extrusion, or major medial meniscal extrusion). The Wilcoxon test with the Holm-Bonferroni correction was used to identify statistically significant differences. To compare normal medial meniscus findings with minor and major extrusion across imaging methods, Cochran's Q test was used. McNemar's test with Holm-Bonferroni correction was used for statistically significant comparisons[16-18]. Confounding variables were identified using linear mixed models. The correlation between medial meniscal extrusion with posterior root tear was assessed with Kendall's tau test. Analyses were performed using the statistical platform R (R Core Team, 2023, Vienna, Austria) and RStudio (Posit Team, 2023, Boston, MA, USA).

RESULTS

Fifty-four patients with knee pain were evaluated. One patient with a history of knee surgery, one obese patient with limitations preventing use of the knee antenna, and two patients with incomplete MRI studies were excluded. Fifty knees in 50 patients, including 14 women and 36 men with a mean age of 37.8 ± 10.1 years (range, 25-62), were assessed (Table 1). Posterior root tear was an infrequent finding, identified in only 4 (8.0%) of 50 patients.

Medial meniscal extrusion measurements by MRI, NWB-US, and WB-US

Figure 1 shows a box plot comparing MRI, NWB-US, and WB-US measurements of medial meniscal extrusion. Medial meniscal extrusion by WB-US exhibited higher values (median 2.9 mm; interquartile range – IQR, 2.2-3.6 mm) compared to NWB-US (median 2.1 mm; IQR 1.2-3 mm), and MRI (median 1.0 mm; IQR 0.0-1.8 mm).

Table 1. Patient characteristics in the assessment of medial meniscal extrusion with and without posterior root tear

Description	(n = 50)
Age, years, mean ± SD (min-max)	37.8 ± 10.1 (25.0-62.0)
Sex, n (%)	
Women	14 (28.0)
Men	36 (72.0)
Weight (kg), mean ± SD (min-max)	89.4 ± 20.4 (52.0-160.0)
BMI, mean ± SD (min-max)	29.1 ± 4.8 (17.9-39.7)
Posterior root tear, n (%)	
Yes	4 (8.0)
No	46 (92.0)

BMI: body mass index; SD: standard deviation.

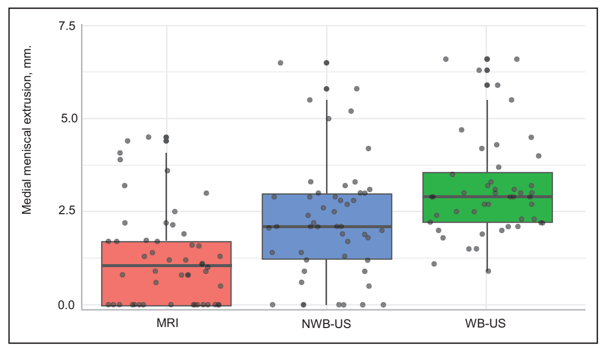

Figure 1. Box plot comparing medial meniscal extrusion measurements obtained by MRI, NWB-US, and WB-US. Medial meniscal extrusion measured by WB-US was significantly higher (median 2.9 mm; IQR 2.2-3.6 mm) compared to NWB-US (median 2.1 mm; IQR 1.2-3 mm) and MRI (median 1.0 mm; IQR 0.0-1.8 mm). Two 9.4 mm outliers, both assessed by WB-US, are not shown.

MRI: magnetic resonance imaging; NWB-US: non-weight-bearing ultrasound; WB-US: weight-bearing ultrasound; IQR: interquartile range.

Statistically significant differences were identified among the three medial meniscal extrusion ($p < 0.001$) measuring methods (Table 2). Medial meniscal extrusion was higher when assessed using WB-US than NWB-US or MRI. Post-hoc analysis showed that all pairwise comparisons between the imaging methods were significant. Comparisons involving WB-US versus NWB-US and versus MRI had greater statistical significance.

Comparison of MRI, NWB-US, and WB-US findings with normal medial meniscus and minor and major medial meniscal extrusion

MRI classified more knees as normal medial meniscus (n = 40, 80.0%) than NWB-US (n = 20, 40.0%) and

Table 2. Comparison of medial meniscal extrusion between MRI, NWB-US, and WB-US

Description	Nemenyi statistic	p
NWB-US vs. MRI	4.8	0.002
WB-US vs. MRI	12.79	< 0.001
WB-US vs. NWB-US	7.99	< 0.001

MRI: magnetic resonance imaging; NWB-US: non-weight-bearing ultrasound; WB-US: weight-bearing ultrasound.

WB-US (n = 7, 14.0%) ($p < 0.001$) (Table 3). WB-US identified minor and major medial meniscal extrusion more frequently (n = 20, 40.0%: p = 0.495 and n = 23, 46.0%: $p < 0.001$, respectively), while NWB-US identified 17 (34.0%) and 13 (26.0%) minor and major cases, respectively. MRI identified minor and major medial meniscal extrusion in 4 (8.0%) and 6 (12.0%) cases, respectively.

