Evaluation of diagnostic accuracy of physical examination and MRI for ligament and meniscus injuries

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Abstract. Surgical planning shall be based on thorough physical examination and radiological findings during patient evaluation. The use of computational methods in the evaluation of diagnostic tests may facilitate the decision-making process as well as reduce treatment costs. Conventional X-ray is a modality of choice for bone visualisation however, it is not suitable for soft tissue evaluation. MRI is a tool designated for soft tissue examination however, its accuracy is debated in the literature. This study was performed to evaluate the diagnostic accuracy of MRI in most common knee injuries in comparison to physical examination. The evaluation of selected diagnostic methods used in the evaluation of ligaments and meniscus was carried out based on statistical indicators and ROC (Receiver Operating Characteristic) curves. The indicators were determined using Statistica and Matlab software. 69 patients were enrolled in the study, who were previously scheduled for arthroscopic knee surgery. Each patient underwent a closed protocol physical evaluation prior to surgery. MRI reports were collected and stored. Diagnostic accuracy was evaluated with the use of ROC curves. Physical examination presented greater diagnostic accuracy than MRI in ACL tears. The same dependency was found in lateral and medial meniscal tears. MRI showed AUC of 0.835 for MM, 0.788 for LM, and 0.870 for ACL, respectively. The physical examination had the greatest diagnostic accuracy in comparison with ACL tears, where AUC for the Lachman test reached 0.902. Apley test was most accurate for LM tears with AUC reaching 0.842, while the McMurray test was the most accurate for MM lesions. MRI is a preferable addition to a thorough physical examination.

1. Introduction
Decision making is usually a difficult matter when it is taken in a situation of uncertainty. Appropriate selection of diagnostic methods may have a huge impact on the outcome of the clinical diagnosis and, as a result, on the whole further treatment process [1–3]. Usually, in clinical practice, disease diagnosis is based on a large number of clinical and laboratory tests, the results of which should be collated to minimise the diagnostic error of a single test [1]. The selection of improper diagnostic tests may result in longer decision-making time and affect the level of generated costs. The current development of medical technology allows creating data sets represented by many variables describing the condition of patients. The use of statistical methods in combination with the possibilities of conducting computer analyses at a high level may lead to the creation of procedures to support medical decisions [1, 4–8].
The knee joint is one of the most common joints that are subjected to injuries. Due to its function and location, the knee joint is subjected to various injuries and is indispensable for daily activities. Tissues such as menisci, ligaments, or cartilage are responsible for the painless smooth movement of the joint. It is well known that cartilage has a limited capacity for healing [9–11]. Knee cartilage lesions may occur as a result of overuse, sports, ligament tears, or meniscal tears and the inflammatory process [12–15]. Moreover, knee cartilage has an extremely limited healing capacity, and cartilage lesions progress over time is the triggering factor if not treated. Therefore, a fast and accurate diagnosis is of paramount importance to preserve joint function. Physical examination is the foundation of the orthopaedic diagnostic process. During physical examination medical history is taken and specialised tests for different anatomic structures are performed. Physical examination, however, has its limitations, and in many cases, it is not fully reliable in detecting intraarticular lesions and imaging techniques are introduced into the diagnostic process. Magnetic resonance imaging (MRI) is of particular interest regarding knee injuries, while it enables visualisation tissues such as ligaments or menisci. However, as shown by Solivetti et al [16] that 40% of MRI examinations are not necessary for diagnostic purposes and nearly 20% of patients undergoing MRI have not been previously examined by an orthopaedic surgeon. This study shows that reliance on imaging techniques is high and it seems that not justified. This study was performed to compare the diagnostic accuracy of MRI and physical examination in most common meniscal and ligamentous injuries of the knee joint.

2. Materials and methods
Among patients scheduled for arthroscopic surgery in the Orthopaedic Department of Łęczna Hospital, 70 patients were enrolled in the study. At the hospital admission, a physical examination was performed due to the study protocol. Special interest was put on meniscal and anterior cruciate ligament (ACL) lesions. Common tests for detecting meniscal pathologies such as McMurray [17], Apley [18], Thessaly [19] tests were utilised (figure 1). All these tests rely on compression and entrapment of menisci between the articular surface of the femur and tibia. Sagittal laxity was evaluated with the Lachman test [20], anterior drawer [20], pivot shift [21], and Lelli test [22] (figure 2). After the physical examination, all patients included in the study provided images and written reports from the MRI examination. Written MRI reports, as well as MRI scans, were stored for further evaluation. Arthroscopy was performed by an orthopaedic specialist with interest in knee surgery having 10 years of experience. All arthroscopies were performed with the use of a standard 30-degree scope introduced through anteromedial and anterolateral portals. If necessary, additional portals were established to ensure proper visualisation of the joint structures. All intraarticular structures were visualised and probed with an arthroscopic probe. Photographic documentation from each procedure was taken for later evaluation. The study was approved by the Bioethical Committee by Medical University in Lublin with the number of approval KE-0254/262/2019.

