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The Value of the T2-Weighted Multipoint Dixon MRI Sequence in Evaluation of the Bone Marrow Edema of Knee Joint

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Abstract:

Background: The preferable method for assessing acute and chronic joint disorders is magnetic resonance imaging (MRI), which is capable of visualizing soft tissues, cartilage, and bone. This study aimed to assessment of knee bone marrow edema (BME) using the T2-weighted multipoint Dixon method in its entirety. **Methods:** This cross-sectional observational study included 50 bone marrow edematous patients subjected to closed MRI 1.5 T with dedicated knee coil were included at the Radiology Department, Faculty of Medicine, Benha University Hospital. All cases were subjected to standard pulse MRI sequences for imaging of the knee joint. **Results:** The age of the total patients ranged from 9 to 54 years with a mean ± SD of 32.6 ± 14.3 years. There were 19 (38%) females and 31 (62%) males. The contrast-to-noise ratio of lesions was significantly increased in water-only T2-weighted multipoint Dixon than fat-saturated T2-weighted (P value <0.001). There was no agreement between the water-only T2-weighted multipoint Dixon and fat-saturated T2-weighted for grading of signal intensity of BME (kappa value =0.196, P value 0.484). **Conclusion:** Instead of using fat-saturated T2-weighted, contrast-enhanced fat-saturated T1-weighted, or T1-weighted imaging, a single MRI sequence of multiple-point T2-weighted Dixon imaging can be used to identify BME in the knee without invasive procedures. A single sequence can save time and money while reducing the likelihood of negative effects compared to a contrast medium.

Keywords: T2-Weighted Multipoint Dixon; Magnetic Resonance Imaging; Bone Marrow Edema; Knee Joint.

Introduction

A magnetic resonance imaging (MRI) scan, which can detect bone, cartilage, and soft tissues, is the diagnostic tool of choice for both acute and chronic joint problems [(1)]. Bone marrow signal anomalies are common when interpreting magnetic resonance imaging (MRI). They can be seen as a standalone symptom in cases of trauma, chronic cartilage damage, or osteoarthritis (OA), or they can be present alongside other diseases like inflammation or osteonecrosis [(2)].

The T2-weighted multipoint Dixon Bone marrow edema (BME)-like signal alterations on magnetic resonance imaging (MRI) exhibit typical signal characteristics. The subchondral bone marrow is not visible to X-ray or ultrasound technology, making it the most suitable instrument for assessing these pathologies [(3)]. MRI findings frequently fail to precisely identify the underlying condition. Therefore, it is necessary to establish a correlation with clinical history, biochemical markers, and other imaging modalities. By gaining a comprehensive comprehension of the patterns of marrow abnormalities in the knee, the radiologist can narrow the list of differential diagnoses and direct them to an appropriate treatment recommendation [(4)].

When interpreting knee MRIs, BME is encountered on a daily basis. Miscellaneous disorders, trauma, ischemia, and degenerative disease are the four broad categories into which disease entities can be classified [(5)]. Marrow edema analysis is conducted using a pattern approach that assesses the entity's morphology, distribution, location, and signal characteristics. Marrow signal edema can be categorized as diffuse, multifocal, or focal, even though there is a significant amount of overlap among the entities. The selection of diagnostic possibilities can be further restricted by the location of the signal abnormality [(6)].

MRI has become a standard diagnostic and research tool in many branches of medicine due to its remarkable ability to delineate different areas of interest in soft tissues. The usual sequence of procedures for MRI of the knee includes taking sagittal images using T1 and T2-turbo spin-echo (TSE), T2-fat-suppressed coronal images taken after discharge, and T2-turbo spin-echo (TSE) sagittal images taken before discharge. A fat-suppressed sagittal proton-density-weighted (PDW) TSE image is the gold standard for evaluating BME [(7)].

In order to better image patients with bone marrow edema, a T2-weighted multipoint Dixon sequence was incorporated into a standard MRI protocol. There are fat-only, in-phase, inverted-phase, and water-only images in this sequence as well. Two radiologists checked the images that were taken as part of the standard procedure. Next, we looked at the Dixon images that were T2-weighted multipoint independently. We looked at pictures that only contained water and images that revealed inflammation activity on fat-saturated T2-weighted.