Pairwise comparison of medial meniscal extrusion grading

The pairwise comparison showed that MRI identified more patients with a normal medial meniscus than NWB-US (10/1) ($p < 0.032$) and WB-US (16/0) ($p < 0.001$) (Table 4). NWB-US also detected more normal knee examinations than WB-US (7/0) ($p < 0.032$). Statistically significant differences in major medial meniscal extrusion were observed among the three imaging methods. NWB-US and WB-US identified more cases of major medial meniscal extrusion than MRI (0/4) (p = 0.134) and 0/13 ($p < 0.001$), respectively. In contrast, minor meniscal extrusion showed concordance among the three imaging methods.

Analysis of variance of confounding variables and their interaction with imaging modality

Age was significantly associated with medial meniscal extrusion (Table 5). There was a trend toward greater medial meniscal extrusion with increasing patient age across all three imaging methods (Figure 2A). BMI had significantly more interaction depending on the imaging modality used. Extrusion increased with MRI and WB-US as BMI increased. In contrast, medial meniscal extrusion decreased with increasing BMI in NWB-US (Figure 2B). There was no significant association with sex, weight, or height.

Figure 3 shows images of a 39-year-old woman with normal weight and knee pain. MRI with fat suppression shows a 2.0 mm minor medial meniscal extrusion, and NWB-US a 2.6 mm minor medial meniscal extrusion. In contrast, WB-US shows a major 3.3 mm medial meniscal extrusion. Figure 4 shows images of a 58-year-old obese man with right knee pain. MRI with fat suppression shows a minor 2.8 mm medial meniscal extrusion, and NWB-US shows a major 3.7 mm medial meniscal extrusion. In contrast, WB-US shows a 4.6 mm major medial meniscal extrusion.

Figure 5 shows images of an obese woman with knee pain. MRI with fat suppression shows a 2.8 mm minor medial meniscal extrusion, NWB-US a 3.3 mm major medial meniscal extrusion, and WB-US a 4.5 mm major medial meniscal extrusion. Figure 6 shows images of a 48-year-old obese man with knee pain. MRI with fat suppression shows a 3.5 mm major medial meniscal extrusion, and NWB-US a 4.1 mm major medial meniscal extrusion. In contrast, WB-US shows a 4.6 mm major medial meniscal extrusion.

These cases illustrate that WB-US shows greater medial meniscal extrusion than MRI or NWB-US, underscoring the importance of mechanical loading conditions for more accurate evaluation of medial meniscal extrusion.

DISCUSSION

Our study showed that WB-US detects medial meniscal extrusion at both minor and major grades more frequently than NWB-US and MRI. WB-US is useful for real-time dynamic assessment and more accurately assesses meniscal biomechanics under physiological loading conditions.

Medial meniscal extrusion increases significantly under weight-bearing conditions[2]. Therefore, static evaluation may underestimate the diagnosis of medial meniscal extrusion[19]. WB-US is a useful tool for detecting medial meniscal extrusion under load[1,5,20]. The review by Papalia et al.[6] synthesizes evidence from multiple studies using various imaging modalities, such as MRI and dynamic WB-US, and introduces the key concept of “dynamic extrusion.” They concluded that US allows an accurate dynamic assessment of meniscal extrusion. Boksh et al.[10], in a systematic review of 31 studies assessing 3,747 knees, compared NWB-US and WB-US with MRI as the reference standard for measuring medial meniscal extrusion. WB-US consistently and significantly detected more knees with meniscal extrusion compared to NWB-US. WB-US identified medial

Table 3. Comparison of MRI, NWB-US, and WB-US findings for normal medial meniscus, minor, and major medial meniscal extrusion

Description	MRI (n = 50)	NWB-US (n = 50)	WB-US (n = 50)	p
Normal, n (%)	40 (80.0)	20 (40.0)	7 (14.0)	< 0.001
Minor medial meniscal extrusion, n (%)	4 (8.0)	17 (34.0)	20 (40.0)	0.495
Major medial meniscal extrusion, n (%)	6 (12.0)	13 (26.0)	23 (46.0)	< 0.001

MRI: magnetic resonance imaging; NWB-US: non-weight-bearing ultrasound; WB-US: weight-bearing ultrasound.

Table 4. Pairwise comparison of medial meniscal extrusion grading between MRI, NWB-US, and WB-US

Description	Comparison	Discordant pairs[a] (A = 1, B = 0/A = 0, B = 1)	p	Holm-adjusted p
Normal examination	Global test (Cochran's Q)	-	< 0.001	-
	MRI vs NWB-US[b], n	10/1	0.016	0.032
	MRI vs WB-US[b], n	16/0	< 0.001	< 0.001
	NWB-US vs WB-US[b], n	7/0	0.023	0.032
Minor meniscal extrusion	Global test (Cochran's Q)	-	0.495	-
Major meniscal extrusion	Global test (Cochran's Q)	-	< 0.001	-
	MRI vs NWB-US[b], n	0/4	0.134	0.134
	MRI vs WB-US[b], n	0/13	< 0.001	0.003
	NWB-US vs WB-US[b], n	0/9	0.008	0.015

[a]Discordant pairs are shown as (A = 1, B = 0/A = 0, B = 1) where A and B are the first and second image measurement methods named in the comparison; [b]pairwise tests are McNemar with continuity correction; Holm adjustment was applied within each category. MRI: magnetic resonance imaging; NWB-US: non-weight-bearing ultrasound; WB-US: weight-bearing ultrasound.