2.1. Statistical analysis
Statistical analysis of the obtained results of physical examination and magnetic resonance imaging of meniscus and anterior cruciate ligament damage was carried out using Dell Statistica version 13.1 (2019), Microsoft Excel (2013), and MATLAB software (2020). The evaluation and comparison of diagnostic values of the examined methods were based on the analysis of ROC (Receiver operating characteristic) curves. To compare the ROC curves 95% of confidence intervals for areas under the ROC curve were used. Parameters such as sensitivity and specificity may take values from the closed interval <0.1> so the maximum value of the area under the curve was 1. The AUC field, SE (standard error), and confidence interval for the AUC were calculated using the non-parametric DeLong method [23, 24]. The larger the field, the more accurately the objects had been classified into a group based on the diagnostic variable under analysis.
Figure 1. Physical examination – meniscal tests McMurray (1a), Apley (1b), Thessaly (1c).

Figure 2. Physical examination – ACL tests Lachman (1a), anterior drawer (1b), pivot shift (1c), Lelli (1d).
The course of the ROC curve along the diagonal corresponded to a probability of 0.5, which means that the parameter under test had no discriminatory properties. The sensitivity and specificity of each test were calculated from the ROC curves. Statistically significant were those results which were significant at a typical level of significance (i.e. when $p < 0.05$).

3. Results
The mean patient’s age was 45 at the time of hospital admission. Males represented a higher percentage of patients 55% vs 45% of females. Medial meniscus (MM) lesions were found in 37 patients and the body of the meniscus was affected most frequently in 26 patients. The posterior and anterior horn of MM was affected only in 7 and 4 patients respectively. The same correlation was found in the lateral meniscus (LM), where the midbody of the meniscus was affected in 10 patients followed by the posterior horn (n=4) and anterior horn (n=1). ACL rupture was found in 31 patients. Regarding the medial meniscus, the most sensitive test was found to be the Thessaly flexion test (68.9%). Overall physical examination sensitivity for medial meniscus was low and ranged from 62.9% for Thessaly in extension. McMurray test was found to be the most specific test with a specificity of 78%. Diagnostic performance of physical examination evaluated in AUC ranged from 0.600 for Thessaly in extension to 0.732 for the McMurray test. MRI proved to be more accurate in the diagnosis of medial meniscus rupture with AUC of 0.835, a specificity of 95%, and sensitivity of 72%. Regarding lateral meniscus, the results showed different distribution with MRI inferior to physical examination, with AUC of 0.788 in comparison to Apley AUC 0.842. Also, the Apley test showed the highest sensitivity of 80%. Flexion Thessaly presented the highest specificity among all meniscal tests for LM. Also, MRI showed a high specificity of 90.9% in the detection of LM lesions. As shown for lateral meniscus, also for ACL ruptures the physical examination showed superior diagnostic performance in comparison to MRI with AUC for Lachman test of 0.902 vs. 0.870 for MRI. Pivot shift and Lelli test showed to be the most sensitive test for ACL deficiency with a sensitivity of 100%. Lachman test, however, showed to be most specific with a specificity of 84.4%. MRI specificity was higher than physical examination reaching 91.7%, with a lower sensitivity of 82.4%. The summary of all results is shown in table 1 and on figures 3-5.

![Figure 3. ROC curve showing relations between medial meniscus tests and MRI.](image-url)
Table 1. Summary of results of diagnostic performance for physical examination and MRI concerning medial meniscus, lateral meniscus, and the anterior cruciate ligament.