Images that were in phase, fat-only, and opposed-phase were compared to it, as were images that detected BME on T1-weighted images [(8)]. Finally, T2-weighted multipoint Dixon performs exceptionally well in detecting subtle BME, which is a huge boon to traditional MRI methods. Subtle and more extensive extension of the knee BME requires additional research to confirm and assess its efficacy in diagnosis [(9)].

The goal of this research was to find out how useful the T2-weighted multipoint Dixon method is for evaluating BME of the knee joint when used alone.

Patients and methods

This cross-sectional observational study included 50 bone marrow edematous patients subjected to closed MRI 1.5 T with dedicated knee coil were included at the Radiology Department, Faculty of Medicine, Benha University Hospital from 2024 to 2025

The patients provided written consent that was informed. The purpose of the study was explained to each patient, and they were assigned a secret code number.**ms 31-8-2024.** The research was conducted with the approval of the Research Ethics Committee at the Faculty of Medicine at Benha University.

Exclusion criteria were contraindication of MRI including claustrophobic patients and cases with metallic implants, foreign body and pacemakers.

All studied cases were subjected to the following: Regular pulse MRI sequences, like coronal oblique fat-saturated (Spectral Attenuated Inversion Recovery [SPAIR]) (Philips Healthcare), are used to image the knee joint in addition to a comprehensive medical history. Incorporating a multipoint Dixon sequence, turbo spin-echo T2-weighted and T1-weighted sequences, axial oblique fat-saturated T2-weighted and T1-weighted images, and water-only coronal oblique and axial oblique T2-weighted images were among the many sequences utilized. The sequences' intersection gaps were 0.35 mm, and their slice thickness was 3.5 mm.

Patient preparation for MRI: Reassure the patient and request that they refrain from moving during the examination. Prior to the MRI, the patient was advised to consume standard diet and continue to take their regular medications, unless otherwise directed. He was typically instructed to don a garment and discard any items that could potentially interfere with the magnetic imaging, including jewellery, hairpins, spectacles, watches, wigs, dentures, hearing aids, and underwire bras. Repetitive pounding, hammering, and other sounds were generated by the internal component of the magnet during the MRI scan. Earplugs or music may be provided to mitigate the commotion. The BME was imaged using closed GE-Creator MR-Systems that operated at 1.5 tesla. The MRI images were evaluated for the presence of the BME, the size, location, borders, and relationships.

MRI protocol:

Both the coronal oblique plane and the axial oblique plane were almost perpendicular to each other and parallel to the sacral long axis.

Qualitative image analyses: The cases with a diagnosis of BME detected on fat-saturated T2-weighted images were also reviewed in the T2-weighted multipoint Dixon images. T2 Dixon sequences were routinely incorporated into all MRI examinations of the knee joint. BME were observed in images that were exclusively composed of water. The conspicuity (intensity) of the high signal intensities was evaluated on a scale of 0 to 2: 0 indicates an absence of high signal area, 1 indicates a modest increase, and 2 indicates a moderate increase up to a fluid-like signal.

Quantitative image analyses: For every patient, we used this formula to determine the CNRs of BME lesions: For the CNR, all you have to do is divide the difference between the mean signal intensities of the lesion (MeanL) and the nearby normal-appearing bone marrow (MeanBM) (SDair). The variables in question include the standard deviation of the signal intensities in the artifact-free airspace close to the previously measured intensities (SDair), the mean signal intensity of the bone marrow (MeanBM) near the lesion (MeanL), and the lesion (MeanL) [(10)].

T2-weighted multipoint Dixon images with fat saturation and images without water were utilized to quantify and compute CNRs for identical BME lesions. All patient's knees were individually measured, but only the largest lesion was considered. For every patient, we measured the signal intensity of a lesion that was at least 5 mm in diameter. To make sure our measurements were accurate, we used a matching location and a matching round ROI of the same size. For each set of images, we used a same-diameter ROI to measure the air signal intensity and standard deviation.

Approval code: MS 31-8-2024.

