REVIEW / PREGLEDNI RAD

Comparison 1.5T and 3T Magnetic Resonance in the Diagnostics of Knee

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Abstract

With its multiplanar capabilities and excellent soft-tissue contrast, magnetic resonance imaging has established itself as the leading modality for non-invasive evaluation of the musculoskeletal system. Most clinical evaluation are performed at the field strength 1.5T due to a less availability of 3T MRI machines. Although at first used primarily for neurological imaging, an increasing number of studies have demonstrated the abilities and advantages of 3T MR systems in musculoskeletal imaging. The most notable advantage includes an increased signal-to-noise ratio (SNR) which can lead to a shorter imaging time and reduces the chance of motion artefacts or improved image resolution.Much promising research is being done in how to optimize the 3T MRI protocol to achieve the best possible evaluation of the musculoskeletal system.

Keywords: 1.5T and 3T, MRI, knee

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Introduction

MRI (Magnetic Resonance Imaging) has become the leading modality for detection and evaluation of acute and chronic knee injuries. Although radiography is still used as the initial imaging modalityto diagnose knee pathology, primarily bone structures, MRI is useful in characterisation of meniscal, cruciate ligament, collateral ligament injuries, as well as articular cartilage, synovial and tendon disorders.There are wide variations of MRI system, including open and closed bore magnet systems, various field strengths and coil technologies and MRI protocols are customised for specific indications. These factors lead to the high variability of pulse sequences utilised from institution to institution. A compromise between appropriate SNR (signal-to-noise ratio), spatial resolution and duration of the examination is needed to ensure that diagnostic quality images are acquired [1].Although knee MRI can be performed on lower field strength systems, including open bore magnets, it is most commonly performed with either 1.5T or 3T closed bore magnets. Both magnet strengths provide diagnostic images, but 3T systems often have superior SNR and spatial resolution, which can help to improve diagnostic confidence and reduce scan time. Moreover, advanced 3T imaging applications may help improve detection and characterisation of tumours and peripheral nerve disorders [2]. On the other hand, 1.5T imaging is useful to reduce metallic susceptibility artefacts from hardware or other metallic substances within the field of view, and some MRI-compatible medical devices may only be safe to image at 1.5T [3,4]. Regardless of magnetic field strength, dedicated knee coils will provide the best quality images.

Aim

The aim of this paper is to present use of 1.5T and 3T knee MRI in everyday clinical practice. This paper is based on an overall search of the scientific literature published from 2009 to 2021 on PubMed platform using search terms: „1.5T and 3T", „knee MRI", „comparison", „knee pathology". The initial search yielded 256 published articles. Finally, after reviewing potential articles based on predetermined criteria, 35 articles were selected and used in writing this paper.

Methods

According to the European Society of Musculoskeletal Radiology guidelines, knee imaging protocols consist of T2 TSE FS or PD (proton density) FS sequences and T1 sequences in three orthogonal planes – sagittal, axial, coronal and T2 axial oblique for ACL (anterior cruciate ligament) evaluation. Coronal and sagittal PD sequences provide

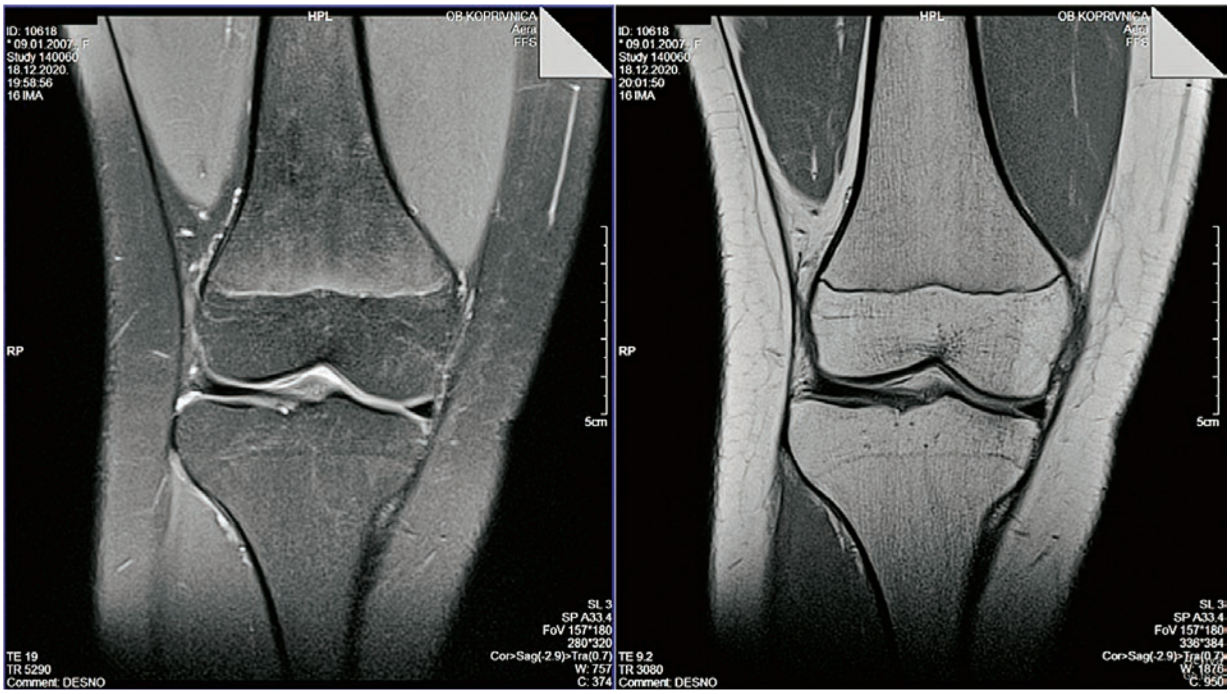

Figure 1 Coronal planes with and without fat saturation (Source: General Hospital „Dr.Tomislav Bardek“, Koprivnica)