Table 5. Analysis of variance of confounding variables and their interaction with each imaging modality in patients with medial meniscal extrusion

Description	Degrees of freedom[a,b]	p	Significance
Age	1,44	< 0.001	Highly significant
Sex	1,44	0.759	Not significant
Weight	1,44	0.492	Not significant
Height	1,44	0.127	Not significant
BMI	1,44	0.630	Not significant
MRI, NWB-US, WB-US × Age	2,88	0.151	Not significant
MRI, NWB-US, WB-US × Sex	2,88	0.089	Trend toward significance
MRI, NWB-US, WB-US × Weight	2,88	0.059	Trend toward significance
MRI, NWB-US, WB-US × Height	2,88	0.366	Not significant
MRI, NWB-US, WB-US × BMI	2,88	0.011	Significant

[a]Numerator degrees of freedom. [b]Denominator degrees of freedom. MRI: magnetic resonance imaging; NWB-US: non-weight-bearing ultrasound; WB-US: weight-bearing ultrasound; BMI: body mass index.

meniscal extrusion when conventional supine MRI did not. In an experimental study in human cadavers, pressure sensors on a 3D scanning system were used in 10 knees with and without an axial force of 1,000 Newtons. Tibiofemoral contact mechanics and medial meniscal extrusion were quantified. The magnitude of meniscal extrusion significantly increased when the knee was flexed to 90° and loaded, compared with conventional measurements with the knee extended and unloaded[19]. Patel et al.[2] in a study of 143 subjects performed MRI with no load (supine) and with an axial load (simulating standing) and demonstrated that medial meniscal

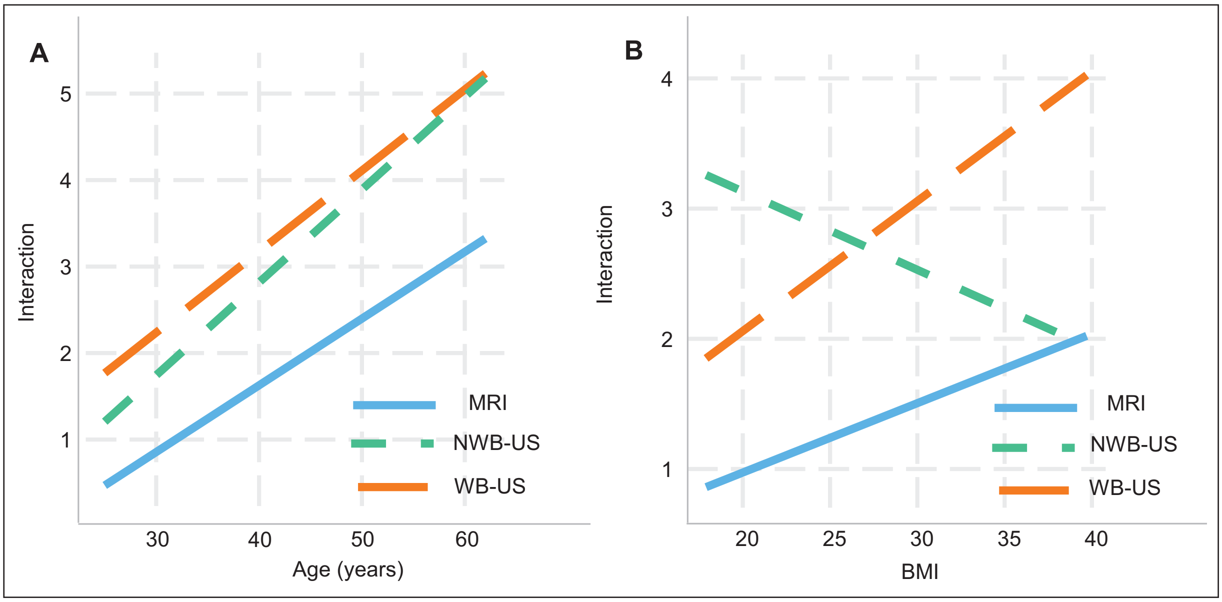

Figure 2. Interaction between imaging modalities and age and BMI. **A:** there is a trend toward greater medial meniscal extrusion as patient age increases with all three methods. **B:** extrusion increases with MRI and WB-US as BMI increases. In contrast, extrusion decreases with increasing BMI in NWB-US.

MRI: magnetic resonance imaging; NWB-US: non-weight-bearing ultrasound; WB-US: weight-bearing ultrasound.