|                        | Asymptotic 95% Confidence Interval |
|------------------------|-----------------------------------|
|                        | AUC  | SE   | Inferior Boundary Value | Superior Boundary Value | z    | p    | Sensitivity | Specificity | Youden |
| Thessaly in extension  | 0.600| 0.068| 0.467                   | 0.733                   | 1.469| 0.142| 0.629       | 0.429       | 0.200  |
| Thessaly in flexion    | 0.724| 0.064| 0.599                   | 0.850                   | 3.503| 0.000| 0.689       | 0.240       | 0.449  |
| McMurray               | 0.732| 0.064| 0.606                   | 0.858                   | 3.609| 0.000| 0.681       | 0.217       | 0.463  |
| Apley compression      | 0.614| 0.068| 0.481                   | 0.746                   | 1.677| 0.094| 0.639       | 0.412       | 0.227  |
| Apley distraction      | 0.595| 0.069| 0.459                   | 0.731                   | 1.373| 0.170| 0.643       | 0.452       | 0.190  |
| Total physical examination | 0.719| 0.064| 0.594                   | 0.844                   | 3.435| 0.001| 0.698       | 0.259       | 0.438  |
| MRI                    | 0.835| 0.050| 0.737                   | 0.933                   | 6.713| 0.000| 0.720       | 0.050       | 0.670  |

|                        | Asymptotic 95% Confidence Interval |
|------------------------|-----------------------------------|
|                        | AUC  | SE   | Inferior Boundary Value | Superior Boundary Value | z    | p    | Sensitivity | Specificity | Youden |
| Lateral Meniscus       |      |      |                        |                        |      |      |             |             |        |
| Thessaly in extension  | 0.745| 0.081| 0.586                   | 0.905                   | 3.022| 0.003| 0.600       | 0.109       | 0.491  |
| Thessaly in flexion    | 0.766| 0.078| 0.614                   | 0.918                   | 3.434| 0.001| 0.625       | 0.093       | 0.532  |
| McMurray               | 0.692| 0.079| 0.537                   | 0.848                   | 2.426| 0.015| 0.500       | 0.115       | 0.385  |
| Apley compression      | 0.842| 0.078| 0.689                   | 0.994                   | 4.394| 0.000| 0.800       | 0.117       | 0.683  |
| Apley distraction      | 0.802| 0.093| 0.619                   | 0.985                   | 3.239| 0.001| 0.750       | 0.145       | 0.605  |
| Total physical examination | 0.714| 0.077| 0.564                   | 0.864                   | 2.795| 0.005| 0.526       | 0.098       | 0.428  |
| MRI                    | 0.788| 0.077| 0.637                   | 0.939                   | 3.741| 0.000| 0.667       | 0.091       | 0.576  |

|                        | Asymptotic 95% Confidence Interval |
|------------------------|-----------------------------------|
|                        | AUC  | SE   | Inferior Boundary Value | Superior Boundary Value | z    | p    | Sensitivity | Specificity | Youden |
| Anterior Cruciate Ligament |      |      |                        |                        |      |      |             |             |        |
| Lachman                | 0.902| 0.040| 0.824                   | 0.980                   | 10.118| 0.000| 0.960       | 0.156       | 0.804  |
| Pivot Shift            | 0.836| 0.047| 0.744                   | 0.929                   | 7.118 | 0.000| 1.000       | 0.328       | 0.672  |
| Anterior drawer Lelli  | 0.846| 0.049| 0.750                   | 0.942                   | 7.057 | 0.000| 0.947       | 0.255       | 0.692  |
| Total physical examination | 0.893| 0.043| 0.809                   | 0.977                   | 9.200 | 0.000| 0.926       | 0.140       | 0.786  |
| MRI                    | 0.870| 0.047| 0.778                   | 0.962                   | 7.883 | 0.000| 0.824       | 0.083       | 0.740  |
Figure 4. ROC curve showing relations between lateral meniscus tests and MRI.

Figure 5. ROC curve showing relations between ACL tests and MRI.
4. Discussion

Intraarticular lesions of the knee joint commonly affect menisci and ligaments. If untreated and undiagnosed the lesions progress over time and result in cartilage damage, which has truly little potential for healing. In our study, we have shown that medial meniscus is better evaluated with MRI rather than with physical examination. MRI showed higher sensitivity and specificity than physical examination.

The sensitivity of the McMurray test presented in our study corresponds with previously published literature however, the specificity of the McMurray test found in our study is higher than previously published by other authors [25]. It was also shown that apart from the Apley test, all other tests presented a lower diagnostic performance in the detection of lateral meniscus lesions than for medial meniscus, which is consistent with previously published literature[26]. Also, MRI showed inferior performance concerning lateral meniscus than for MM in our study and literature [27,28]. This phenomenon is attributed to the anatomical structure and location of LM, which creates problems for MRI clear visualisation.