high SNR and spatial resolution and are more sensitive than T2 sequences in detection of meniscal pathology, but scan time is relatively long. Most protocols contain at least one PD sequence in sagittal or coronal plane. T2 sequences may make bone and soft tissue oedema-like signal changes more conspicuous. Also, they are useful for better characterisation of postoperative meniscus[5].

TSE (Turbo Spin Echo) sequences are SE (Spin Echo) sequences, but with much shorter scan time. There are two main differences between SE i FSE/TSE. First difference is that the fat stays brighter on T2 images due to the number of RF pulses, but this can be compensated by applying fat saturation sequences. The second difference is due to repetitive 180º pulses which increase the effect of magnetization shift and decrease magnetic susceptibility. E.g. the muscle is shown darker on the FSE/TSE than on the SE sequence, and because reduced susceptibility small haemorrhages are difficult to detect. Image blurring on FSE/TSE occurs at tissue edges due to different T2 values, but in patients with metal implants

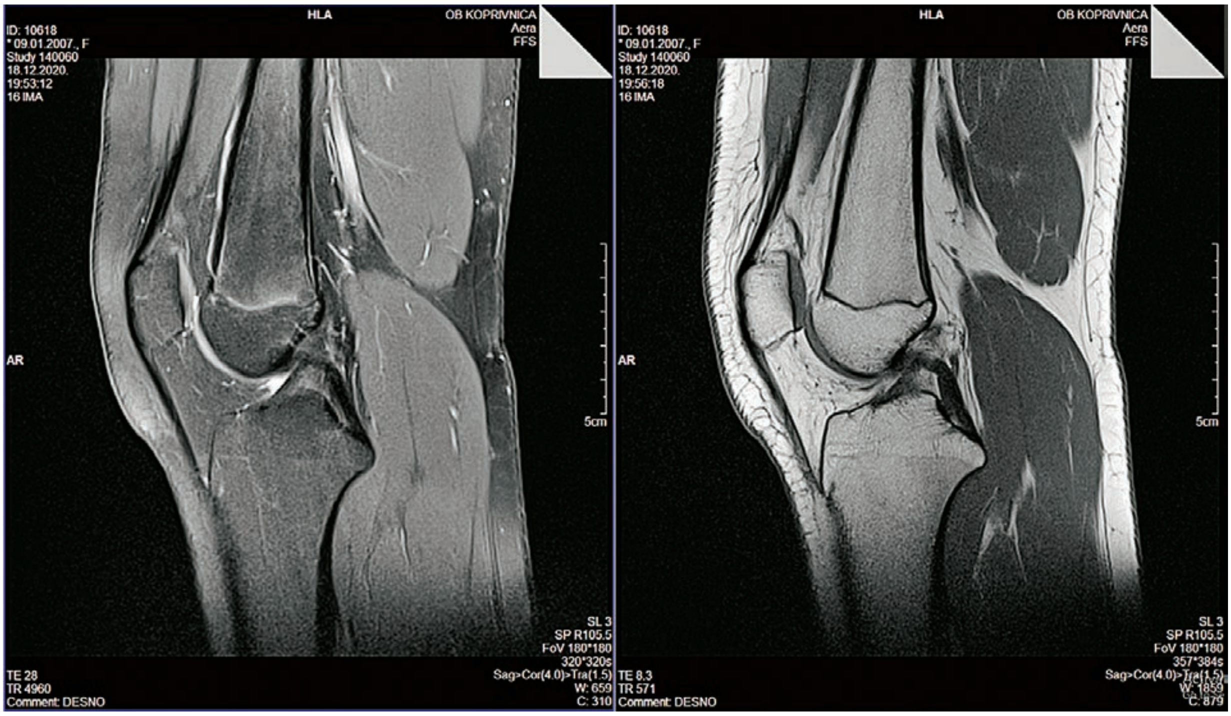

Figure 2 Sagittal planes with and without fat saturation (Source: General Hospital „Dr.Tomislav Bardek“, Koprivnica)

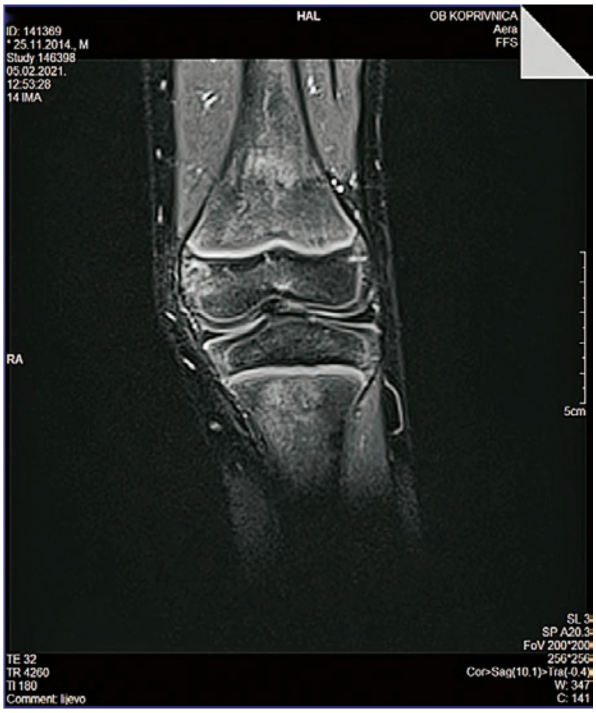

Figure 3 STIR sequence (Source: General Hospital „Dr.Tomislav Bardek Koprivnica)