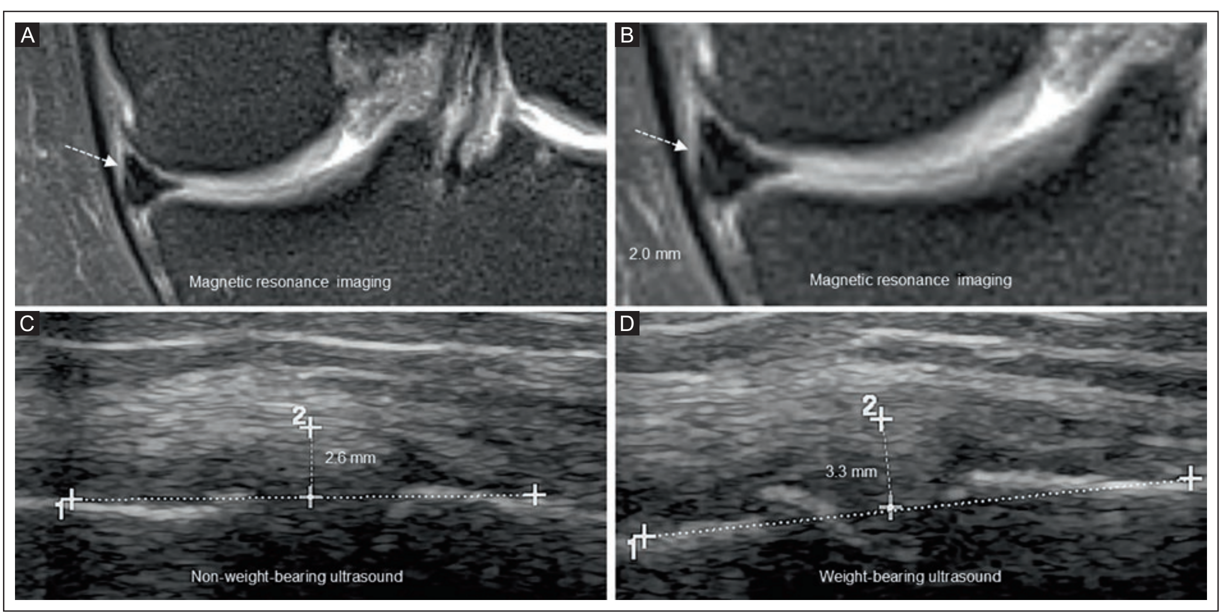

Figure 3. Comparison between imaging modalities in detecting medial meniscal extrusion in a 39-year-old woman with normal weight (BMI 24.2 kg/m²) and knee pain. **A-B:** coronal proton density-weighted MRI with fat suppression shows minor medial meniscal extrusion of 2.0 mm (arrows). **C:** NWB-US shows minor medial meniscal extrusion of 2.6 mm. **D:** WB-US shows major medial meniscal extrusion of 3.3 mm. WB-US highlights the ability to assess meniscal biomechanical responses to loading.

MRI: magnetic resonance imaging; NWB-US: non-weight-bearing ultrasound; WB-US: weight-bearing ultrasound.

extrusion increased significantly with a load (from 1.0 mm to 1.8 mm on average; $p < 0.001$). In our study, medial meniscal extrusion by WB-US showed higher values (median 2.9 mm; IQR 2.2-3.6 mm) than NWB-US (median 2.1 mm; IQR 1.2- 3 mm) and MRI (median 1.0 mm; IQR 0.0-1.8 mm). Our WB-US findings assess