Statistical analysis

Data was compiled using SPSS v26 by statisticians working for IBM Inc. in Armonk, NY, USA. Histograms and the Shapiro-Wilks test were used to ensure that the data distribution was normal. Our quantitative analysis was conducted using an unpaired student t-test. The results are presented as the mean plus standard deviation (SD). After using Fisher's exact test or a chi-square test, as appropriate, frequency and percentage (%) were used to present qualitative data. The degree of agreement between the qualitative variables was determined by applying kappa analysis. The following quantifications were employed to depict degrees of coordination: For agreement levels, 0 indicates no agreement, 0.01-0.20 is poor, 0.21-0.40 is satisfactory, 0.41-0.60 is moderate, 0.61-0.80 is good, and 0.81-1.00 is remarkably good. One criterion for statistical significance is a two-tailed *P* value lower than 0.05.

Case presentation:

Case 1: Female patient 36 years old, history: Left knee pain, trauma and falling down for 30 days ago and chronic pain.

Case 2: Male patient 54 years old, left knee with history of chronic knee pain and difficulty of walking and OA.

Results

The age of the studied patients ranged from 9 to 54 years with a mean ± SD of 32.6 ± 14.3 years. There were 19 (38%) females and 31 (62%) males. (**Table 1)**

The CNR of lesions was significantly increased in water-only T2-weighted multipoint Dixon than fat-saturated T2-weighted (*P* value <0.001). (**Table 2)**

There was no agreement between water-only T2-weighted multipoint Dixon and fat-saturated T2-weighted for grading of signal intensity of BME (kappa value =0.196, *P* value 0.484). (**Table 3)**

Table 1: Demographic data of the studied patients.

		n=50
Age (years)	**Mean ± SD**	32.6 ± 14.3
	Range	9 - 54
Sex	**Male**	31 (62%)
	Female	19 (38%)

SD: standard deviation

Table 2: Comparison of CNR of BME between fat-saturated T2-weighted and water-only T2-weighted multipoint Dixon

		Fat-Saturated T2-Weighted	Water-Only T2-Weighted Multipoint Dixon	P value
CNR	**Mean ± SD**	187.55 ± 61.03	286.82 ± 139.73	**<0.001***
	Range	88 - 284	97 – 497	

CNR: contrast to noise ratio, BME: bone marrow Edema, SD: standard deviation, *: significant as P value ≤ 0.05.

Table 3: Comparison of signal intensity of BME between fat-saturated T2-weighted and water-only T2-weighted multipoint Dixon

		Water-Only T2-Weighted Multipoint Dixon intensity			κ	P value
		Mild signal	**Moderate signal**	**Total**		
Fat-Saturated T2-Weighted intensity	**Mild signal**	17 (65.38%)	11 (45.83%)	28 (56%)	0.196	0.484
	Moderate signal	9 (34.62%)	13 (54.17%)	22 (44%)		
	Total	26 (52%)	24 (48%)	50		

BME: bone marrow Edema, κ: kappa analysis for level of agreement

PD

DIXON

Figure 1: Coronal Dixon T2 water only image nicely demonstrating bone marrow edema and increasing its conspicuity and nicely demonstrating the extent of bone marrow edema along the retro-patellar surface with mild lateral patellar sub-laxation