the artefacts are significantly reduced. Significant shortening of scan time, using high resolution matrix and NEX (Number of Excitations) and improved image quality are the advantages of these sequences. Disadvantages are image blur, the fat signal „lights up" on T2 images and increased flow and movement effects [6].

T1 sequences are usually performed without fat saturation because they are used for bone marrow fat evaluation or to detect fracture lines. T1 FS are used after intravenous or intra-articular administration of contrast agent. According to American College of Radiology guidelines, knee imaging protocol parameters include maximum FOV (Field of view) of 16 cm, maximum slice thickness of 4 mm, matrix of at least 192x256 and maximum gap spacing of 50%. With continued improvements in coil and magnet technology, many institutions utilise thinner slice thickness and high spatial resolution for better visualization of meniscal and articular cartilage structures while preserving adequate SNR within the time limits of an examination [6].

Very important sequence in musculoskeletal imaging is STIR (Short Time Inversion Recovery) sequence. STIR is applied to attenuate fat signal because healthy bone contains fat bone marrow which is suppressed by this sequence and lesions within bone are clearly visible. The main disadvantage of these sequences is long scan time since complete proton relaxation must occur [7].

Results

With conflicting results in the literature, whether a higher field strength automatically increases the sensitivity and specificity of MRI for detecting pathological lesions in the knee, 2 orthopaedic surgeons (Cheng et Zhao) [8] performed a systematic review and meta-analysis of studies comparing the diagnostic accuracy of 1.5T and 3T MRI for lesions within the knee. The initial search yielded 563 papers, and after application of the exclusion criteria (the absence of arthroscopy results as the gold standard for diagnosis of lesions, and a study population of <10 patients), 48 articles were selected for full-text review. Of these, 16 clinical studies specifically designed to analyse the diagnostic accuracy of 1.5T and/or 3T MRI for lesions in the articular cartilage, ligaments, or meniscus of the knee joint were identified and included in the present meta-analysis. To reduce the heterogeneity among the clinical studies, separate meta-analyses of studies investigating lesions in different parts of the knee, specifically the articular cartilage, ligaments, and meniscus were performed.The 16 studies were published between 2005 and 2017 and described results from 1886 patients, including 824 lesions of the ligaments, 6686 lesions of the articular cartilage, and 3631 lesions of the meniscus. Arthroscopic evaluation was the reference method for the assessment of the knee joint pathology in all studies. In both the MRI and arthroscopic surgery reports, the articular surfaces of the knee were divided into 6 regions (i.e., patella, trochlea, medial femoral condyle, medial tibial plateau, lateral femoral condyle, and lateral tibial plateau).

As can be seen in Table 1, the analysis included 6 prospective and 10 retrospective studies published from 2005 to 2017. The age range of the patients included in the study is from 15 to 68. The shortest time between performed MRI and arthroscopy was within 3 days and the longest 192 days.

From Moses-type sROC curve plots for 1.5T and 3T MRI of articular cartilage lesions, the Q test for heterogeneity demonstrated wide homogeneity among all studies ($P>.05$), including those reporting 1.5T and/or 3T MRI results [9-13]. From these sROC curves, calculated AUC values are 0.7867 for 1.5T MRI and 0.9106 for 3T MRI. A significant difference was detected in the diagnostic effectiveness of 1.5T and 3T MRI ($Z=3.4$, $P<.05$), and the diagnostic effectiveness of 1.5T MRI (Fig. 4) for articular cartilage lesions was lower than that of 3TMRI (Figure 5).

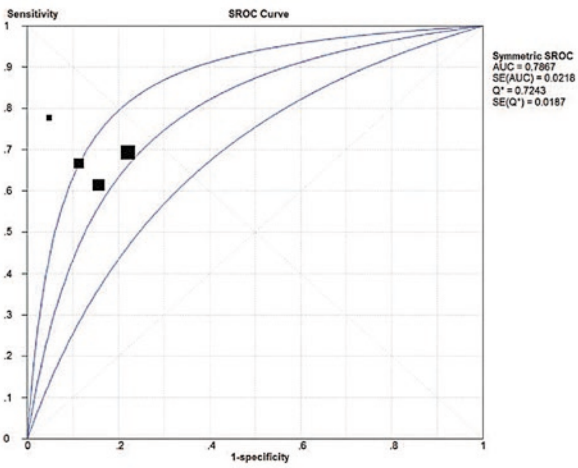

Figure 4 Moses-type sROC curves for the diagnosis of articular cartilage lesions on 1.5T MRI
MRI = magnetic resonance imaging, sROC = summary receiver operating characteristic
(Source: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6160024)

Table 1 Summary of the characteristics of the included studies
(Source: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6160024/)

