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# Role Of Musculoskeletal Ultrasound In Assessment Of Extrusion Of The Medial Meniscus Of The Knee Joint Compared To MRI As A Reference Standard

Gehad Mohamed Mahmoud Elkwesny [1], Khaled Ahmed Mohamed Ali [1], Hossam Moussa El Sayed Sakr [1], Mohsen Gomaa Hassan Ismael [1]

Radio diagnosis Department-Faculty of Medicine-Ain Shams University, Cairo, Egypt
Corresponding Author, Gehad Mohamed Mahmoud Elkwesny

## ABSTRACT

Background: When a medial meniscal posterior root tear occurs, changes in the biomechanics of the medial tibiofemoral joint and inability to convert axial loads into hoop stresses occur with subsequent meniscal extrusion. A meniscal extrusion of 3mm is associated with accelerated articular cartilage loss and osteophyte formation resulting in a more rapid progression of osteoarthritis.
Although MRI doesn't evaluate the meniscus during axial loading, it is considered the gold standard for evaluation of meniscal extrusion. On the other hand, US can assess the patients at supine and weight-bearing positions. This advantage facilitates early detection of meniscal extrusion, so we can limit its poor effects on the medial knee compartment.
Results: This study included thirty patients with medial meniscal posterior root tear diagnosed by MRI. This study's aim is to recognize the value of dynamic ultrasound in evaluating medial meniscal extrusion compared to MRI.
A statistically significant difference was found when the absolute measures for extrusion distance were compared between standing and supine US, between supine US and MRI as well as between standing US and MRI (P-value= 0.000 for all those comparisons). Also, when the absolute measures of the extruded area at standing and supine US were compared, a statistically significant difference was found (P-value=0.000).
Comparing the qualitative data, there was no statistically significant difference between the results of supine US and MRI (P-value=0.541) with a statistically significant difference found between the results of standing US and MRI (P-value=0.0.002) and between the results of supine and standing US (P-value=0.010).
Compared to MRI, supine and standing US showed excellent sensitivity (100%). Also, supine US showed good specificity (75%) while standing US showed poor specificity (0%). The explanation for this poor specificity is that standing US detected dynamic radial meniscal extrusion occurring during axial loading while non-weight-bearing MRI didn't, so those patients detected only by standing US were considered false-positive during statistical analysis causing a poor specificity value.
Conclusion: Dynamic US facilitates early detection of significant meniscal extrusion before it can be evident on MRI because it can detect dynamic radial meniscal displacement seen on axial loading.

**Keywords:** Posterior root tear, medial meniscal extrusion, weight-bearing, dynamic US, MRI

**Correspondence**:
Gehad Mohamed Mahmoud Elkwesny
Radio diagnosis Department-Faculty of Medicine-Ain Shams University, Cairo, Egypt

*Corresponding author: Gehad Mohamed Mahmoud Elkwesny

## INTRODUCTION

The medial meniscus is a crescent-shaped disc of fibrocartilage seen at the medial knee compartment at the interface between the femur and tibia. During weight-bearing, the meniscus is compressed because the tensile strength of its healthy collagen fibers prevents extrusion. So, the main meniscal functions are load transmission to a large area of the articular cartilage, stabilization of the knee joint and shock absorption during joint movement **(1).**

The posterior horn of the medial meniscus is the main structure that maintains the hoop tension during loading. It is attached strongly to the tibial spine by the posterior root. The posterior root of the medial meniscus is almost fixed, so it is susceptible to damage **(2).**

Medial meniscus posterior root tear leads to increased contact pressure at the medial compartment of the knee joint and this is similar to the effects of subtotal meniscectomy. On the other hand, knee joints with posterior root repair show a contact pressure equal to the maximum contact pressure seen at a knee with an intact medial meniscus **(3).**

When a posterior root tear occurs, this leads to abnormal biomechanics of the medial tibiofemoral joint as well as inability to convert axial loads into hoop stresses thus, a radial displacement of the medial meniscus called medial meniscal extrusion is induced **(4).**

The degree of medial meniscal extrusion can affect the postoperative clinical outcome after posterior root repair. Patients with small degrees of medial meniscal extrusion show more promising clinical and radiographic findings after posterior root repair than those with higher degrees of medial meniscal extrusion **(4).**