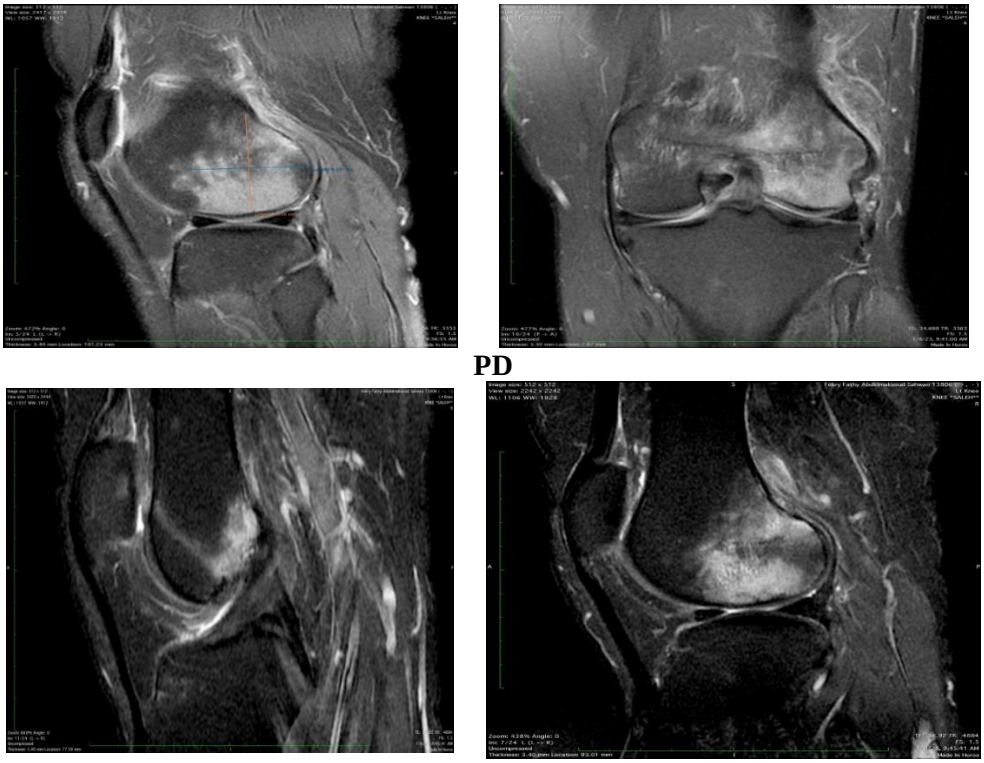

Figure 2: Coronal Dixon T2 water only image nicely demonstrating bone marrow edema and increasing its conspicuity and nicely demonstrating the extent of bone marrow edema of the marrow contusions of both femoral condyles notably the lateral with underlying fracture line likely insufficiency fracture

Discussion

In patients with knee symptoms, BME is a common MRI finding. The knee's BME can be categorized into three primary categories based on the etiology: ischemic, mechanic, and reactive. The weak radiographic findings and the specificity of the symptoms may make the diagnosis challenging [(11)].

The gold standard in MRI can detect an area of changed bone signal on fat-suppressed T2-weighted images with a strong signal and on T1-weighted images with a medium or weak signal. Over time, treatment is not necessary for the majority of BME cases. [(12)].

However, articular degeneration can progress to total joint destruction if not detected and treated well in its early stages. In the first stage, known as conservative therapy, patients are given anti-inflammatory or analgesic medications to alleviate symptoms. They are also instructed to avoid bearing weight on the affected side for three to six weeks. Minimally invasive preservative surgery can yield significant outcomes in non-responding forms and more advanced phases. The two primary procedures in this category are subchondroplasty and core decompression [(13)].

When diagnosing early-stage acute sacroiliitis, it is best to use MRI since it provides a more comprehensive look at the joint anatomy, including the marrow, cartilage, subchondral bone, surrounding ligaments, and capsule. This updated standard is now part of the Assessment of Spondylo Arthritis (SpA) International Society's (SpA) paper. These criteria determine the manifestation of acute sacroiliitis caused by SpA, which can be

BME/osteitis, synovitis, enthesitis, or capsulitis [14].

A MRI scan can aid in the diagnosis of sacroiliitis and the monitoring of treatment efficacy. The T1-weighted (T1W) and fat-saturated T2-weighted/short tau inversion recovery (STIR) images are part of the standard MRI sequence for the sacroiliac joints. T1W-FS-PC images, which are contrast-enhanced fat-saturated, can confirm STIR hyperintensities and osteitis. A diagnosis of BME can often be made with just STIR [15].

You can use the T1W-FS-PC sequence as a last resort if STIR doesn't produce any results or if you suspect artifacts. half a dozen Chemical shift imaging and similar Dixon-based fat suppression techniques allow for the localization and study of lesions in the adrenal glands, liver, kidneys, and certain regions of the bone marrow. Four groups of automatically corrected and post-processed pictures are produced by the T2W multipoint Dixon method [13].