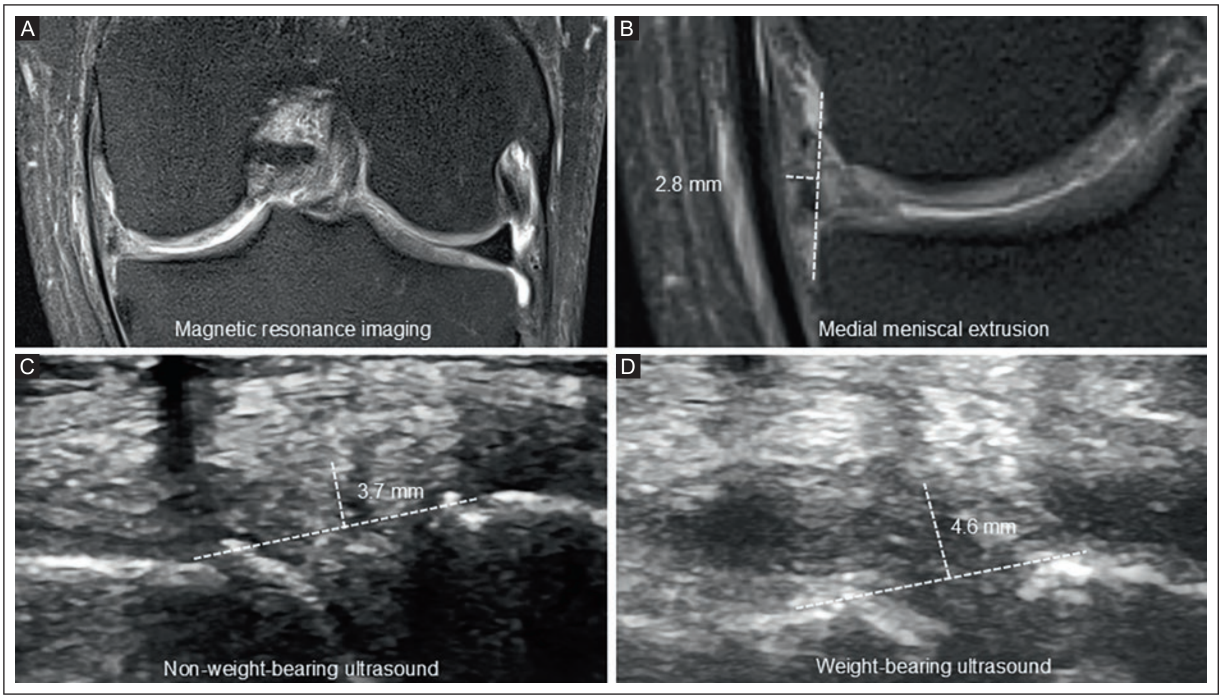

Figure 4. Comparison of imaging modalities of the medial meniscus in a 58-year-old obese man (BMI 31.5 kg/m²) with right knee pain. **A-B:** coronal proton density-weighted MRI with fat suppression shows minor medial meniscal extrusion of 2.8 mm. **C:** NWB-US shows a major 3.7 mm medial meniscal extrusion. **D:** WB-US shows a major 4.6 mm medial meniscal extrusion.

MRI: magnetic resonance imaging; NWB-US: non-weight-bearing ultrasound; WB-US: weight-bearing ultrasound.

meniscal biomechanics under load, thereby increasing the detection of medial meniscal extrusion.

Traditionally, medial meniscal extrusion assessment is performed using unloaded supine MRI[8], focusing predominantly on structural anatomy at rest[1,3]. In our study, WB-US detected 20 (40.0%) cases of minor meniscal extrusion versus 17 (34.0%) cases with NWB-US while 23 (46.0%) cases had major meniscal extrusion compared to only 13 (26.0%) by NWB-US, and 4 (8.0%) minor and 6 (12.0%) major meniscal extrusion cases by MRI, outperforming both techniques in identifying medial meniscal extrusion. Minor extrusion in the supine position may represent functionally relevant instability under load, detectable by WB-US[6,21]. WB-US provides a functional assessment of meniscal competence. By identifying more cases across the full spectrum of severity, this technique enables earlier diagnosis and more accurate characterization of meniscal instability, supporting a dynamic, functional assessment of meniscal pathology. WB-US identified more cases with minor and major medial meniscal extrusion than NWB-US and MRI. The dynamic nature of extrusion explains the disparities with static values and underscores WB-US's ability to identify early meniscal instability.

Older age and elevated BMI are significant risk factors for increased medial meniscal extrusion. The prospective study by Achtnich et al.[22] in 75 healthy volunteers showed a significant correlation between age and extrusion detected by NWB-US and WB-US ($p < 0.001$). Increased BMI was also significantly associated with meniscal extrusion under a load ($p = 0.002$). These researchers concluded that medial meniscal extrusion is an age- and BMI-dependent phenomenon, even in asymptomatic knees. In a study of 104 volunteers, Gregio-Junior et al.[9] evaluated medial meniscal extrusion using NWB-US and WB-US. Age had a significant impact on the increase in meniscal extrusion ($p = 0.001$). The study also showed significant variation in extrusion measurements between NWB-US and WB-US ($p = 0.0002$), suggesting that the loading condition is a critical factor. The authors concluded that age is a determining factor in meniscal extrusion and that differences in measurements across techniques underscore the complexity of its evaluation, in which the influence of other variables, such as BMI, may vary depending on the imaging method. The multicenter study by Crema et al.[4] analyzing a cohort of 1,527 subjects found a significant interaction between higher BMI and the imaging modality,

