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ORIGINAL STUDY

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Meniscal extrusion under increasing varus in stress patients with a medial meniscus posterior root-tear

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Posterior root-tear of the medial meniscus and accompanied meniscal extrusion can lead to functional loss of the meniscus. The aim of this study is to assess medial meniscus extrusion at increasing varus forces utilizing magnetic resonance imaging (MRI), in order to evaluate the contribution of the adduction moment of the knee during gait. We prospectively enrolled 19 patients (38 knees). Patients underwent gait analysis testing to calculate adduction moment, followed by an MRI at rest and with increasing varus forces according to the patient's specific adduction moment. Meniscal extrusion and root gap at increasing varus forces were measured and compared. Functional outcomes and their association to meniscal extrusion was analyzed. We found the average meniscal extrusion at rest, 100% and 150% applied varus force for the control group to be 1.7mm, 1.7mm and 1.9mm, respectively; and for the index group average meniscal extrusion was 5.3mm, 6.4mm and 6.8mm, respectively. Meniscal extrusion increase from rest to 100% varus force was significantly higher in the index group (p=0.0002). Further meniscal extrusion and root gap increase from 100% varus force to 150% varus force did not show a statistically significant difference (p=0.39). The association between greater increase of meniscal extrusion with varus force and WOMAC scores was not statistically significant. In conclusion this study defines the contribution of the varus force component of the adduction moment to meniscal extrusion, in patients with a medial meniscus posterior root-tear.

Keywords : Medial meniscus; root-tear; extrusion; MRI; gait analysis.

INTRODUCTION

The menisci main functions are shock absorption, reduction of pressure loads across the knee and to assist knee stability *(1-3)*. Medial meniscus root-tears compromise meniscal integrity, often resulting in meniscal extrusion and impairment in transmission of circumferential hoop stresses. Root-tear of the meniscus and the consequential meniscal extrusion may be practically equivalent to a non-functional meniscus or a status post of total meniscectomy *(4)*. Previous literature has demonstrated root-tear and accompanied meniscal extrusion to promote degeneration of articular cartilage; subsequently leading to osteoarthritis *(5-9)*.

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Magnetic resonance imaging (MRI) is the primary tool for diagnosing medial meniscus root-tear, besides arthroscopy. Studies report MRI has a sensitivity and specificity of up to 93.3% and 100%, respectively *(4)*. MRI is a static examination normally performed in a supine, non-weight bearing position; therefore studying the effect of gait on the meniscal movement is difficult.

Several previous studies have attempted to imitate the effect of gait on meniscus positioning with or without meniscal pathology, *(8-11)* however, we are unaware of any study assessing the effect of adduction moment on meniscal extrusion in patients with a posterior root tear of the medial meniscus.

The purpose of our study is to assess medial meniscal extrusion and posterior root gap in patients with medial meniscus posterior root-tear, at increasing varus forces, in order to imitate the adduction moment of the knee during gait. Our hypothesis is that greater varus forces will lead to a greater increase in meniscal extrusion and posterior root gap in patients with medial meniscus posterior root tear.

MATERIALS AND METHODS

Patient Population: In this single center prospective study conducted between the years 2016-2017, we compared meniscal extrusion under varus force in both patients with medial meniscus posterior root tear and healthy patients. We evaluated a consecutive group of patients with medial meniscus posterior root-tear labeled as the index group and a control group of patients without a known knee pathology or knee complaints. Patients included in the index group had medial meniscus posterior root-tear according to previous MRI examination reviewed by a musculoskeletal radiologist and a senior orthopedic surgeon specializing in sport's medicine. We included only patients with a complete posterior root tear without bony avulsion, LaPrade classification system types two, three, and four *(12)*.

We excluded patients with (1) prior knee surgery, (2) comorbidity precluding repeat MRI examination, (3) pregnancy, (4) moderate-to-severe osteoarthritis (5) knee malalignment (>5° varus/valgus) *(12)* cruciate ligaments deficiency. Patients included in the control group had no known knee pathology or complaints. Patients were excluded if major knee pathology was detected during the MRI examination. The study was approved by the institutional review board (IRB) and all patients signed an informed consent form.

