



Original Research

A new method for diagnosis of anterior cruciate ligament tear: MRI with maximum flexion of knee in the prone position: A case control study

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ABSTRACT

Background: The diagnosis of anterior cruciate ligament tear can be made by physical examination and magnetic resonance imaging (MRI) in the supine position. In cases where the tear is partially evaluated on MRI, the choice of treatment may vary. The purpose of the study was to investigate the efficiency of MRI at maximum knee flexion in the prone position and to compare the images with findings of the ACL detected during surgery.

Materials and methods: Sixty-one patients with partial ACL tears with meniscal and cartilage lesions requiring arthroscopic knee surgery were included in the study between 2017 and 2019. MRI of these patients was prescribed at maximum knee flexion in the prone position. Then, an arthroscopic operation was performed on 61 patients and the findings (intact, partial or total tear of ACL) were recorded. The ACL was evaluated as being intact and partial or total tear. The statistical significance of the efficacy of MRI in the supine position with the knee at maximum flexion in the prone position was compared.

Results: It was found that, of 61 patients with suspected partial ACL tears, 25 patients had intact ACLs, 22 patients had partial tears and 14 patients had total ACL tears, through the interpretation of MRIs of the prone position by the radiologist. In the arthroscopic surgery of 61 patients, 20 patients had intact ACLs, 27 patients had a partial tear and 14 patients had a total tear. The MRI results with maximum knee flexion in the prone position were more compatible with the findings of the arthroscopic surgery.

Conclusions: It could be considered that MRI with maximum knee flexion in the prone position may also be guiding in the diagnosis and treatment of patients with partial anterior cruciate ligament rupture.

1. Introduction

The anterior cruciate ligament (ACL) has been described as two bundles according to the tibial attachment site [1], but it has been shown in recent anatomic studies that it consists of 3 bundles [2]. These are anteromedial (AM), posterolateral (PL) and intermediate bundles. However, the ACL is functionally divided into AM and PL bundles. The AM bundle is stretched in flexion and primarily prevents anterior-to-posterior displacement and the PL band is stretched in extension and prevents rotational instability of the knee [1]. These bundles work synergistically during the movement of the knee [3]. The intermediate bundle supports the AM and PL bundles to resist rotational forces

during this synergistic movement [4].

Although ACL tears are defined as at least one of the bundles being intact while the other bundles are not [5], there is no consensus on the definition of ACL tears [6]. Noyes et al. described tears in 50–75% of the ACL diameter as partial tears [7]. In the study of Hong et al. in which magnetic resonance imaging (MRI) was evaluated, they described tears in less than 50% of ACL fibers as partial tears [8]. Among all ACL tears, the rate of partial ACL tears was found as 10–35% [9].

DeFranco and Bach emphasized that the diagnosis of partial tears was difficult and that diagnosis should be made as a result of the combination of a clinical exam; knee laxity and arthroscopic evaluation [10]. According to the arthroscopic evaluation, Noyes et al. defined the

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partial ACL tear as a quarter, half, and three-quarters according to the ratio of ACL tear [7]. Partial ACL tears progress to total tear at a rate of 38% [7], and just as there are those who recommend surgery [11,12], there are also reports stating that conservative treatment provides good-to-excellent functional outcomes [7,13]. A partial ACL tear is difficult to detect in physical examinations and additional methods, and it is not easy to diagnose a partial tear in MRI taken in the neutral position [8].

In the study, it was aimed to compare patients with suspected partial ACL tears who were recommended to undergo arthroscopic surgery due to additional intra-articular lesions according to MRI findings of the knee in the supine position at full extension and of MRI findings at maximum flexion in the prone position with ACL findings determined during arthroscopic surgery. In addition, to investigate the efficacy of MRI with the knee at maximum flexion in the prone position in determining partial ACL tears that had been evaluated as suspicious. The hypothesis of the study was that MRI in the prone position with maximum knee flexion would be able to obtain more accurate findings of partial ACL tears.

2. Material and method

This study was approved by the Local Ethics Committee (Date:06/09/2018, No: 2018/83/06/04).

Knee MRI (General Electric Optima MR 360 1.5 T, USA) was requested for patients who were suspected of having a partial ACL lesion, meniscal tear, and chondral lesion, who presented to the outpatient clinic between January 2017 and February 2019. Among the total number of 105 patients who were diagnosed as having a partial ACL tear according to MRI, a total of 61 patients who underwent surgery and could perform knee extension in supine-position MRI and had an additional surgical indication at the same time (meniscus tear, cartilage injury) that required arthroscopic surgery were included in the study.