Therefore, as shown by our study, LM is better evaluated by physical examination than by MRI. Similar findings were shown for ACL deficiency, where the Lelli test and pivot shift showed 100% sensitivity. Such a high sensitivity was published by Lelli himself however, none of the other studies proved such a high sensitivity [22,29,30]. Our results may be caused by the fact that the lever sign was incorporated in our standard knee examination, which influenced our familiarity with the test and resulted in higher sensitivity and specificity than previously published. As in LM also in ACL inferior MRI diagnostic performance to the physical examination could be observed. As shown by previous literature, the sensitivity of 77% can be observed for MRI in detecting ACL lesions [31]. In our study, oftentimes “partial ACL tear” was outlined in the MRI report, however as shown by van Dyck [32] and our results, MRI based evaluation of partial ACL tears is unreliable even if 3T coils are being utilised [33]. The MRI examinations in our study were made in different departments and we were not able to retrieve the referrals of all examinations to verify if the referral included all important information for the leading radiologist, which could strongly influence the sensitivity and specificity of MRI in menisci and ligamentous lesions diagnosis. However, this situation resembles a typical clinical setting and the results might be more helpful in everyday practice. This data suggest that clinical examination is grossly superior to the MRI in detecting ACL deficiency, and in isolated ACL tears MRI has limited application.