Gait analysis and adductor moment measurement: Patients underwent gait analysis testing in order to assess kinematics and kinetics of both knees. Gait analysis was performed in a similar fashion to the one published by Hetsroni et al. *(13)*.

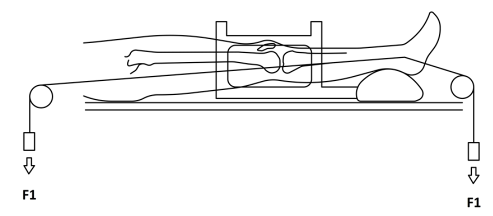
Adduction moment of both knees was calculated according to the gait analysis testing. We attached 21 photo-reflective markers to anatomical landmarks on the pelvis and lower extremity of each patient. Markers were positioned according to the "standard plug-in gait protocol" (UserManual, ViconMotion Systems, Ltd., Oxford, UK). After setup, the participants were asked to walk normally on a walkway in the gait lab several times until they landed on force plates (Kistler Group, Winterthur, Switzerland), attempting to avoid any alteration in the natural gait pattern. The gait lab is equipped with six cameras optical stereometric system (Vicon Motion Systems, Ltd., Oxford, UK), sampling at 120 Hz, which allowed tracking of the patient motions. For each patient we recorded three gait cycle trials. Each foot landed on a different force plate sampled at 960Hz. We collected data using NEXUS 1.7.1 program with Woltring filter for filling gaps and Butterworth fourth order filter with a cut off frequency of 6 Hz built in the program. The results were processed with Polygon 3.5.1 software (Vicon Motion Systems, Ltd., Oxford, UK). The knee adduction moment (relative to body weight) was calculated for both legs by inverse dynamics with NEXUS 1.7.1 program. (See supplemental material)

Dynamic MRI assessment: Coronal proton density (PD) MRI (Siemens Magnetom Skyra 3 Tesla) of both knees was done in supine position. Dynamic MRI testing was performed with the knee at rest and with increasing varus forces according to the patient's specific adduction moment imitating the varus force applied to the knee during gait. We performed three separate MRI examinations of each knee: at rest, with 100% varus force and with 150% varus force. The calculation of the weight needed to apply varus force was calculated using the patient's specific adduction moment. Varus force was applied using a simple and safe method of applying varus force in an MRI environment. (Fig. 1A-B, also see supplemental material)

Data collection: The extent of medial meniscal extrusion and posterior gap at increasing varus forces in both healthy knees and knees with a medial meniscus posterior root-tear, were measured by two different investigators (blinded for peer-review). (Fig. 2A-F) The investigators were blinded to any identifying information of patients while performing the measurements. One investigator is a senior musculoskeletal radiologist and the other is a senior orthopedic surgeon specializing in sports medicine. Measurements of meniscal extrusion were performed on the coronal MRI slice corresponding to the apex of the medial tibial spine as described by Jones et al. *(14).* All measurements were performed using the hospital's picture archiving communication system (PACS, Sectra Workstation IDS7, version 14.3.7.1; Sectra Ltd., Milton Keynes, United Kingdom). All patients completed the Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC) questionnaires following the MRI exam.

Statistical Analysis: In order to perform power analysis we used meniscal extrusion means and standard deviations previously published *(3-15)*. Given we wanted to detect differences in meniscal extrusion under varus stress between the two groups, with 80% power and a significance level of $p < 0.05$, these values were estimated with nine knees in each group. Microsoft Excel (2013) and Stata v.13.0 (StataCorp, College Station, TX) software were utilized for all calculations.

In order to analyze differences in meniscal extrusion at increasing varus forces between healthy knees and knees with a posterior root-



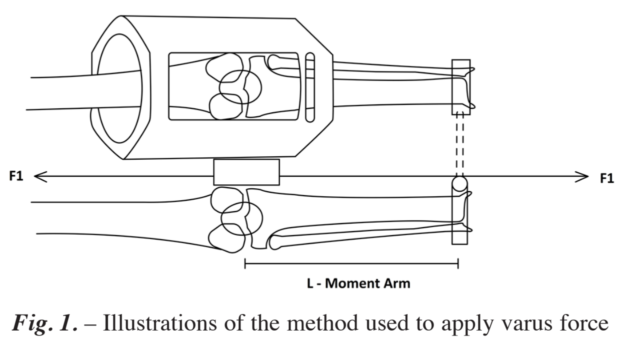


Fig. 1. – Illustrations of the method used to apply varus force across the knee during MRI. 2F1=Ma/L. Where 2F1 is the force needed to apply to the leg in order to create the appropriate adduction moment across the knee. Ma is the adduction moment and L is the length from joint level to medial malleolus where the force is applied.