Medial meniscal extrusion may also occur with degenerative meniscal tears **(2)**. Despite the strong association between medial meniscal subluxation and meniscal tears, it is thought that meniscal subluxation is an independent predictor of articular cartilage damage and subchondral bone erosions seen at the medial tibiofemoral joint **(5).**

A medial meniscus extrusion of 3mm or more has been linked to increased articular cartilage loss and osteophyte formation. Thus, detection of the degree of medial meniscal extrusion is an important prognostic clue as a large degree of meniscal extrusion suggests a more rapid progression of knee osteoarthritis **(6, 7).**

The presence of medial meniscal extrusion carries a high risk for development of bone marrow lesions and contributes to the joint-space narrowing seen at knee radiographs. Thus, meniscal extrusion is an integral part of progression of knee osteoarthritis **(1).**

MRI is the gold standard for non-invasive evaluation of meniscal disorders and meniscal extrusion. Both semi quantitative and quantitative methods have been used to assess meniscal extrusion. However, routine MRI studies don't assess the meniscus in the weight-bearing position and this is a drawback of MRI when evaluation of meniscal extrusion is important for the patient **(5).**

On the other hand, ultrasound is a perfect imaging technique for assessment of musculoskeletal soft tissues. In the knee joint, ultrasound is proven to be more sensitive than clinical examination for detecting intra- or periarticular conditions, including meniscal abnormalities, medial collateral ligament (MCL) lesions, bursitis and knee joint effusion **(8).**

It is also a non-invasive, simple, relatively fast and less expensive technique, compared to MRI, which offers assessment of the patient at both supine and weight bearing positions **(9).**

Those factors suggest that ultrasound can help us to recognize the causes and outcome of meniscal extrusion as well as its role in progression of medial tibiofemoral compartment abnormalities **(5).**

The aim of this study is to recognize the value of knee ultrasound performed at both supine and standing (weight bearing) positions in evaluating the degree of medial meniscal extrusion and to compare the results with non-weight-bearing MRI.

## METHODS

**Participants:** This prospective study was performed on thirty patients with knee osteoarthritis who had an already diagnosed posterior root tear of the medial meniscus based on MRI of the knee performed at our department. Those patients were included whether the root tear was associated with meniscal extrusion on the MRI study or not **(Inclusion criteria).**

**Exclusion criteria:**

- Patients who can't stand during the US examination.
- Patients with an age of 18 years or less.
- Inflammatory arthritis and Rheumatoid arthritis.
- Previous surgery to the knee being assessed.
- Previous fracture of the knee being assessed.
- Ligamentous injury of the knee being assessed.
- Meniscal tears other than medial meniscal posterior root tear at the knee being assessed.

The US procedure details were explained to the patients and written informed consents were obtained. This study was approved by the research ethical committee and it was conducted during the period from March 2019 to December 2019.

**Technique:**

A full history was taken prior to the US examination including age, affected knee, and past history of minor or major trauma, fractures and knee surgery.

Patients underwent an ultrasound assessment of the medial compartment of the affected knee using a Logiq p7 (General electric) machine with a real-time 5-12MHz linear array transducer. The patients were examined in the supine position with fully extended knees. Ultrasound images were acquired at the medial aspect of the knee with the transducer aligned with the long axis of the examined limb. Longitudinal sections parallel to the medial collateral ligament (MCL) were obtained.

Medial meniscal extrusion distance and extruded meniscal area were measured using the longitudinal ultrasound sections at the site where the medial collateral ligament is most clearly visualized while the reader, who is a radiology consultant having 12 years of experience in musculoskeletal ultrasound, is blinded to clinical and MRI data. A line was drawn connecting the external edges of the medial tibial plateau and medial femoral condyle, excluding osteophytes, and used as a reference for extrusion measurements. Both extrusion distance and area were then measured.