Study	Country	Year published	Study type	Cases, n	Patient age (y), mean or range	Time between MRI and arthroscopy
Krampla (13)	Austria	2009	Retrospective	32	15-60	Within 4 wk
Mandell (14)	USA	2017	Retrospective	297	42.8	68.2 d
Grossman (19)	USA	2009	Retrospective	200	36	62.9 d
Van Dyck (10)	Belgium	2013	Prospective	100	45	46 d
Wong (6)	USA	2009	Retrospective	19	38.5	56 d
Kijowski (1)	USA	2009	Retrospective	200	39	19.1 d
Magee and Williams (20)	Merritt Island	2006	Retrospective	100	41	8 d
LaPrade (21)	USA	2014	Retrospective	287	41.7	18 d
Craig (16)	USA	2005	Retrospective	58	13-68	56 d
Esmaili Jah (7)	Iran	2005	Prospective	70	—	—
Lee (21)	South Korea	2008	Retrospective	192	51	192 d
von Engelhardt (15)	Germany	2007	Prospective	40	49.5	4.3 d
Khan (18)	Saudi Arabia	2006	Prospective	60	35	Within 1 mo
Arif (22)	Pakistan	2013	Prospective	50	30	—
Timotijevic (23)	Serbia	2013	Retrospective	107	29.17	—
Alizadeh (24)	Iran	2013	Prospective	74	33.5	Within 3 d

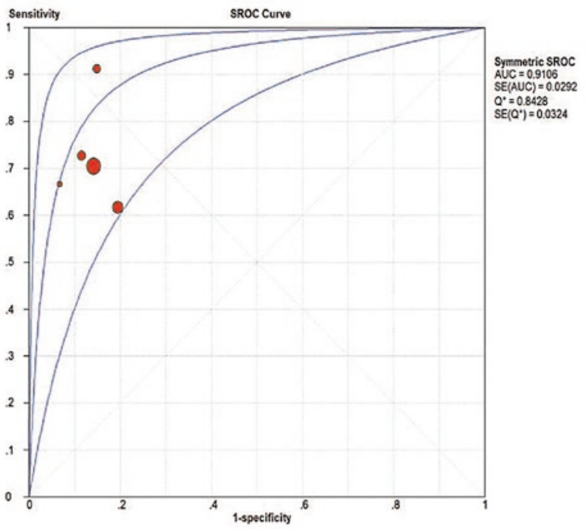

Figure 5 Moses-type sROC curves for the diagnosis of articular cartilage lesions on 3T MRI
MRI = magnetic resonance imaging, sROC = summary receiver operating characteristic
(Source: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6160024)

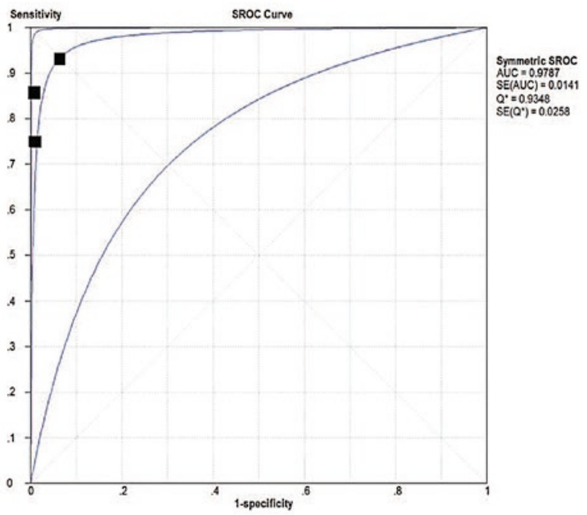

Figure 6 Moses-type sROC curves for the diagnosis of lesions of the ligament on 1.5T MRI
MRI = magnetic resonance imaging, sROC = summary receiver operating characteristic
(Source: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6160024)

From the Moses-type sROC curves for 1.5T and 3T MRI of lesions within the knee ligaments, the Q test for heterogeneity demonstrated a wide homogeneity among all studies ($P > .05$), including those reporting 1.5T and/or 3T MRI results [11,13-15].

For these sROC curves, calculated AUC valuesare 0.9787 for 1.5T MRI and 0.9894 for 3T MRI. We observed no significant difference in the diagnostic accuracy of 1.5 T (Figure 6) and 3T (Figure 7) MRI for lesions in knee ligaments ($Z = 0.32$, $P > .05$).

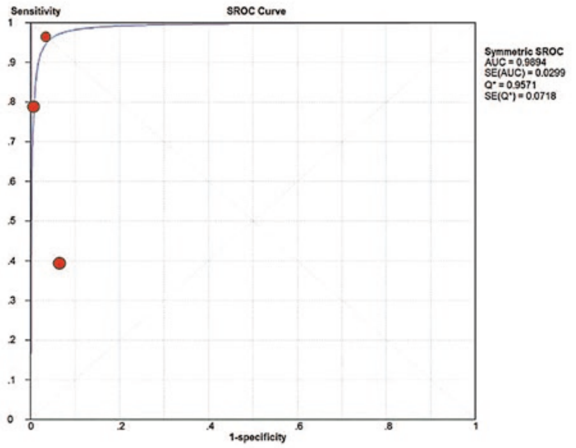

Figure 7 Moses-type sROC curves for the diagnosis of lesions of the ligament on 3T MRI
MRI = magnetic resonance imaging, sROC = summary receiver operating characteristic
(Source: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6160024)