Fig. 2. – A-F Coronal proton density MRI slices of a patient with medial meniscus root tear of the left knee. (A-C) Demonstrate meniscal extrusion (A) at rest, (B) with 100% varus force, (C) with 150% varus force, with increasing meniscal extrusion of 5.2mm, 8.1mm and 9mm, respectively. (D-F) Demonstrate a posterior gap of the medial meniscal root tear (D) at rest, (E) with 100% varus force, (F) with 150% varus force, with increasing posterior gap of 16.7mm, 19mm and 20.1mm, respectively.

tear of the medial meniscus, we used two-tailed student t-test for paired samples. We compared meniscal extrusion increase from rest to 100% varus force and from 100% to 150% varus force between the two groups of patients. We also used the same method to assess increase in posterior gap at increasing varus forces between healthy knees and knees with a root-tear. Intra-class correlation coefficient (ICC) was used to evaluate inter-rater reliability of medial meniscal extrusion measurements.

RESULTS

The demographic characteristics of the study participants are summarized in Table I. We analyzed nineteen patients (thirty-eight knees). Thirteen patients had a unilateral medial meniscus posterior root-tear, two patients had bilateral medial meniscus posterior root-tear and four patients did not have a known knee pathology. There were seventeen knees with medial meniscus posterior root-tear in the index group and twenty-one knees in the control group. There were 15 females and four males included in the study. Mean age for the index group was 58.5 (range 46-74) and 55.3 (range 52-57) for the control group. In the index group the right knee was affected in nine patients, the left knee was affected in six patients and in two patients both knees had medial meniscus posterior root-tear. In the index group seven patients were Kellgren-Lawrence Grade I and ten patients were grade II. In the control group 15 patients were Kellgren-Lawrence Grade I and six patients were grade II.

Average extrusion distance for the index group was 5.3 mm without varus force, 6.4mm with 100% varus force and 6.8mm with 150% varus force. Average extrusion distance for the control group without varus force, 100% and 150% applied varus force was 1.7mm, 1.7mm and 1.9mm, respectively.

Extrusion increase from rest to 100% varus force was significantly higher in the index group (p=0.0002). However, further extrusion increase from 100% varus force to 150% varus force did not show a statistically significant difference between the groups (p=0.386) (Fig. 3A).

Average posterior gap for the index group was 7.7mm without varus force, 10.2mm with 100% varus force and 10.8mm with 150% varus force. Average posterior gap for the control group was 0 at rest and with 100% or 150% varus force, 100%.

Posterior gap increase from rest to 100% varus force was significantly higher in the index group (p=0.0001). However, further extrusion increase from 100% varus force to 150% varus force did not show a statistically significant difference between the groups (p=0.223) (Fig. 3B).

Intraclass Correlation Coefficient (ICC) between the two raters for meniscal extrusion and posterior gap measurements was 0.95.

Table I. – Demographic characteristics of the study participants

	Index Group	Control Group
N (Number of knees)	17	21
Age (Mean)	58.5	55.3
Sex		
Female	14 (82%)	16 (76%)
Male	3 (18%)	5 (24%)
Side		
Rt	9 (53%)	10 (48%)
Lt	8 (47%)	11 (52%)
BMI (Mean)	27.8	29.8
Kellgren-Lawrence Grade		
I	7	15
II	10	6