The skin was marked at the site where the measurements were taken to ensure the exact placement of the transducer at the standing ultrasound examination. The patients were examined at the standing (weight-bearing) position and again extrusion distance and area were measured using the same steps as in supine position. The method used for taking the measurements is described in **Fig. 1.**

It is important to mention that MCL is visualized at the US images as a three-layer structure: two hyperechoic layers separated by a thin hypoechoic layer. The deep hyperechoic layer of the MCL closely adheres to the external edge of the medial meniscus. In patients with osteoarthritic changes, the meniscus is mostly extruded and macerated, so it would be difficult to visualize the deep layer of the MCL as a separate layer from the macerated meniscus at US images. On the other hand, the middle hypoechoic band of the MCL is clearly visualized, so it was used as our reference landmark for MCL. This same landmark was previously used by Acebes et al. **(8).**

MR images were obtained with the same 1.5 T machine (Achieva and Ingenia, Philips medical system, Eindhoven, Netherlands) using an 8-channel dedicated phased array knee coil. Our routine MRI knee protocol included six sequences: axial (T2WI), sagittal (T2WI, PDWI and STIR) and coronal (T1WI and STIR) performed while the patient is positioned in the supine position with his knees fully extended. The MRI images were interpreted by a radiology consultant having 9 years of experience at interpreting musculoskeletal MRI.

Both qualitative and quantitative approaches were used for evaluation of medial meniscal extrusion distance using MRI, supine and weight-bearing ultrasound then the results were compared. The qualitative approach refers to the evaluation of extrusion distance in terms of significance, so the results were divided into significant extrusion distance (positive case) if this distance is ≥ 3 millimeters or insignificant (negative case) if extrusion distance is < 3 millimeters. The quantitative approach in our study refers simply to the use of the absolute measurements of meniscal extrusion distance (in millimeters).

For evaluation of the medial meniscal extrusion area at both supine and weight-bearing US, quantitative approach only was followed using the absolute measurements of meniscal extrusion area (in square centimeters).

**Statistical Analysis:**

Data were collected, revised, coded and entered to the Statistical Package for Social Science (IBM SPSS) version 23. The quantitative data were presented as mean, standard deviations and ranges while the qualitative variables were presented as numbers and percentages.

The comparison between paired groups regarding quantitative data was done using Paired t-test while the

comparison between groups regarding qualitative data was done by using Chi-square test.
Receiver operating characteristic curve (ROC) in the form of quali[redacted]ata was used to assess the sensitivity, specifici[redacted]tive predictive value (PPV), negative predictiv[redacted] (NPV) and accuracy of supine and standing US taking MRI as a gold standard.

The confidence interval was set to 95% and the margin of error accepted was set to 5%. So, the p-values were interpreted as follows:
P-value >[redacted]n-significant (NS)
P-value <[redacted]nificant (S)
P-value [redacted]ighly significant (HS)