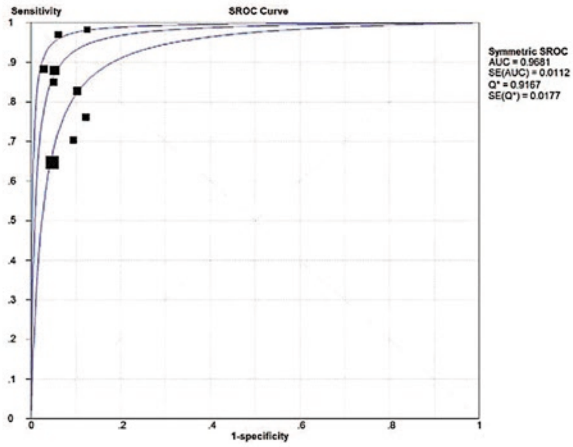

Figure 8 Moses-type sROC curves for the diagnosis of meniscal lesions on 1.5T MRI
MRI = magnetic resonance imaging, sROC = summary receiver operating characteristic
(Source: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6160024)

From Moses-type sROC curves for 1.5T and 3T MRI of meniscal lesions, the Q test for heterogeneity demonstrated a wide homogeneity among all studies ($P > .05$), including those reporting 1.5T and/or 3T MRI results [11,13-20]. From these sROC curves, calculated AUC values are 0.9681 for 1.5T MRI and 0.9578 for 3T MRI. We observed no significant difference in the diagnostic accuracy of 1.5T (Figure 8) and 3T (Figure 9) MRI for meniscal lesions ($Z = 0.33$, $P > .05$).

Buttin et al. [21] in 2020 published an article showing the advantages and disadvantages of 3T MRI over 1.5T. Increased SNR which reduces the acquisition time and increases spatial resolution, better visualisation and detection of small blood vessels at TOF compared to 1.5T, higher sensitivity of GRE and SWI sequences in detection of stroke, tumours, etc. are some of the 3T advantages. However, increasing the magnetic field also has a disadvantage as it is also responsible for a greater susceptibility effect (distortion, signal loss at air/tissue interfaces) which makes shimming optimization even more important. The chemical shift artefact is also increased which is a challenge particularly when using CSI. At 3T, acoustic noise increases, in theory, in relation to the 1.5T system as the magnetic field is stronger and therefore the vibrations produced by the strong currents passing through the copper (gradient) coils should be multiplied in proportion to the field. In practice, however, this is not the case, as the 3T gradient amplifiers and shock absorbers (filter behind the amplifiers) compensate for this noise so that, ultimately, a 3T system only produces slightly more noise than a 1.5T system. Also, SAR at 3T is much higher than at 1.5T.

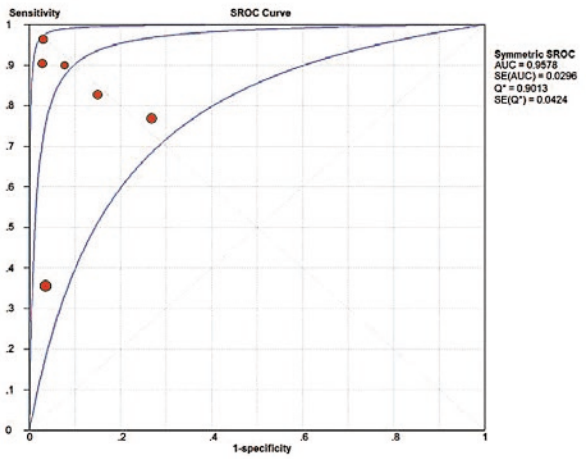

Figure 9 Moses-type sROC curves for the diagnosis of meniscal lesions on 3T MRI
MRI = magnetic resonance imaging, sROC = summary receiver operating characteristic
(Source: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6160024)

In May 2021, Abdulaal et al.[22] published a research about the impact of parameter optimisation for novel three-dimensional 3D sequences at 1.5T and 3T on resultant image quality.MR phantom and knee joint imaging on healthy volunteers (n = 16) was performed with 1.5 and 3T MRI scanners, respectively incorporating 8- and 15-channel phased array knee radiofrequency coils. The MR phantom and healthy volunteers were prospectively scanned over a six-week period. Acquired sequences included standard two-dimensional (2D) turbo spin echo (TSE) and novel three-dimensional (3D) TSE PDW (SPACE) both with and without fat-suppression, and T2∗W gradient echo (TrueFISP) sequences. Phantom and healthy volunteer images revealed higher SNR for sequences acquired at 3T (p-value <0.05). 3D image data sets demonstrated less sensitivity to partial volume averaging artefact (PVA) compared to 2D sequences. Inter- and intra-observer agreements for evaluation across all sequences ranged from 0.61 to 0.79 and 0.71 to 0.92, respectively. Both 2D and 3D images demonstrated higher image quality at 3T than at 1.5T. Optimised 3D sequences performed better than the standard 2D PDW TSE sequence for contrast