MRI was performed in the extension position in patients with a suspected partial ACL tear as a result of the examination performed in the outpatient clinic. In the event of doubt about an ACL tear after the MRI examination, an arthroscopic intervention was planned in patients who were diagnosed as having meniscal tears and chondral lesions according to the MRI.

Patients with partial ACL tear who planned arthroscopic surgery were informed about the treatment with meniscal and cartilage lesions and arthroscopic ACL evaluation; patients were informed that ACL reconstruction would be performed for total tears or partial tears with more than 50% ACL bundle tears and that no reconstruction would be performed for intact ACLs or tears of less than 50%. These circumstances were specified at informed consent.

MRI examinations were performed on these patients in the prone position while the knee was in maximum flexion (110°–140°). Performing MRI with the knee at flexion facilitates understanding of the ACL pathology [14–16]. In order to have an MRI on a patient's knee, the patient must lie in the prone or supine position in the MRI scanner. However, once the knee of the patients is flexed, their hips should also be flexed in the supine position accordingly. This condition limits the degree of knee flexion. It is possible to flex the knees more when the patient is lying in the prone position.

The patients were asked to bend their knees as much as they could while they were in the supine position and the knee was fixed with fixing straps and sponges in this position. The patients were informed about how to keep their knees as stable as possible during the imaging (Figs. 1 and 2).

Patients who had no additional pathology (meniscus tears, cartilage injury) despite having a suspicion of a partial tear as determined in the MRI in the normal position were excluded from the study without any further investigation. In addition, patients who had previously undergone arthroscopic or open knee surgery and had multiple ligament damages, patients with inflammatory arthritis and patients with MRI in

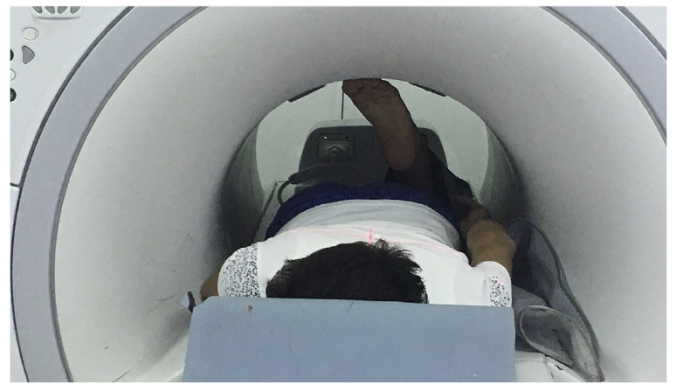


Fig. 1. Maximum flexion position of the knee with the patient lying in the prone position.



Fig. 2. Maximum flexion position of the knee with the patient lying in the prone position.

an inappropriate position were not included in the study.

Among the patients, 61 patients with a pre-diagnosis of a partial ACL tear and at concomitant meniscal tears and chondral damage were evaluated arthroscopically. While the patients were under anesthesia, the findings of the preoperative physical examination, the ACL findings obtained during the arthroscopy (intact, partial or total tear of the ACL), and the postoperative findings of the physical examination were recorded.

Knee MRIs in the supine position and MRI with maximum flexion in the prone position were evaluated as an intact, partial or total tear of the ACL by an experienced musculoskeletal system radiologist who was unaware of the anamnesis, physical examination, and arthroscopic findings (Figs. 3–8). The results of the radiologist's evaluation were compared with the results of the findings of the arthroscopic surgery; thus, the efficacy of MRI in knee flexion was investigated statistically.

The SPSS version 17 software package was used for statistical analysis. Both findings of MRI performed in the supine position and the findings of MRI with the knee at maximum flexion in the prone position were compared with the findings obtained during the surgery by calculating the intraclass correlation coefficient (ICC) values. ICC values were given with 95% confidence intervals (CI). ICC values greater than 0.75 were considered excellent values from 0.40 to 0.75 were considered good, and values less than 0.40 were considered low [17]. This study has been reported in line with the STROCSS criteria [18].