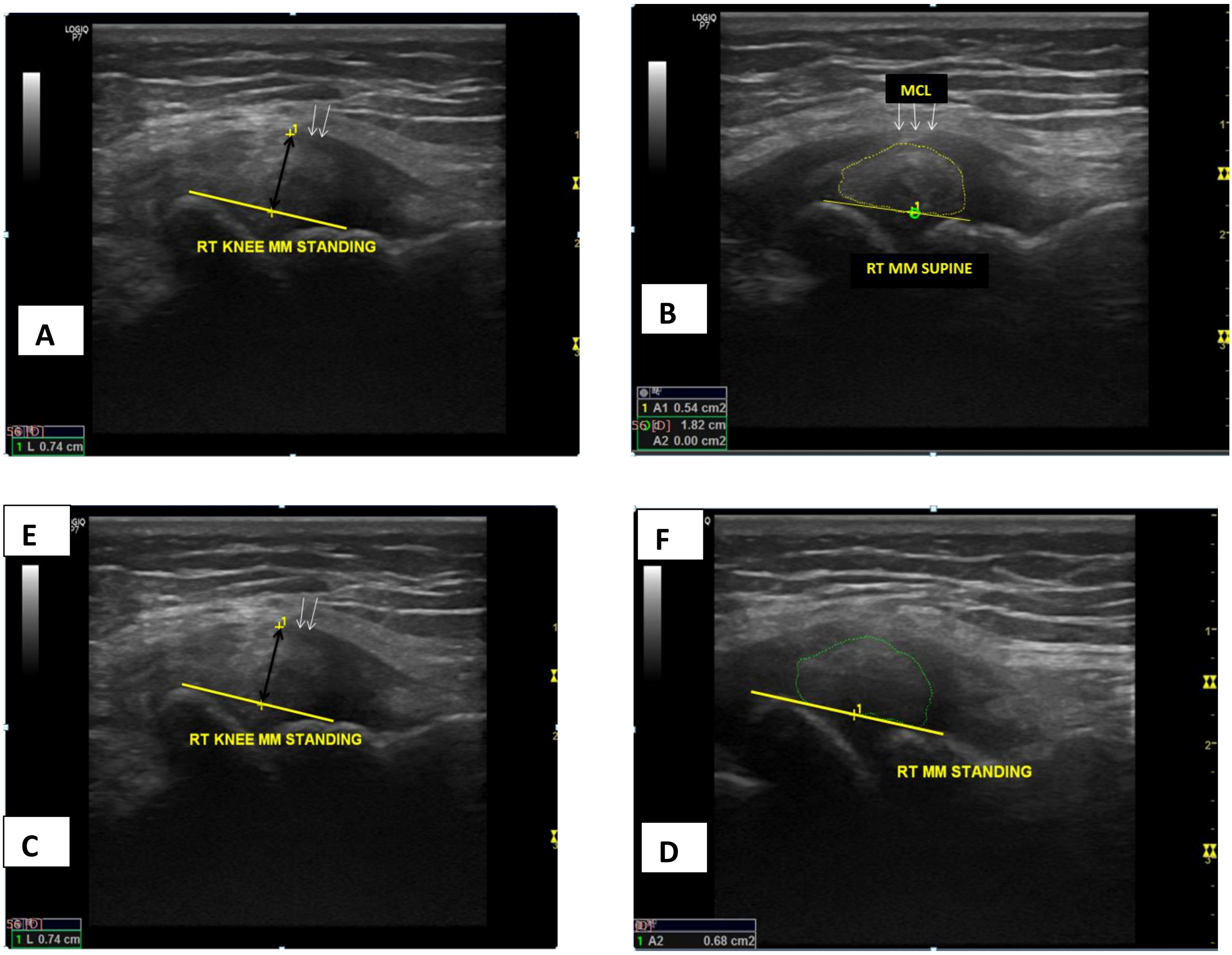
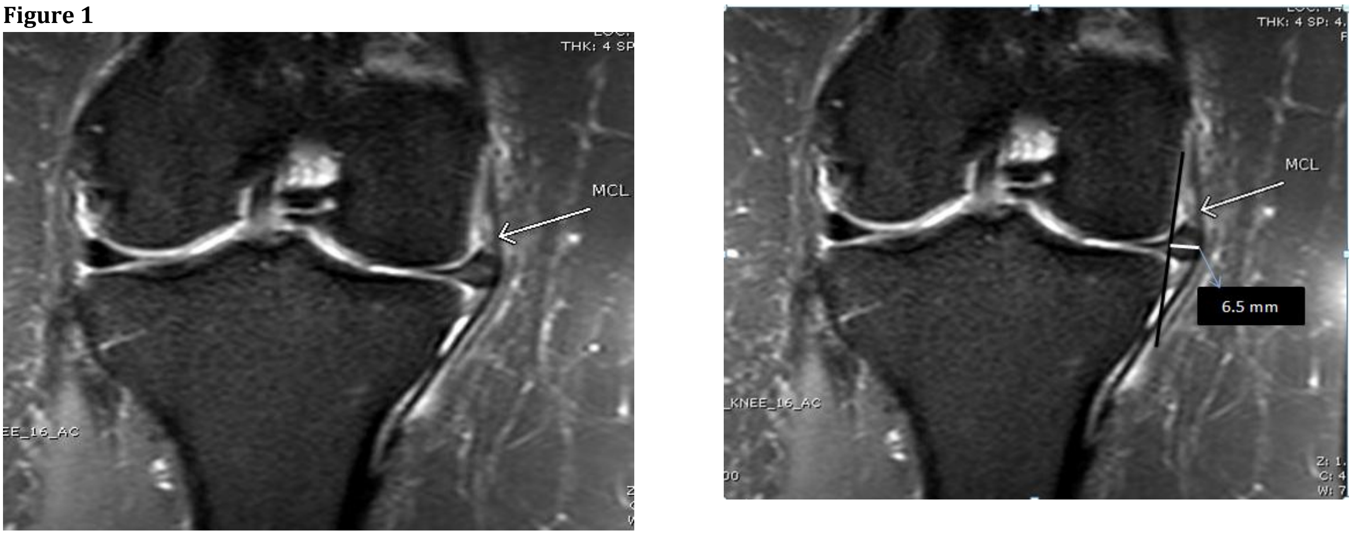