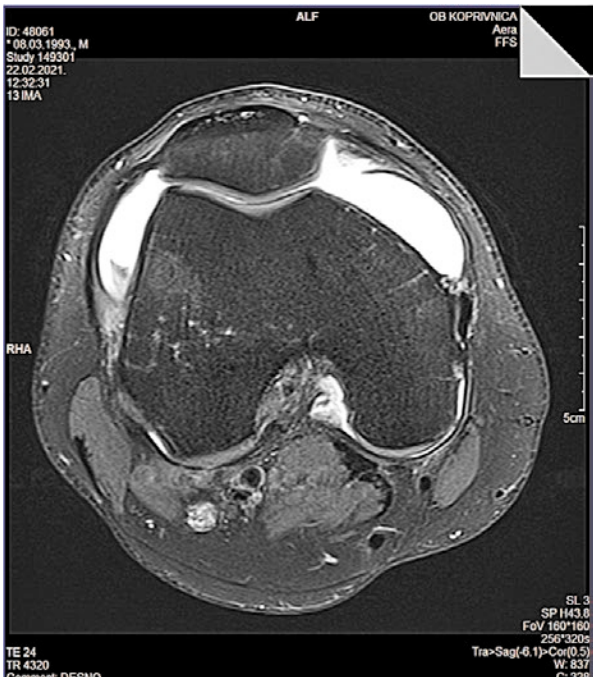

Figure 10 pd_tse_fs_tra 1.5T SNR=1 (Source: General Hospital „Dr. Tomislav Bardek Koprivnica)

Figure 11 pd_tse_fs_tra 3T SNR=1.8 (Source: Clinical Hospital „Sveti Duh" Zagreb)

resolution between cartilage and joint fluid, with reduced PVA artefact.

Ultra-high field (UHF) MRI, in particular 7T MRI, has a well-demonstrated role in musculoskeletal imaging. In comparison with lower magnetic fields, UHF-MRI provides an increased signal-to-noise ratio (SNR) that can selectively increase spatial and/or temporal resolution that allow finer structures to be visualized and smaller physiological effects to be detected. Also it provides improved spectral resolution and sensitivity for X-nucleus imaging, *i.e.*, ^{23}Na, ^{31}P, ^{13}C, and ^{39}K. Imaging at such high frequencies presents several challenges including non-uniform radiofrequency fields, enhanced susceptibility artifacts, and higher radiofrequency energy deposition in the tissue. [23].

Welsch et al. demonstrated the superiority of 7-T over 3-T magnets for quantitative and qualitative cartilage evaluation, in terms of higher spatial resolution, higher contrast-to-noise ratio (CNR) and potentially reduced acquisition time [24]. Aringhieri et al. [25] scanned the same knee of the same subject at 1.5 T, 3 T, and 7 T (Figure 13) to compare the quality of obtained images. They showed that optimized spatial and contrast resolution at 7T allowed for more accurate cartilage assessment.

At the bottom left, a detail of the comparison of the femoral-patellar compartment at 1.5-T, 3-T, and 7-T is displayed (from left to right) (Source:https://eurradiolexp.springeropen.com/articles/10.1186/s41747-020-00174-1)

Springer et al. [26] analysed the diagnostic confidence by comparing similar clinical protocol at 3T and 7T

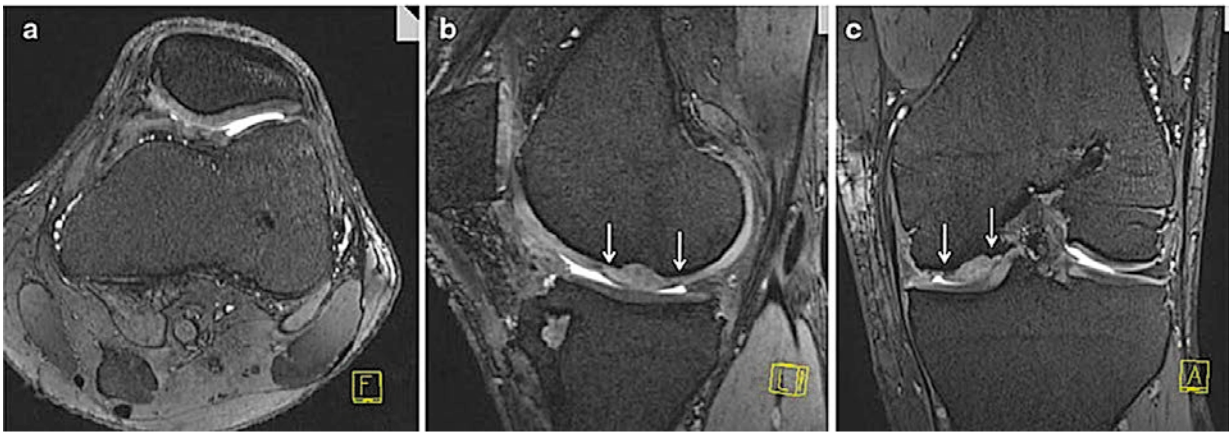

Figure 12 3D TrueFISPsequence (Source: https://www.researchgate.net/figure/Morphological-3D-isotropic-True-FISP-sequence-of-one-patient-12-months-after-MACT-of-the_fig2_23686393)