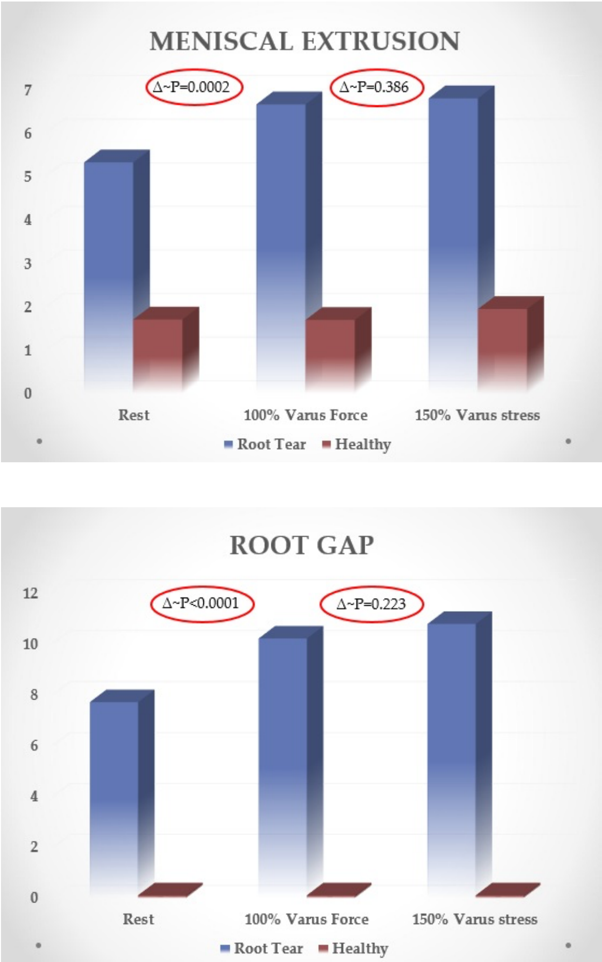


Fig. 3. – 3A-B (A) graphic presentation of increasing meniscal extrusion and (B) posterior gap with use of 100% varus force in patients with medial meniscal root tear. To note, further increase to 150% varus force did not result in a statistically significant increase in meniscal extrusion or posterior gap.

Average WOMAC scores were 11.5, 4.7 and 37.9, for the WOMAC pain, stiffness and function scores, respectively. The association between greater increase of meniscal extrusion with varus force and WOMAC pain, stiffness and function scores was p=0.14, p=0.26, and p=0.37, respectively.

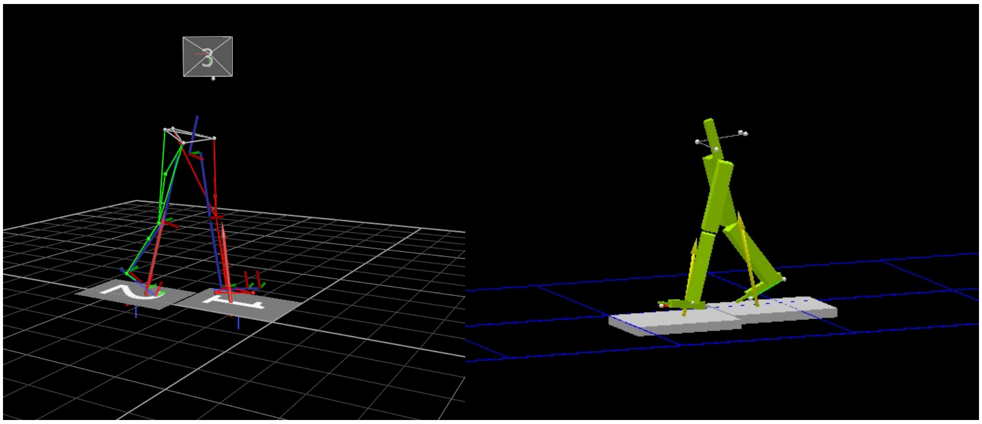
DISCUSSION

We evaluated medial meniscal extrusion comparing knees with a posterior root-tear of the medial meniscus and healthy knees, while applying increasing varus force, imitating the adductor moment during gait. We found meniscal extrusion to be common in the presence of posterior root-tear. Difference in meniscal extrusion at increasing varus force was greater in knees with root-tear. We found no association between greater increase of meniscal extrusion with varus force and peri-exam WOMAC scores.