**Figure 1**



Longitudinal US images of the medial femoro-tibial joint for a 46-year-old male patient at the level where the medial collateral ligament (white arrows) is most clear (A, B, C & D).

The meniscal extrusion distance was measured by drawing a tangential line to the external edge of the medial tibial plateau (excluding osteophytes) which is extended to pass tangentially by the external edge of the medial femoral condyle and then this line (yellow line) was used as a reference for extrusion measurements. Perpendicular to the above-mentioned line, a second line (black double-ended arrow) was drawn connecting the reference line (yellow line) to the outer margin of the extruded meniscus (almost at the internal edge of the intermediate hypoechoic layer of the MCL) and used as a measurement for meniscal extrusion distance at both supine position (A) and weight-bearing standing position(C). While the extruded meniscal area was obtained by measuring the meniscal area seen in-between the reference line (yellow line) and the outer margin of the extruded meniscus. The extruded area was measured at both supine and weight-bearing standing positions as shown at (B &D) respectively.

Coronal STIR MR images for the same patient at the level where the medial collateral ligament (white arrow) is most clear (E &F). The meniscal extrusion distance was again measured by drawing a reference line similar to that drawn at US images connecting the external edges of the medial tibial plateau and the medial femoral condyle and excluding osteophytes (black line). Again, a perpendicular line (white line) similar to that used at US images was drawn connecting the reference line to the outer margin of the extruded meniscus and used as a measurement for meniscal extrusion distance.

## RESULTS

This study was carried on 30 patients (24 females and 6 males) with their age ranging between 40 and 64 years (mean age = 47.8 ± 7.58 years). The right knee was examined at 22 cases (73.3%) while the left knee was examined at 8 cases (26.7%). In one of the patients, bilateral root tears were detected and both knee joints were thus included in our study.

For quantitative evaluation of meniscal extrusion distance, the mean (± SD) extrusion distance was 4.31 ±1.52 mm on supine US, 6±1.21 mm on standing US and 4 ±1.53 mm on MRI. When comparing those absolute measures between standing and supine US, a statistically significant difference was found (P-value=0.000). Also, when the absolute values for extrusion distance obtained by supine and standing US were compared to those obtained by MRI, a statistically significant difference was also present (P-value= 0.000 for both comparisons) **(Tables 1, 2 &3).**

For qualitative evaluation of meniscal extrusion distance, supine US detected significant meniscal extrusion at 24 cases (80%) while weight-bearing US detected significant meniscal extrusion at 30 cases (100%). Finally, MRI detected significant meniscal extrusion at 22 cases (73.3%). When comparing the qualitative data obtained by supine US and MRI, there was no statistically significant difference between them (P-value=0.541). When a similar comparison of the qualitative data obtained by standing US and MRI was performed, there was a statistically significant difference (P-value=0.002). A statistically significant difference was also found when the same comparison was performed between the results of supine and standing US (P-value=0.010) **(Tables 1, 2 &3).**

For quantitative evaluation of meniscal extrusion area, the mean (± SD) extrusion area was 0.34 ± 0.21 $cm^2$ on supine US while the mean (± SD) extrusion area was 0.53 ± 0.25 $cm^2$ on standing US. When comparing those absolute measures of extruded area between standing and supine US, there was a statistically significant difference between them (P-value=0.000) **(Table 1).**

When the qualitative data obtained by supine and standing US were compared with MRI as a reference, excellent sensitivity (100%) was obtained for both supine and standing US. This comparison also revealed a high PPV (91.7%) for supine US and a relatively low PPV (73.3%) for standing US **(Table 4).**