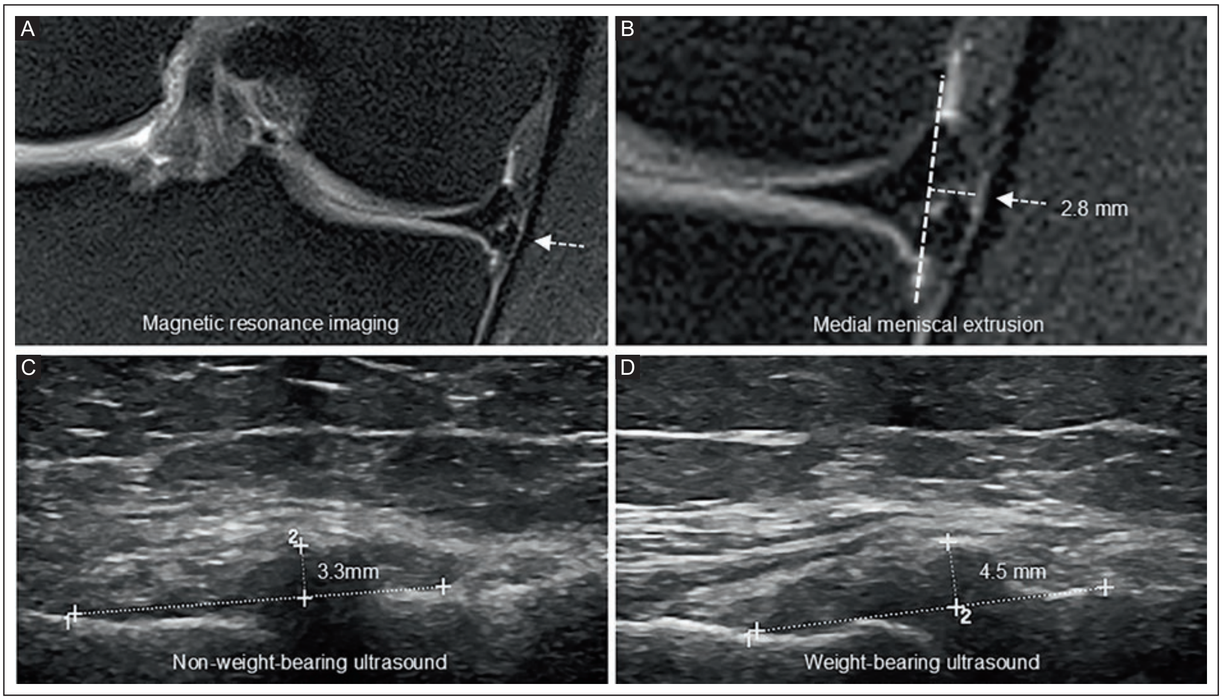

Figure 5. Comparison of imaging modalities of medial meniscal extrusion in a 41-year-old obese woman (BMI 39.7 kg/m^2) with knee pain. **A-B:** coronal proton density-weighted MRI with fat suppression shows minor medial meniscal extrusion of 2.8 mm (arrows). **C:** NWB-US shows major 3.3 mm medial meniscal extrusion. **D:** WB-US shows major 4.5 mm medial meniscal extrusion.

MRI: magnetic resonance imaging; NWB-US: non-weight-bearing ultrasound; WB-US: weight-bearing ultrasound.

suggesting that its influence on extrusion measurement may not be apparent on supine MRI but does manifest significantly under dynamic loading conditions such as WB-US, where joint forces are amplified. These findings support our results regarding age. The variation observed between NWB-US and WB-US suggests that the influence of BMI may be modulated by the imaging modality, an interaction our results demonstrate. The magnitude of extrusion depends on individual factors such as age, BMI, and loading conditions during assessment, linking the measurement to the imaging method used. The interpretation of medial meniscal extrusion should be contextualized by the patient's anthropometric profile and the imaging modality used, especially under functional loading conditions.

The most common finding associated with meniscal extrusion is a posterior meniscal root tear; isolated meniscal extrusion can also be observed[1]. The study by Gregio-Junior et al.[9] found that medial meniscal extrusion was associated with meniscal root tear in a small number of patients. They showed that knees with an extrusion ≥ 3 mm under load had MRI-confirmed tears, suggesting that extrusion severity may be an indirect indicator of structural damage and may present as an isolated finding in some cases. Krych et al.[23] examined 63 serial MRIs in patients with medial knee pain and noted that extruded menisci with intact roots progressed to develop a posterior root tear. Therefore, the extruded meniscus may increase biomechanical forces on the root attachment, leading to a complete root tear with minimal trauma. Chiba et al.[13] using fat-suppressed T2 MRI demonstrated that medial meniscal extrusion greater than 5 mm may be a risk factor for posterior root tear. This finding likely did not show a strong association in our study because the median medial meniscal extrusion was 2.9 mm (IQR 2.2-3.6 mm). WB-US may indicate meniscal instability even without a meniscal tear.

The main strength of this study is the direct comparison of imaging modalities for medial meniscal extrusion, including evaluation under actual axial loading – a rarely explored aspect. The appropriate use of nonparametric tests based on data distribution, corrections for multiple comparisons to reduce error risk, and the combined application of global and post hoc analyses to identify specific differences are also strengths. Additionally, the inclusion of robust tests for categorical variables, the consideration of potential confounding