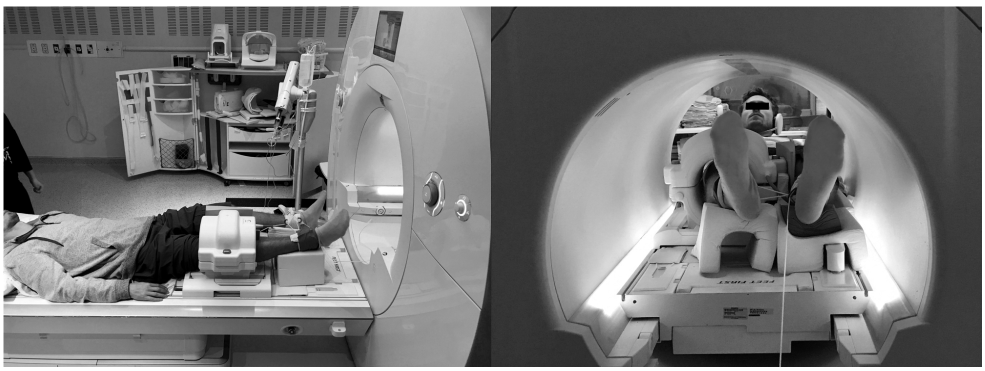
Vedi et al.*(8)* studied 16 young footballers using an open MRI scanner to describe meniscal movement under load. They have demonstrated the medial meniscus moves less than the lateral meniscus and that the anterior horns move more than the posterior horns. They emphasized that the posterior horn of the medial meniscus moves least. The restricted movement of the posterior horn of the medial meniscus may account for the frequency of posterior horn and posterior root-tears of the medial meniscus. The relative immobility of this part of the meniscus may also reinforces the argument that posterior root-tear of the medial meniscus would result in greater meniscal extrusion and subsequent loss of functionality of the meniscus.

Papparo et al.*(10)* evaluated medial meniscus extrusion in 26 patients with knee osteoarthritis using an open MRI scanner. They compared medial meniscus extrusion delta between clinostatic and orthostatic positions (82° upright). They have found medial meniscus extrusion was greater in the orthostatic position than that measured in the clinostatic position. They have also reported significant correlation between medial meniscus extrusion and the Kellgren-Lawrence score, cartilage loss, meniscal damage and osteophytes. Their study differs from ours as it focuses on osteoarthritic patients and it does not report on medial meniscus posterior root-tear. Also, using the open MRI they ascertain almost an upright position, however it does not take into account the adductor moment of the knee that is created during normal gait.

Stehling et al.*(11)* studied 30 patients, ten healthy patients and 20 patients with evidence of mild to moderate osteoarthritis. They used standard knee MRI with an MRI-compatible loading device to assess meniscal extrusion under load in the two groups of patients. They have reported a significant increase of medial meniscus extrusion under load



Supp. Files. – Computer generated images of a patient during gait analysis testing.



Supp. Files. – Photos demonstrating the simple and reproducible method that was applied.

in patients with mild to moderate osteoarthritis and in patients with meniscus lesions. Their study did not report the incidence of root-tears and did not evaluate its relationship to extrusion under load. Their method also does not evaluate the adduction moment created during gait.

Knee movement is complex and we are yet to fully understand the biomechanics of the knee. It is understandable that a posterior root tear of the meniscus combined with the hoop-stress created by varus force will result in meniscal extrusion. We can speculate that perhaps this finding of greater meniscal extrusion during varus stress in these patients provides another explanation why most of these patients do not exhibit pain while at rest, however they are painful during gait. When the patient is walking the meniscus becomes even more extruded unravelling more articular surface for engagement and also creating more pressure on the medial collateral ligament.

Of note, is the relatively high mean age of our patient population in both the control and the index group. Most of our patients presented with an insidious knee pain for many months without a definite precipitating traumatic event.

Lastly, from an operative point of view we believe meniscal extrusion should be evaluated preoperatively and dealt with intraoperatively while repairing the posterior root of the medial meniscus. Perhaps a preoperative varus stress MRI will allow the surgeon to better appreciate the true meniscal extrusion and assist in patient selection and preoperative planning. Further clinical studies are needed to establish or reject these assumptions.