It also revealed good specificity (75%) and an excellent NPV (100%) for supine US with poor specificity (0%) and NPV (0%) for standing US **(Table 4).**

The resultant diagnostic accuracy of supine and standing US were 93.3% and 73.3% respectively **(Table 4).**

| | | Supine US | Standing US | Test value | P-value | Sig. |
|---|---|---|---|---|---|---|
| | | No.= 30 | No.= 30 | | | |
| Extrusion Distance (mm) | Mean ± SD | 4.31 ± 1.52 | 6.00 ± 1.21 | -16.781• | 0.000 | HS |
| | Range | 1 – 7 | 3.7 – 8 | | | |
| Significant extrusion distance or not | No | 6 (20.0%) | 0 (0.0%) | 6.667* | 0.010 | S |
| | Yes | 24 (80.0%) | 30 (100%) | | | |
| Area ($cm^2$) | Mean ± SD | 0.34 ± 0.21 | 0.53 ± 0.25 | -11.389• | 0.000 | HS |
| | Range | 0.08 – 0.8 | 0.2 – 1.08 | | | |

P-value >0.05: Non significant (NS); P-value <0.05: Significant (S); P-value< 0.01: highly significant (HS)
*:Chi-square test; •: Paired t- test

**Table (1):- Comparison of meniscal extrusion distances and areas between supine and standing US.**

| | Supine US | MRI | Test value | P-value | Sig. |
|---|---|---|---|---|---|

| | | No.= 30 | No.= 30 | | | |
|---|---|---|---|---|---|---|
| Extrusion Distance (mm) | Mean ± SD<br>Range | 4.31 ± 1.52<br>1 – 7 | 4.00 ± 1.53<br>1.3 – 7 | 5.388• | 0.000 | HS |
| Significant extrusion distance or not | No<br>Yes | 6 (20.0%)<br>24 (80.0%) | 8(26.7%)<br>22 (73.3%) | 0.373* | 0.541 | NS |

P-value >0.05: Non significant (NS); P-value <0.05: Significant (S); P-value< 0.01: highly significant (HS)
*:Chi-square test; •: Paired t- test

**Table (2): Comparison of meniscal extrusion distances between supine US and MRI.**

| | | Standing US | MRI | Test value | P-value | Sig. |
|---|---|---|---|---|---|---|
| | | No.= 30 | No.= 30 | | | |
| Extrusion Distance US (mm) | Mean ± SD<br>Range | 6.00 ± 1.21<br>3.7 – 8 | 4.00 ± 1.53<br>1.3 – 7 | 14.936• | 0.000 | HS |
| Significant extrusion distance or not | No<br>Yes | 0 (0.0%)<br>30 (100%) | 8 (26.7%)<br>22 (73.3%) | 9.231* | 0.002 | HS |

P-value >0.05: Non significant (NS), P-value <0.05: Significant (S), P-value< 0.01: highly significant (HS)
*:Chi-square test; •: Paired t- test

**Table (3):- Comparison of meniscal extrusion distances between standing US and MRI.**

Diagnostic accuracy of US standing and supine in prediction of MRI results

| | | Significant Extrusion Distance on MRI | | | | Sensitivity | Specificity | PPV | NPV | Accuracy |
|---|---|---|---|---|---|---|---|---|---|---|
| | | No | | Yes | | | | | | |
| | | No. | % | No. | % | | | | | |
| **Significant extrusion distance on supine US** | No | 6 | 75.0% | 0 | 0.0% | 100.00% | 75.00% | 91.70% | 100.00% | 93.30% |
| | Yes | 2 | 25.0% | 22 | 100.0% | | | | | |
| **Significant extrusion distance on standing US** | No | 0 | 0.0% | 0 | 0.0% | 100.00% | 0% | 73.30% | 0% | 73.30% |
| | Yes | 8 | 100.0% | 22 | 100.0% | | | | | |

**Table (4): Sensitivity, specificity, positive predictive value (PPV), negative predictive value (NPV), and accuracy of supine and standing US in prediction of MRI results.**

## DISCUSSION

Although MRI is considered as the gold standard for non-invasive evaluation of meniscal extrusion, routine MRI studies don't evaluate the meniscus under weight-bearing. On the other hand, ultrasound which is a widely available, relatively non-expensive technique offers the advantage of dynamic evaluation of meniscal displacement under axial-loading.