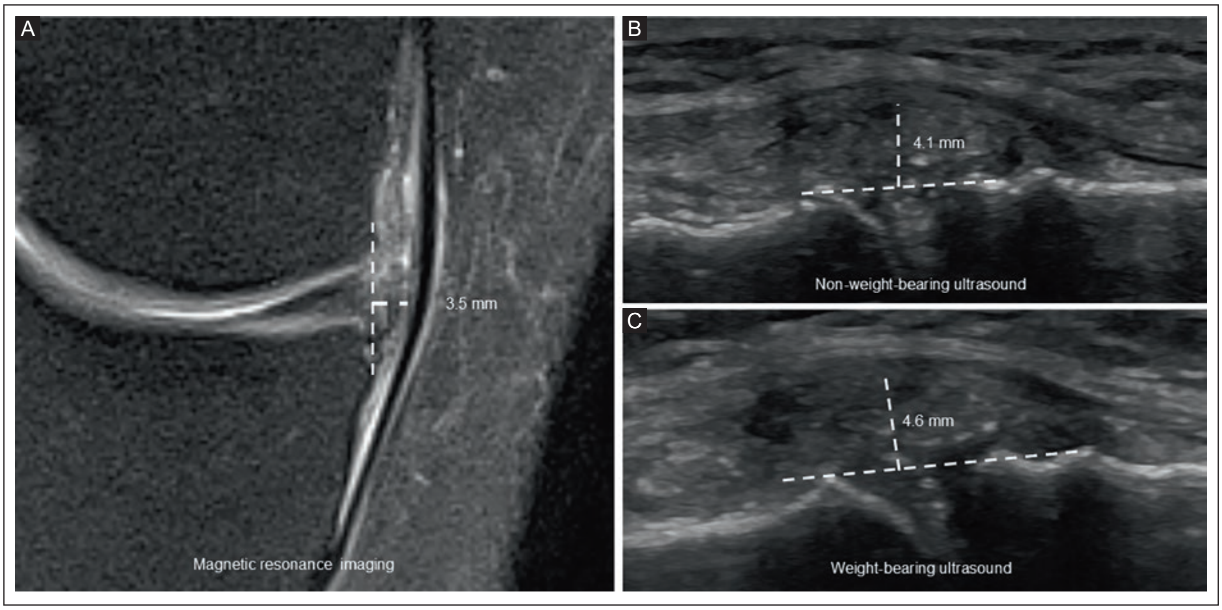

Figure 6. Comparison of imaging modalities for the medial meniscus of a 48-year-old obese man (BMI 31.2 kg/m²) with knee pain. **A:** coronal proton density-weighted MRI with fat suppression shows major 3.5 mm medial meniscal extrusion. **B:** NWB-US shows a major 4.1 mm medial meniscal extrusion. **C:** WB-US shows a major 4.6 mm medial meniscal extrusion.

MRI: magnetic resonance imaging; NWB-US: non-weight-bearing ultrasound; WB-US: weight-bearing ultrasound.

factors using linear mixed models, and the evaluation of correlations with appropriate methods further strengthen the study. As limitations, we acknowledge the cross-sectional design and small sample size, the operator-dependent nature of US, the potential influence of the patient's ability to stand. Interobserver and intraobserver concordance was not evaluated, although excellent intra- and interobserver agreement has been reported (ICC 0.95, 95% CI: 0.92-0.97)[10].

CONCLUSION

Our study provides evidence that WB-US has a greater ability than MRI and NWB-US to detect medial meniscal extrusion, supporting its value as a functional, accessible, and rapid diagnostic tool. Medial meniscal extrusion evaluated by WB-US should be considered a complementary functional assessment, not a replacement for the structural diagnosis provided by knee MRI. In clinical practice, a multimodal diagnosis of extrusion using ultrasound and MRI is ideal. WB-US can be used for screening and primary diagnostics, while MRI can confirm medial meniscal extrusion and assess associated pathology such as bone marrow edema, articular cartilage status, and meniscus integrity[1]. Incorporating WB-US as a first-line modality into diagnostic algorithms is recommended, along with the development of standardized protocols that account for loading conditions and individual patient characteristics. Future longitudinal studies with larger samples will be essential to validate the prognostic impact of these findings on the progression of meniscal pathology.

Acknowledgments

The authors thank Professor Ana M. Contreras-Navarro for her guidance in preparing and writing this scientific paper. The authors express their sincere gratitude to the Instituto Mexicano del Seguro Social for granting access to its facilities, equipment, and personnel, and especially for enabling patient recruitment and data collection. This original research in the Radiology Specialty field was an awarded thesis at the Tercera Convocatoria Nacional 2024-2025 "Las Mejores Tesis para Publicar en el JMeXFRI".

Funding

The authors declare that they have not received funding.

Conflicts of interest

The authors declare no conflicts of interest.

Ethical considerations

Protection of humans and animals. This study complied with the Declaration of Helsinki (1964) and subsequent amendments.

Confidentiality, informed consent, and ethical approval. The authors declare they followed their center's protocol for sharing patient data. Written informed consent was obtained from all study participants.

Declaration on the use of artificial intelligence. The authors did not use generative artificial intelligence to prepare this manuscript and/or create tables, figures, or figure legends.