3. Results

Fifty-five of the 61 patients included in the study were male and 6 patients were female. The mean age of the patients was 29.8 (range, 18–39) years. Thirty-four patients reported problems in their right knee, and 27 patients had pain in their left knee. The mean angle of knee flexion during MRI was found as 124.5° (range, 104–145°). In the MRI images of these patients with the maximum flexion of the knee in the prone position, it was found that 25 (41%) patients had an intact



Fig. 3. Total tear image of a patient with a suspected partial tear in the sagittal section in supine knee MRI with the knee in maximum flexion



Fig. 5. Total tear image of a patient with a suspected partial tear in the sagittal section in supine knee MRI with the knee in maximum flexion.



Fig. 4. Total tear image of a patient with a suspected partial tear in the sagittal section in supine knee MRI with the knee in maximum flexion.



Fig. 6. Total tear image of a patient with a suspected partial tear in the sagittal section in supine knee MRI with the knee in maximum flexion.

ACL, 22 (36%) patients had partial tears and 14 (23%) patients had total tears (Table 1).

Arthroscopic surgery was performed by a single surgeon. In the arthroscopic surgery of 61 patients, it was found that 20 (32.8%) patients had intact ACLs, 27 (44.2%) patients had partial tears and 14 (23%) patients had total tears (Table 1). In the study, 22 patients with an arthroscopic partial tear were found to have torn anteromedial bundles and intact posterolateral bundles, and 5 patients with arthroscopic partial tears were found to have torn posterolateral bundles and intact anteromedial bundles. Arthroscopic ACL reconstruction with the anatomic single-band method was performed in 41 patients with partial and total tears. Fifty-five patients had a tear in their meniscus; 20 patients underwent partial meniscectomy and 35 patients underwent meniscus repair. Of these patients with meniscus tears, 18 patients' meniscal tears were found in the lateral meniscus; 12 patients underwent partial meniscectomy and 6 patients underwent meniscus repair.

Of the 37 patients with a tear in the medial meniscus, 20 patients underwent meniscus repair and 17 patients underwent partial meniscectomy. Chondral damage was detected in 10 patients who were treated for microfractures. Regarding the chondral damage of these patients, 5 patients had damage in the medial femoral condyle and the others had it in the lateral femoral condyle (Table 2).

In the comparison of ACL findings during surgery between MRI findings in the prone position with maximum knee flexion and knee extension in the supine position, the ACL was observed to be more consistent with images with maximum knee flexion in the prone position (ICC values 0.933 [0.898–0.956] and 0.000 [-0.546–0.353]).

It was revealed that the sensitivity of MRI at maximum knee flexion in the prone position was 87.8%, its specificity was 100%, and the positive predictive and negative values were 100%, 80%, respectively.

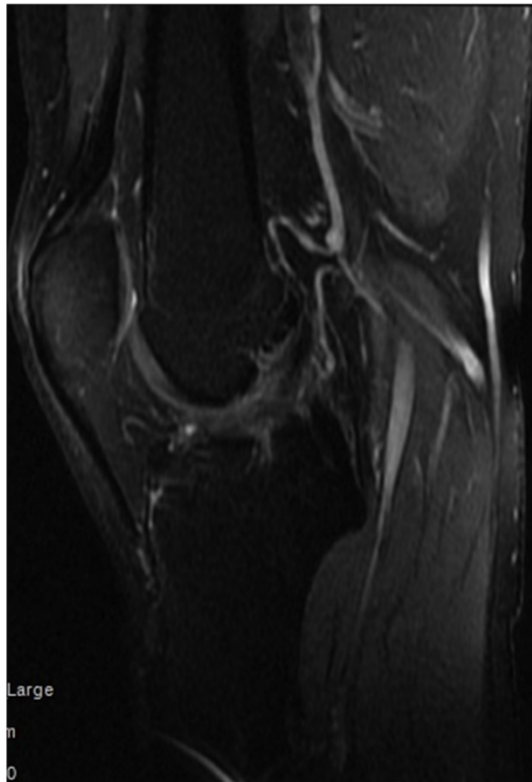


Fig. 7. Partial tear image of a patient with a suspicion of a partial tear in the sagittal section in supine knee MRI with the knee in maximum flexion.



Fig. 8. Partial tear image of a patient with a suspicion of a partial tear in the sagittal section in supine knee MRI with the knee in maximum flexion.

4. Discussion

There is no consensus on the criteria for the definition and diagnosis of partial ACL tears [6]. According to the French Society of

Arthroscopy, partial tears are defined as the continuity of a portion of the fibers between the femoral and tibial adhesion points of the ACL, whereas partial tears are defined as tears of either AM or PL with one of the bundles left intact [5]. For diagnosis, partial ACL tears should first be suspected in the physical examination. An asymmetrical Lachman test and the negative Pivot Shift test, a low-grade KT1000 arthrometer measurement (≤ 3 mm), and an absence of total tear despite deterioration of the ACL in the arthroscopic evaluation should suggest partial ACL tear [10]. It has been reported that MRI reduced unnecessary surgical or arthroscopic interventions and was also a cost-effective technique [19].