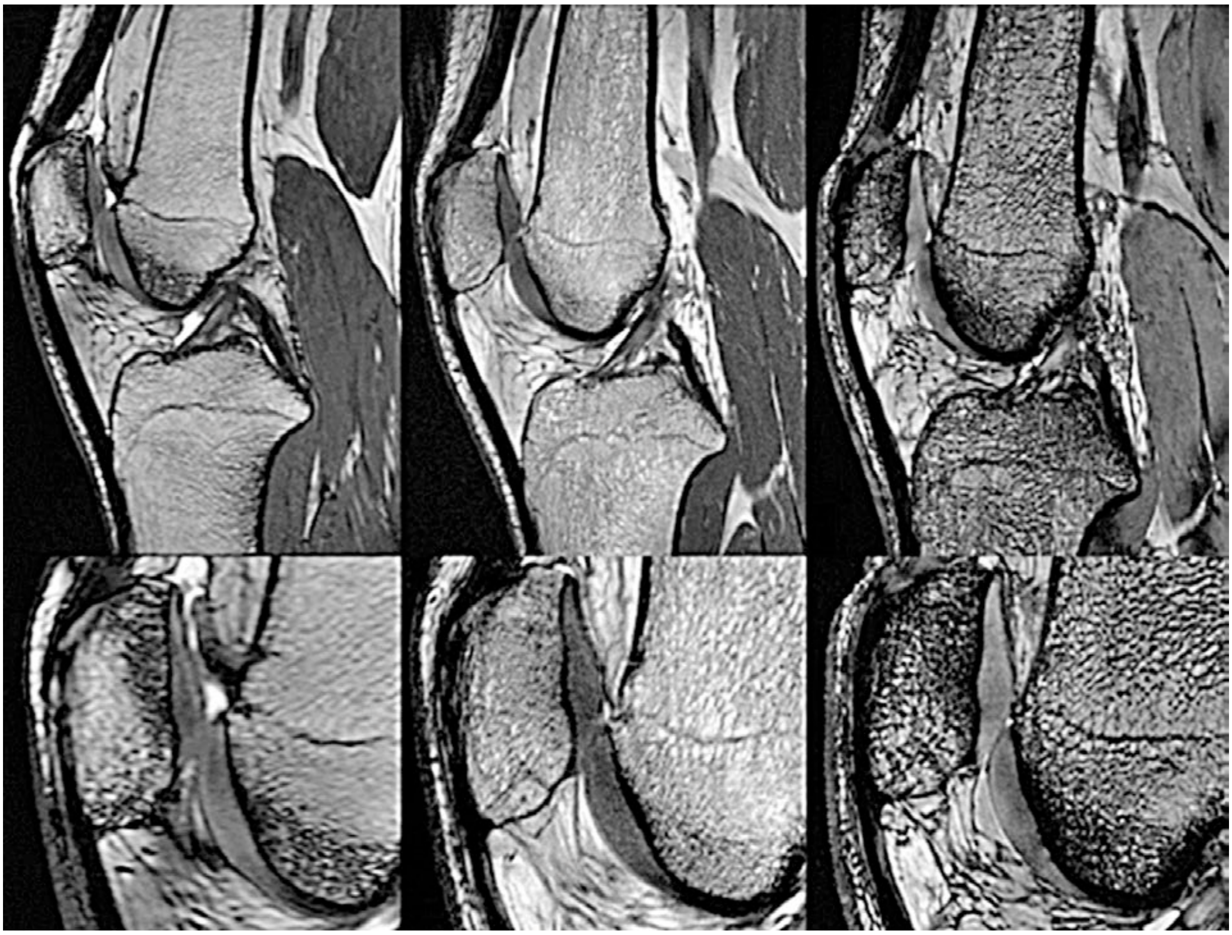

Figure 13 The comparison of the same knee of the same healthy volunteer acquired with fast imaging employing steady-state acquisition with coherence interference (FIESTA-C) at 1.5-T, 3-T, and 7-T (from left to right)

in a study with 40 patients who had knee pain. Despite image quality reduction due to chemical shift artefacts, they found an improvement in overall diagnostic potential at 7T which shows enhanced detection of subtle lesions due to higher SNR and resolution.Wang et al. [27] first obtained 3D sodium images of the whole knee at 7 T in less than 15 min with a 3D GRE sequence with radial k-space acquisition. They observed a significant reduction in sodium concentration in patients with OA compared to healthy subjects. The average signal-to-noise ratio (SNR) for different spatial resolutions (1.2-4 mm) varied from approximately 14-120, respectively. The mean sodium concentration of healthy subjects ranged from approximately 240 +/- 28 mM/L to 280 +/- 22 mM/L. However, in OA patients the sodium concentrations were reduced significantly by approximately 30%-60%, depending on the degree of cartilage degeneration.

Conclusion

Both 1.5T and 3T MRI show a high degree of diagnostic accuracy and clinical relevance for the diagnosis of lesions within the ligaments and meniscus of the knee. However, 3.0-T MRI of the knee does not yield a significantly higher diagnostic accuracy than 1.5-T MRI for detecting meniscal and ligament tears.Although these results may seem surprising at first glance, they are not completely unexpected. Evaluation of meniscal and ligament pathology with standard magnetic field strengths (<1.5T) has been generally successful so any further improvement with higher-field strength systems is likely to be small. Furthermore, image quality and diagnostic accuracy are not determined only by magnetic field strength, but also by other factors such as imaging planes and coil technology. However, 3T has significantly higher accuracy for detecting knee cartilage lesions compared to a similar protocol performed at 1.5T.