References

[1] Jędrychowski W 2004 Zasady planowania i prowadzenia badań naukowych w medycynie (Kraków: Wydawn. Uniwersytetu Jagiellońskiego)
[2] Krukow P, Jonak K, Karpinski R and Karakula-Juchnowicz H 2019 Abnormalities in hubs location and nodes centrality predict cognitive slowing and increased performance variability in first-episode schizophrenia patients Sci. Rep. 9 9594
[3] Jonak K, Krukow P, Jonak K E, Grochowski C and Karakula-Juchnowicz H 2019 Quantitative and Qualitative Comparison of EEG-Based Neural Network Organization in Two Schizophrenia Groups Differing in the Duration of Illness and Disease Burden: Graph Analysis With Application of the Minimum Spanning Tree Clin. EEG Neurosci. 50 231–41
[4] Jurkowska M M Ć 2013 Klasyfikatory pojedyncze i zintegrowane jako narzędzie wspomagania medycyny 16
[5] Harańczyk G 2010 Krzywe ROC czyli ocena jakości klasyfikatora i poszukiwanie optymalnego punktu odcięcia 11
[6] McNeil B J and Hanley J A 1984 Statistical Approaches to the Analysis of Receiver Operating Characteristic (ROC) Curves Med. Decis. Making 4 137–50
[7] Surtel W, Maciejewski M and Maciejewska B 2013 Processing of simultaneous biomedical signal data in circulatory system conditions diagnosis using mobile sensors during patient activity 2013 Signal Processing: Algorithms, Architectures, Arrangements, and Applications (SPA) 2013 Signal Processing: Algorithms, Architectures, Arrangements, and Applications (SPA) pp 163–7
[8] Maciejewski M, Surtel W, Maciejewska B and Małecka-Massalska T 2015 Level-set image processing methods in medical image segmentation Bio- Algorithms Med-Syst. 11
[9] Cibere J, Sayre E C, Guermazi A, Nicolau S, Kopec J A, Esdaile J M, Thorne A, Singer J and Wong H 2011 Natural history of cartilage damage and osteoarthritis progression on magnetic resonance imaging in a population-based cohort with knee pain Osteoarthritis Cartilage 19 683–8
[10] Karpiński R, Jaworski L and Zubrzycki J 2016 Structural analysis of articular cartilage of the hip joint using finite element method Adv. Sci. Technol. Res. J. 10 240–6
[11] Karpiński R, Jaworski L, Jonak J and Krakowski P 2019 Stress distribution in the knee joint in relation to tibiofemoral angle using the finite element method ed M Kulisz, M Szala, M Badurowicz, W Cel, M Chmielewska, Z Czyż, K Falkowicz, J Kujawska and T Tulwin MATEC Web Conf. 252 07007
[12] Królikowska A, Sikorski L, Czamara A and Reichert P 2018 Effects of Postoperative Physiotherapy Supervision Duration on Clinical Outcome, Speed, and Agility in Males 8 Months After Anterior Cruciate Ligament Reconstruction Med. Sci. Monit. 24 6823–31
[13] Krakowski P, Gerkowicz A, Pietrzak A, Krasowska D, Jurkiewicz A, Gorzelak M and Schwartz R A 2019 Psoriatic arthritis – new perspectives Arch. Med. Sci. 15 580–9
[14] Jones M H and Spindler K P 2017 Risk factors for radiographic joint space narrowing and patient reported outcomes of post-traumatic osteoarthritis after ACL reconstruction: Data from the MOON cohort: PTOA AFTER ACL RECONSTRUCTION IN MOON J. Orthop. Res. 35 1366–74
[15] Jordan M, Aagaard P and Herzog W 2017 Anterior cruciate ligament injury/reinjury in alpine ski racing: a narrative review Open Access J. Sports Med. Volume 8 71–83
[16] Solivetti F M, Guerrisi A, Salducca N, Desiderio F, Graceffa D, Capodieci G, Romeo P, Sperduti I and Canitano S 2016 Appropriateness of knee MRI using arthroscopic findings as golden standard Musculoskelet. Surg. Am. J. Bone Jt. Surg. 29 78–84
[17] Karachalios T, Hantes M, Zabis A H, Zachos V, Karantanas A H and Malizos K N 2005 Diagnostic Accuracy of a New Clinical Test (the Thessaly Test) for Early Detection of Meniscal Tears: J. Bone It. Surg. 87 955–62
[18] Paessler H H and Michel D 1992 How new is the Lachman test? Am. J. Sports Med. 20 95–8
[19] Galway H R and MacIntosh D L 1980 The lateral pivot shift: a symptom and sign of anterior cruciate ligament insufficiency Clin. Orthop. 45–50
[20] Lelli A, Di Turi R P, Spenciner D B and Dòmini M 2016 The “Lever Sign”: a new clinical test for the diagnosis of anterior cruciate ligament rupture Knee Surg. Sports Traumatol. Arthrosc. 24 2794–7
[21] DeLong E R, DeLong D M and Clarke-Pearson D L 1988 Comparing the Areas under Two or More Correlated Receiver Operating Characteristic Curves: A Nonparametric Approach Biometrics 44 837–45
[22] Hanley J A and Hajian-Tilaki K O 1997 Sampling variability of nonparametric estimates of the areas under receiver operating characteristic curves: An update Acad. Radiol. 4 49–58
[23] Meserve B B, Cleland J A and Boucher T R 2008 A meta-analysis examining clinical test utilities for assessing meniscal injury Clin. Rehabil. 22 143–61
[24] Speziali A, Placella G, Tei M M, Georgoulis A and Cerulli G 2016 Diagnostic value of the clinical investigation in acute meniscal tears combined with anterior cruciate ligament injury using arthroscopic findings as golden standard Musculoskelet. Surg. 100 31–5
[25] Wong K P L, Han A X, Wong J L Y and Lee D Y H 2017 Reliability of magnetic resonance imaging in evaluating meniscal and cartilage injuries in anterior cruciate ligament-deficient knees Knee Surg. Sports Traumatol. Arthrosc. 25 411–7
[26] Ahn J H, Kang D M and Choi K J 2017 Risk factors for radiographic progression of osteoarthritis after partial meniscectomy of discoid lateral meniscus tear Orthop. Traumatol. Surg. Res.
[29] Jarbo K A, Hartigan D E, Scott K L, Patel K A and Chhabra A 2017 Accuracy of the Lever Sign Test in the Diagnosis of Anterior Cruciate Ligament Injuries *Orthop. J. Sports Med.* 5 232596711772980

[30] Massey P A, Harris J D, Winston L A, Lintner D M, Delgado D A and McCulloch P C 2017 Critical Analysis of the Lever Test for Diagnosis of Anterior Cruciate Ligament Insufficiency *Arthrosc. J. Arthrosc. Relat. Surg.*

[31] Grevitt M P, Pool C J, Bodley R N and Savage P E 1992 Magnetic resonance imaging of the knee: initial experience in a district general hospital *Injury* 23 410–2

[32] Van Dyck P, De Smet E, Veryser J, Lambrecht V, Gielen J L, Vanhoenacker F M, Dossche L and Parizel P M 2012 Partial tear of the anterior cruciate ligament of the knee: injury patterns on MR imaging *Knee Surg. Sports Traumatol. Arthrosc.* 20 256–61

[33] Van Dyck P, Vanhoenacker F M, Lambrecht V, Wouters K, Gielen J L, Dossche L and Parizel P M 2013 Prospective Comparison of 1.5 and 3.0-T MRI for Evaluating the Knee Menisci and ACL: *J. Bone Jt. Surg.-Am. Vol.* 95 916–24