MRI findings are evaluated as primary and secondary findings in ACL tears. The Primary signs are loss of continuity in connective fibers, increased signal intensity within the ligament (hyper-intensity of ACL, which normally appears as hypo-intense on T1-weighted images), an increased signal activity that fills the inter-condylar notch due to heterogeneous hematoma in T2-weighted images, abnormal morphologic ligament features, and empty notch sign. Secondary signs can be considered as a bone bruising, osteochondral lesions, forward translation of the tibia relative to the femur, uncovered posterior horn of the lateral meniscus, excessive buckling of the posterior cruciate ligament, deep lateral femoral notch and Segond fracture [10,20,21]. In partial ACL tears, primary findings can only be encountered at a rate of 33%, and secondary findings can only be found in 43% of cases [7].

MRI findings in chronic ACL tears are considered as absence of the ACL in sequences, the appearance of the ACL as fragments, the loss of parallelism and abnormal horizontal extension of the ACL, which normally extends parallel to the roof of the inter-condylar notch, and the adhesion of the ACL to the posterior cruciate ligament small fibers through scar tissue [21].

In general, it was emphasized in many publications that the findings detected by MRI might suggest a partial tear of the ACL, but could not be used to establish a definitive diagnosis [8,22,23]. In a study by Alioto et al. it was revealed that MRI changed the plans for orthopedic surgery interventions in 18% of the patients. Furthermore, MRI was found to be more positive in the decision-making process in the meniscus or chondral lesions, whereas it did not show the same success in the evaluation of anterior cruciate ligament tears [24].

In a study by Umman et al. MRI was reported to have a sensitivity of 55% and a specificity of 75% in detecting partial tears [23].

In MRI examinations, total ACL tears were reportedly detected with a sensitivity of 83% at full extension of the knee, 83% at 30° knee flexion, and 93% at 55° knee flexion; however, in partial tears, it showed a sensitivity of 50% at full extension of the knee, 63% at 30° knee flexion, and 63% at 55° knee flexion [14].

MRI examinations are useful for evaluating ACL lesions in knee flexion [14–16]. Niitsu et al. compared MRIs performed on the knee in semiflexion (45° flexion) in the supine position with MRI in the knee extension and stated that MRI with the knee flexion was more effective in diagnosing ACL tears [15].

Muhle et al. explained the reasons for MRI in knee flexion having better-visualized ACL lesions. It was stated that as the knee flexion increased, the femoral adhesion site of the ACL had a more horizontal position and the AM bundle was also tightened. It was revealed that with increased flexion of the knee, the ACL moved away from the inter-condylar roof at the femoral adhesion site and thus the tear could be better detected, especially in sagittal MRI scans in this site [14]. In

Table 1
MRI results of patients in normal and prone positions and ACL findings determined in surgery.

	MRI finding in neutral position (n:61)	MRI finding in flexion position (n:61)	ACL finding in operation (n:61)
Intact	–	25 (41%)	20 (32.8%)
Partial tear	61 (100%)	22 (36%)	27 (44.2%)
Total tear	–	14 (23%)	14 (23%)

Table 2

MRI results of patients in the supine and prone position, and meniscus and cartilage findings determined in surgery.

		MRI finding in neutral position (n:61)	MRI finding in flexion position (n:61)	Meniscal and chondral findings in operation (n:61)
Meniscal lesion	Medial Meniscus	35	36	37
	Lateral Meniscus	18	18	18
	Intact Meniscus	8	7	6
Chondral lesion	Chondral Injury	10	10	10
	Intact Chondral Tissue	51	51	51

addition, it was stated that with knee flexion, the ACL shape was cylindrical and tears could be better detected through knee flexion [14].

In our study, it was determined that increasing the degree of flexion at hyper-flexion level could better evaluate ACL lesions, unlike in previously published studies.