REFERENCES

1. Langhans MT, Lamba A, Saris DBF, Smith P, Krych AJ. Meniscal extrusion: diagnosis, etiology, and treatment options. Curr Rev Musculoskelet Med. 2023;16(7):316-327. doi: 10.1007/s12178-023-09840-4.
2. Patel R, Eltgroth M, Souza R, Zhang CA, Majumdar S, Link TM. Loaded versus unloaded magnetic resonance imaging (MRI) of the knee: effect on meniscus extrusion in healthy volunteers and patients with osteoarthritis. Eur J Radiol Open. 2016;3: 100-107. doi: 10.1016/j.ejro.2016.05.002.
3. Costa CR, Morrison WB, Carrino JA. Medial meniscus extrusion on knee MRI: is extent associated with severity of degeneration or type of tear? AJR Am J Roentgenol. 2004;183(1):17-23. doi:10.2214/ajr.183.1.1830017.
4. Crema MD, Roemer FW, Felson DT, Englund M, Wang K, Jarraya M, et al. Factors associated with meniscal extrusion in knees with or at risk for osteoarthritis: the multicenter osteoarthritis study. Radiology. 2012; 264(2):494-503. doi:10.1148/radiol.12110986.
5. Nogueira-Barbosa MH, Gregio-Junior E, Lorenzato MM, Guermazi A, Roemer FW, Chagas-Neto FA, et al. Ultrasound assessment of medial meniscal extrusion: a validation study using MRI as reference standard. AJR Am J Roentgenol. 2015;204(3):584-588. doi:10.2214/AJR.14.12522.
6. Papalia GF, Za P, Saccone L, Franceschetti E, Zampogna B, Vasta S. Meniscal extrusion: risk factors and diagnostic tools to predict early osteoarthritis, Orthop Rev (Pavía). 2023;15:74881. doi:10.52965/001c.74881.
7. Gajjar SM, Solanki KP, Shanmugasundaram S, Kambhampati SBS. Meniscal extrusion: a narrative review. Orthop J Sports Med. 2021;9(11): 23259671211043797. doi:10.1177/23259671211043797.
8. Swamy N, Wadhwa V, Bajaj G, Chhabra A, Pandey T. Medial meniscal extrusion: detection, evaluation and clinical implications. Eur J Radiol. 2018;102:115-124. doi: 10.1016/j.ejrad.2018.03.007.
9. Gregio-Junior E. Taneja AK, Crema MD, Meneses-Reis R, Müller-Lorenzato M, Chagas-Neto FA. Effect of weightbearing on medial meniscal extrusion: dynamic ultrasound with MRI correlation. Acta Radiol. 2025;66(9): 982-990. doi:10.1177/02841851251339007.
10. Boksh K, Shepherd DET, Espino DM, Shepherd J, Ghosh A, Aujla R. Assessment of meniscal extrusion with ultrasonography: a systematic review and meta-analysis. Knee Surg Relat Res. 2024;36(1):33. doi: 10.1186/s43019-024-00236-3.
11. Cho JC, Tollefson L, Reckelhoff K. Sonographic evaluation of the degree of medial meniscal extrusion during Thessaly test in healthy knees. Chiropr Man Therap. 2021;29(1):31. doi:10.1186/s12998-021-00390-5.
12. Razek AA, Fouda NS, Elmetwaley N, Elbogdady E. Sonography of the knee joint. J Ultrasound. 2009;12(2):53-60. doi:10.1016/j.jus.2009.03.002.
13. Chiba D, Sasaki T, Ishibashi Y. Greater medial meniscus extrusion seen on ultrasonography indicates the risk of MRI-detected complete medial meniscus posterior root tear in a Japanese population with knee pain. Sci Rep. 2022; 12(1): 4756. doi: 10.1038/s41598-022-08604-3.
14. Heismann B, Ott M, Grodzki D. Sequence-based acoustic noise reduction of clinical MRI scans. Magn Reson Med. 2015;73(3):1104-1109. doi: 10.1002/mrm.25229.
15. Nemenyi PB. Distribution-free multiple comparisons: Princeton University; 1963.
16. Cochran WG. The comparison of percentages in matched samples. Biometrika. 1950;37(3-4):256-266. doi: 10.1093/biomet/37.3-4.256.
17. McNemar Q. Note on the sampling error of the difference between correlated proportions or percentages. Psychometrika. 1947;12(2): 153-157. doi: 10.1007/BF02295996.
18. Holm S. A simple sequentially rejective multiple test procedure. Scan J Statistics. 1979;6(2):65-70.
19. Daney BT, Aman ZS, Krob JJ, Storaci HW, Brady AW, Nakama G. Utilization of transtibial centralization suture best minimizes extrusion and restores tibiofemoral contact mechanics for anatomic medial meniscal root repairs in a cadaveric model. Am J Sports Med. 2019;47(7): 1591-1600. doi: 10.1177/0363546519844250.
20. Falkowski AL, Jacobson JA, Cresswell M, Bedi A, Kalia V, Zhang B. Medial meniscal extrusion evaluation with weight-bearing ultrasound: correlation with MR imaging findings and reported symptoms. J Ultrasound Med. 2022; 18(41):2867-2875. doi:10.1002/jum.15975.
21. Muzaffar N, Kirmani O, Ahsan M, Ahmad S. Meniscal extrusion in the knee: should only 3 mm be considered significant? Malays Orthop J. 2015;9(2):17-20. doi:10.5704/MOJ.1507.013.
22. Achtnich A, Petersen W, Willinger L, Sauter A, Rasper M, Wörtler K, et al. Medial meniscus extrusion increases with age and BMI and is depending on different loading conditions. Knee Surg, Sports Traumatol, Arthrosc. 2018;26(8):2282-2288. doi.org/10.1007/s00167-018-4885-7.
23. Krych AJ, LaPrade MD, Hevesi M, Rhodes NG, Johnson AC, Camp CL, et al. Investigating the chronology of meniscus root tears: do medial meniscus posterior root tears cause extrusion or the other way around? Orthop J Sports Med. 2020;8(11):2325967120961368. doi: 10.1177/2325967120961368.