Axial-loading to the knees using MRI can be performed **(10)** however, this procedure is time-consuming and requires special MRI devices. For those reasons, using MRI for evaluation of patients under axial loading is a relatively difficult technique compared to the easy and fast ultrasound technique. Also, it is unlikely that this MRI procedure could achieve the same physiologic axial load seen at the standing position exactly **(5).**

To our knowledge, this is the first study that compared dynamic displacement of the medial meniscus at weight-bearing ultrasound to MRI. We also evaluated the medial meniscal displacement that occurred when the patient's position was changed from supine to standing (weight-bearing) position in patients with a posterior root tear of the medial meniscus.

Using medial meniscal extrusion distance as a measure for meniscal extrusion, the results of this study revealed that the degree of medial meniscal extrusion is significantly higher in the weight-bearing US than in the non-weight-bearing MRI. A significant difference was also found between the weight-bearing US and the non-weight-bearing MRI based on qualitative data.

The results also confirmed that the degree of medial meniscal extrusion is significantly higher in the weight-bearing US than in the non-weight-bearing supine US and this point is consistent with the previous reports of Acebes et al. **(8)** and Kawaguchi et al. **(9).**

The qualitative results of this study revealed no significant difference in the degree of meniscal subluxation between the non-weight-bearing US and the non-weight-bearing MRI and this is consistent with the results obtained by Nogueira-Barbosa et al. **(5).** However, the quantitative results revealed that the degree of medial meniscal extrusion is higher in the non-weight-bearing US than in the non-weight-bearing MRI and this is different from the results obtained by Nogueira-Barbosa et al. **(5)** yet this difference could be explained by the fact that the deep part of the MCL was included in our US measurements for meniscal extrusion because it was difficult to discriminate it from the macerated meniscus in our patients with osteoarthritis leading to some overestimation of meniscal extrusion.

The current study's results are consistent with Gale et al. **(11)** who used MRI to evaluate medial meniscal extrusion and reported a mean medial meniscal extrusion distance of 4.3 ± 3.4 mm in females with osteoarthritis which is similar to our results (4 ±1.56 mm).

The results of this study are also consistent with Acebes et al. **(8)** who studied meniscal subluxation in patients with osteoarthritis as regards the medial meniscal extrusion distance at supine US position. They reported an extrusion distance of 3.96 ± 1.2 mm which is similar to the current results (4.31 ±1.52 mm). However, they reported a medial meniscal extrusion distance of 5.02 ± 1.68 mm at weight-bearing US which is slightly less than the current results (6±1.21 mm). This difference in weight-bearing position may be attributed to a larger dynamic displacement at our patients because of the posterior root tear.

The importance of using the medial meniscal extruded area as a method of determining dynamic meniscal displacement was also examined in this study. The mean medial meniscal extrusion area was 0.34 ± 0.21 $cm^2$ on supine US which is similar to the mean area obtained by Acebes et al. **(8)** (0.35 $cm^2$) yet our mean medial meniscal extrusion area at weight-bearing position (0.53 ± 0.25 $cm^2$) on standing US is relatively higher than the mean area obtained by Acebes et al. **(8)** (0.38 $cm^2$). Again, this difference in weight-bearing position may be attributed to a larger dynamic displacement at the current study's patients because of the posterior root tear.

When medial meniscal extrusion area was used as a measure for meniscal extrusion, our results showed that there is a significant difference between the degree of medial meniscal extrusion in the weight-bearing US and the non-weight-bearing supine US and this point is consistent with Verdonk et al. **(12)** who studied lateral meniscal extrusion in normal and transplanted lateral menisci under different axial loading positions. They found that both extrusion distance and cross-sectional area are good parameters to assess meniscal extrusion. However, our results as regards the importance of area's measurement are different from Acebes et al. **(8).**

Using MRI as a reference, the qualitative results of the current study revealed excellent sensitivity (100%) for supine US which is slightly higher than the previous sensitivity value obtained by Nogueira-Barbosa et al. **(5)** and this could be explained by the fact that our patients with posterior root tears are more likely to have meniscal extrusion than their patients with only chronic knee pain. Also, our results for supine US specificity (75%) are similar to the values obtained by Nogueira-Barbosa et al. **(5).**

When qualitative results of standing US were compared to MRI, excellent sensitivity of 100% and poor specificity of 0% were obtained.