In the evaluation of ACL in MRI, first the sagittal sequences are evaluated, and coronal and axial sequences are used to confirm the diagnosis [19,25]. Due to the oblique course of the ACL in the knee, in addition to the existing classic MRI sections, parasagittal and parasagittal (oblique) plan sequences are added in order to try to differentiate the ACL tear in more detail [26]. It was reported in some publications that the addition of these oblique additional sequences to the MRI series helped diagnose partial ACL tears [8,26,27]. The lack of additional oblique MRI sequences in the supine position is one of the limitations of the study. In a study by Steckel et al. using 6 cadavers, it was stated that using 3 T MRI technology, isolated ACL bands could be obtained more accurately and the diagnosis of partial ACL rupture would be made more accurately [28]. Only a 1.5 T MRI device was available in the hospital where we performed this study, so this was used to provide images.

The ACL is considered to have two major functional bundles [2], the anteromedial bundle is stretched in flexion, whereas the posterolateral bundle is stretched in extension [1,10]. In the present study, it was seen that with maximum flexion of the knee in the prone position, where the anteromedial bundle was stretched, partial tears in the anteromedial bundle were detected better.

Thirty-eight percent of partial tears progress to total tears [7]. Some researchers recommend surgery [29,30], but there are also publications indicating good-excellent functional results with conservative treatment [7,31].

In a study by Colombet et al., 27% of patients with partial tears were reported to have an AM bundle maintained at rate of 11%, and the PL bundle was sustained at a rate of 16% [32]. In the study, 22 patients with arthroscopic partial tears were found to have torn anteromedial bundles and intact posterolateral bundles, whereas 5 patients with arthroscopic partial tears were found to have torn posterolateral bundles and intact anteromedial bundles. Sonnery-Cottet et al., emphasized the importance of the position of Cabot (Fig. 4) in determining the partial tears of the PL bundle [33]; in the arthroscopic evaluation of ACLs of patients in this study, the posterolateral bundle was evaluated by performing an examination in this position, but there was no patient with ruptured PL bundles and intact AMs.

In another study by Sonnery-Cottet et al., it was reported that as a result of all evaluations of the patients, the findings led the surgeon to suspect partial tears, but the explorative arthroscopic evaluation established a definitive diagnosis about the tear, whether it was a total or partial tear [6]. Exploratory arthroscopy takes the flexion of the ACL knee from the extension and involves the examination of ACL fibers at Fig. 4 position [6]. In our study, patients were evaluated by the exploratory arthroscopy.

In conclusion, MRI with maximum knee flexion in the prone position was found to be successful in evaluating ACL lesions compared with conventional MRI. However, when the MRI findings performed in the prone position were compared with the surgical findings, it was determined that this MRI method was successful in evaluating total and partial ACL tears.

Twenty of 25 cases that were thought as intact in the MRI examination were confirmed in arthroscopic surgery, but in 20% of the cases that were considered to be intact in MRI, the ACL was found as having a partial tear at arthroscopy. We think that the effectiveness of the current novel imaging method and the experience of radiologists in evaluating this new MRI position will increase as the number of patients examined in this position increases.

The limitations of the study include the fact that the time between the trauma of the patients and the MRI cannot be standardized. Secondly, time between MRI on the supine position and MRI knee flexion in prone position also cannot be standardized. Regardless of the duration of the trauma normal MRI was requested when the patients presented to the outpatient clinic. Thirdly, when the patients presented to outpatient clinics, no oblique sections were taken in both MRI techniques. Lastly, the number of recruited patients was low. The need for an experienced radiologist to assess the accuracy of a knee MRI performed in flexion is an aspect of the evaluation method to be developed.

5. Conclusion

While evaluating patients with a suspected partial anterior cruciate ligament tear, it should be kept in mind that MRI with the knee in maximum flexion in the prone position can be used as an alternative method. We think that the results of MRI performed in this position will help orthopedic surgeons in planning the treatment of patients with partial tears.

Ethical approval

2018/18/06/04 the Ethics Committee of Tekirdag Namık Kemal University Faculty of Medicine.

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Author contributions

Burak Gunaydin - study desing, data collections, writing, final corrections.

Gulcan Gucer Sahin - data collections, data analysis.

Abdulkadir Sari - data analysis, writing.

Adnan Kara - study desing, writing, final corrections.

Yasar Mahsut Dincel - data analysis, final corrections.

Cagatay Tekin - data collections, data analysis.

Yavuz Selim Kabukcuoglu - study desing, final corrections.

Conflicts of interest

All named authors hereby declare that they have no conflicts of interest to disclose.

Research registration number

None.

Guarantor

Burak Gunaydin – Cagatay Tekin

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Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.ijvs.2019.06.017>.

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