The main limitation of our study is the relatively limited sample size. Supine MRI does not allow weight bearing as an open MRI in an upright-position. However, it allowed us to evaluate the isolated effect of the varus force component of the knee adduction moment. The method applied to induce varus force used the patient's other leg, thus the other leg might somewhat impact the varus force applied to the affected knee. No long-term clinical outcome evaluation is yet available in order to establish the correlation between meniscal extrusion increase with varus stress and functional outcome.

CONCLUSION

Our study demonstrates there is a greater increase of meniscal extrusion and root gap during varus stress in patients with medial meniscus posterior root-tear. This finding may help us better our understanding of the pathological movement of the torn and extruded medial meniscus during gait.

REFERENCES

1. **Bessette GC.** The meniscus. *Orthopedics.* 1992;15(1):35-42.
2. **Noble J, Turner P.** The function, pathology, and surgery of the meniscus. Clin Orthop Rel Res. 1986(210):62-8.
3. **Radin EL, Maquet P.** Role of the menisci in the distribution of stress in the knee. *Clin Orthop Rel Res*. 1984(185):290-4.
4. **Bhatia S, LaPrade CM, Ellman MB, LaPrade RF.** Meniscal root tears: significance, diagnosis, and treatment. *Am J Sports Med.* 2014;42(12):3016-30.
5. **Bloecker K, Wirth W, Guermazi A, Hunter D, Resch H, Hochreiter J, *et al.*** Relationship between medial meniscal extrusion and cartilage loss in specific femorotibial subregions: data from the osteoarthritis initiative. *Arthritis care Res.* 2015;67(11):1545-52.
6. **Hein CN, Deperio JG, Ehrensberger MT, Marzo JM.** Effects of medial meniscal posterior horn avulsion and repair on meniscal displacement. *Knee.* 2011;18(3):189-92.
7. **Lerer D, Umans HR, Hu M, Jones M.** The role of meniscal root pathology and radial meniscal tear in medial meniscal extrusion. *Skeletal Radiol.* 2004;33(10):569-74.
8. **Vedi V, Spouse E, Williams A, Tennant S, Hunt D, Gedroyc W.** Meniscal movement: an in-vivo study using dynamic MRI. *J Bone Joint Surg Br.* 1999;81(1):37-41.
9. **Thompson WO, Thaete FL, Fu FH, Dye SF.** Tibial meniscal dynamics using three-dimensional reconstruction of magnetic resonance images. *Am J Sports Med.* 1991;19(3):210-6.
10. **Paparo F, Revelli M, Piccazzo R, Astengo D, Camellino D, Puntoni M, *et al.*** Extrusion of the medial meniscus in knee osteoarthritis assessed with a rotating clino-orthostatic permanent-magnet MRI scanner. *Radiol Medica.* 2015;120(4):329-37.
11. **Stehling C, Souza RB, Le Graverand M-PH, Wyman BT, Li X, Majumdar S,** et al. Loading of the knee during 3.0 T MRI is associated with significantly increased medial meniscus extrusion in mild and moderate osteoarthritis. *Eur J Radiol.* 2012;81(8):1839-45.
12. **LaPrade CM, James EW, Cram TR, Feagin JA, Engebretsen L, LaPrade RF.** Meniscal root tears: a classification system based on tear morphology. *Am J Sports Med.* 2015;43(2):363-9.
13. **Hetsroni I, Funk S, Ben-Sira D, Nyska M, Palmanovich E, Ayalon M.** Femoroacetabular impingement syndrome is associated with alterations in hindfoot mechanics: A three-dimensional gait analysis study. *Clin Biomech.* 2015;30(10):1189-93.
14. **Jones LD, Mellon SJ, Kruger N, Monk AP, Price AJ, Beard DJ.** Medial meniscal extrusion: a validation study comparing different methods of assessment. *Knee Surg Sports Traumatol Arthro.* 2018;26(4):1152-7.
15. **Teichtahl A, Cicuttini F, Abram F, Wang Y, Pelletier J-P, Dodin P, *et al.*** Meniscal extrusion and bone marrow lesions are associated with incident and progressive knee osteoarthritis. *Osteoarthr Cartilage.* 2017;25(7):1076-83.