This study has several limitations. First, the 1.5T and 3T MRI protocols were performed in different patient populations. Also, the accuracy of the MRI reports is impacted by the radiologists' experience. The study design may be limited by a lack of analysis and comparison with other MRI protocol parameters that affect diagnostic image quality such as coil selection, pulse sequence, 2D vs. 3D, FOV, matrix, and bandwidth. Some of the observers employed in these studies had used only 1T and 1.5T systems in recent years, and they were therefore not accustomed to the typical 3T images. Differences in the definitions of lesions among several reports also could influence the accuracy of the diagnosis. Furthermore, the present study demonstrated a wide heterogeneity among the results of published studies. This heterogeneity and the low number of included studies suggest the need for caution when interpreting the finding of our analyses.

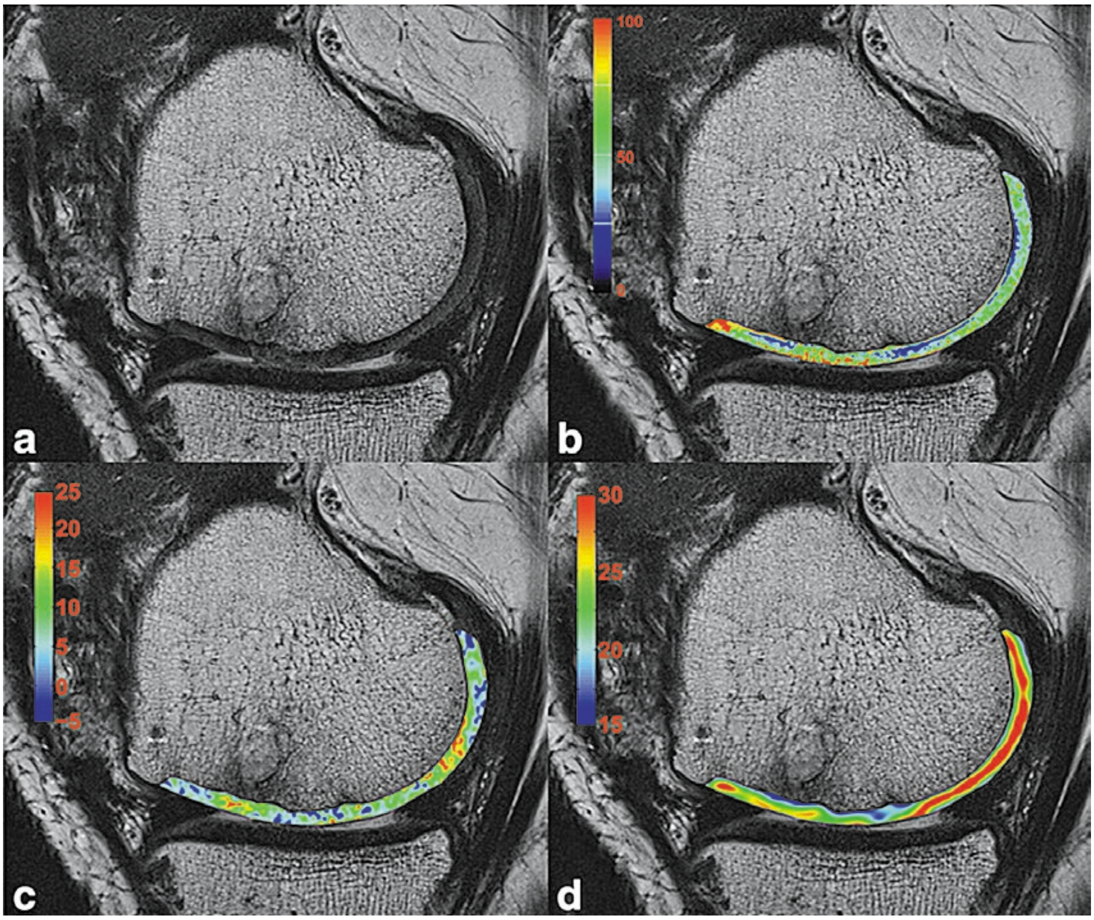

Figure 14 Morphologic proton-density fast spin-echo image. **b** Graphical overlay with T2 map. Colour bar represents relaxation times (ms) (higher values, more water and disturbed collagen architecture). **c** Graphical overlay with glycosaminoglycan chemical exchange saturation transfer (gagCEST) image. Colour bar represents gagCEST asymmetries in % (lower values, less proteoglycan content). **d** Graphical overlay with sodium image. (Source:https://eurradiolexp.springeropen.com/articles/10.1186/s41747-020-00174-1#ref-CR11)

Usporedba magnetske rezonancije od 1.5T i 3T u dijagnostici koljena

Sažetak

Zahvaljujući multiplanarnim mogućnostima i izvrsnim kontrastom mekih tkiva, magnetska rezonancija postala je vodeći modalitet za neinvazivnu procjenu muskuloskeletnog sustava. Većina pacijenata se snima uređajima za magnetsku rezonanciju jačine magnetskog polja 1.5T obzirom da su uređaji jakosti 3T manje dostupni u kliničkoj praksi. Iako se isprva primarno koristio za neurološko snimanje, sve je veći broj studija koje pokazuju mogućnosti i prednosti 3T u muskuloskeletnom oslikavanju. Najistaknutija prednost uključuje povećani omjer signala i šuma (SNR) koji može dovesti do kraćeg vremena snimanja čime se smanjuje šansa za artefakte gibanja ili poboljšati kvalitetu slike povećanjem rezolucije. Mnogo je istraživanja kako optimizirati protokol za 3T MR kako bi se postigla što bolja procjena muskuloskeletnog sustava.

Ključne riječi: 1.5T i 3T, MRI, koljeno

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