To explain this poor specificity value, it is important to mention that medial meniscal extrusion is a frequent observation in patients with posterior root tears and that medial meniscal extrusion value increases progressively within the short duration after the onset of a symptomatic medial meniscal posterior root tear as described by Furumatsu et al. **(4).** Thus, the examined patients are likely to develop a significant meniscal extrusion within a short duration after the development of the posterior root tear. Also, it should be clarified that a positive case in the current study was defined as a case with a meniscal extrusion distance of ≥ 3 mm. Thus, a case with an extrusion distance of < 3mm was considered negative despite the presence of a non-significant extrusion.

On non-weight-bearing MRI, eight of the examined patients showed a non-significant meniscal extrusion of < 3mm, so they were considered negative despite the presence of a posterior root tear. When those eight patients were evaluated under axial-loading using weight-bearing US, a significant extrusion of ≥ 3 mm was detected and so they were considered positive depending on standing US results. During statistical analysis, they were considered false-positive because MRI was used as the reference, so a poor specificity value was obtained. Actually, this discrepancy is likely attributed to the fact that standing US can detect dynamic radial meniscal extrusion occurring during axial loading in patients with a radial root tear while non-weight-bearing MRI can't. This is actually considered a drawback of MRI when detection of significant meniscal extrusion occurring during weight-bearing is important.

However, to confirm this point of view, it would be better if future studies could be able to include a normal control group which was one of the major limitations of this study as it wasn't possible to include a control group. This is because the included subjects were those who already performed MRI at our department, so it was difficult to obtain patients with no knee abnormality to act as normal control. When a comparison of extrusion measurements between MRI and weight-bearing US is going to be performed at those normal controls, it is expected that no significant extrusion would be detected neither at non-weight-bearing MRI nor weight-bearing US and thus confirming the previously mentioned point of view that standing US is a specific tool for detection of significant meniscal extrusion.

The second limitation of the current study is the relatively small number of patients showing a non-significant extrusion at MRI that turned to be significant at weight-bearing US. Meniscal extrusion at those patients wouldn't have been diagnosed if we depended only on MRI. Further investigation for more of those patients is recommended for future studies.

Another limitation of this study is that included patients are those who already performed MRI. Thus, it wasn't possible to put skin markers at the site where extrusion measurements were taken using MRI and so it was difficult to take extrusion measurements at the same point for the same patient using US. Readers tried to overcome this point by using the MCL as a reference for measurement at both techniques and taking the measurements at the site where the MCL was most clearly visualized. This was not the case when comparing supine to standing US because it was possible to put skin markers, so the measurements were taken at the same point for each patient.

Another possible limitation is that medial meniscal extrusion was measured at the standing position with the knee joint extended and thus the dynamic effects of flexion during walking and calf rotation weren't evaluated.

The last limitation is that lateral menisci weren't evaluated because most lateral menisci in the sample weren't extruded, so we aren't sure that those results can also be applied to the lateral menisci. This point should be investigated in future studies.

## CONCLUSION

This study confirms that supine US has excellent diagnostic performance for assessment of meniscal extrusion in patients with radial root tear compared to MRI. It also showed that dynamic US evaluation can detect the dynamic radial meniscal displacement which occurs during axial loading leading to earlier detection of meniscal extrusion before it can be evident on MRI and so trying to limit its poor effects on the medial knee compartment.

List of abbreviations:
MRI: Magnetic Resonance Imaging
US: Ultra-Sound
MCL: Medial Collateral Ligament
MHz: Mega-Hertz
T: Tesla
T2WI:T2-weighted
PDWI: Proton-density-weighted
STIR: Short tau inversion recovery
T1WI: T1 weighted
ROC: Receiver operating characteristic curve
PPV: Positive predictive value
NPV: Negative predictive value
HS: Highly significant
S: Significant
NS: Non-significant
SD: Standard deviation

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