In a reasonable amount of time with uniform fat suppression, this Dixon sequence achieves a better and higher signal-to-noise ratio (SNR). When contrasted with traditional sequences for sacroiliac pathology detection and differentiation, Dixon may offer superior tissue contrast simultaneously. Selecting the right axial disease candidates for biologic therapy relies on high-quality imaging and accurate reporting [15, 16].

In the present study, it was found that the age of patients who were diagnosed with BME of the knee joint on MRI ranged from 9 to 54 years with a mean ± SD of 32.6 ± 14.3 years. There were 19 (38%) females and 31 (62%) males with no significant difference in age and sex between them

.Zadig et al. [17] found that 77 whole-body MRI scans were performed on 77 healthy children, 36 of whom were boys, ranging in age from 6 to 19 years old, with a mean age of 12 years (SD 3.1) included in the analysis. All told, 28,100 pictures were examined. With a median of six areas and a range of one to thirty, every child exhibited some degree of high signal.

Athira et al. [8] revealed that there were 20 men and 17 women involved, with 63 joints examined (26 patients exhibited bilateral involvement, 7 right-sided involvement, and 4 left-sided involvement). With a mean age of 38.1 and a standard deviation of 11.8 years, they ranged in age from 19 to 75. The severity of sacroiliitis varied across stages, with fourteen cases (22.2%) exhibiting acute symptoms, twenty-nine cases (46.1%) chronic symptoms, and thirty-seven cases (31.7%) exhibiting symptoms of both chronic and acute phases. As a result, 54 SI joints in the acute phase and 49 SI joints in the chronic phase were evaluated.

Özgen et al. [18] found that two observers—one diagnosing active sacroiliitis and the other chronic sacroiliitis—diagnosed 32 and 34 patients, respectively. With a mean age of 38 years and an age range of 20-56 years, 34 patients (20 women and 14 men) were ultimately diagnosed with active sacroiliitis, chronic sacroiliitis, or a combination of the two.

Using the water-only T2-weighted multipoint Dixon images to diagnose more cases of BME was not found to be possible in the present investigation. All lesions exhibiting indications of BME were flawlessly captured by both fat-saturated T2-weighted and water-only T2-weighted multipoint Dixon images. A significantly higher CNR of lesions was observed (P value <0.001) when comparing water-only T2-weighted multipoint Dixon to fat-saturated T2-weighted. The BME signal strength was evaluated using two T2-weighted multipoint Dixon algorithms; however, these algorithms were mutually incompatible (kappa = 0.192, p = 0.484).

Changes in the subchondral bone marrow are required for the diagnosis of active sacroiliitis, according to ASAS criteria. In comparison to fat-saturated images,

water-only T2-weighted multipoint Dixon images performed quite well in this regard. Fat-saturated T1-weighted images that are T2-weighted and contrast-enhanced [19].

Multipoint Dixon images that are fat-saturated T2-weighted or water-only perform better than contrast-enhanced fat saturated T1-weighted images. Despite the lack of newly detected cases of active sacroiliitis, the mean CNRs in both datasets were higher than in the contrast-enhanced fat-saturated T1-weighted images. These findings support earlier studies that found no improvement in the ability to detect active bone marrow inflammation when sacroiliac joint MRI was performed using contrast enhanced fat-saturated T1-weighted images [20-24].

The field of clinical imaging has been extensively investigated in recent years, with a particular emphasis on Dixon-based imaging methods. Many studies have demonstrated the effectiveness of the Dixon technique for MRI of the breast, musculoskeletal system, and abdomen [25-30].

The Dixon technique outperformed traditional fat-suppression methods in terms of CNR and artefact reduction, anatomic identification, and the absence of obvious downsides. We also discovered that T2-weighted multipoint Dixon images gave BME MRI the same results as T1-weighted images: better CNRs and less artefact. When using an imaging method based on Dixon, we did not find any potential downsides.

Zadig et al. [17] 490 out of 545 (89.9%) "true" lesions were detected on both sequences when using STIR as the gold standard substitute, while 28 (5.1% of the total) were detected on T2W Dixon alone and 27 (5.0% of the total) on DC alone. True positive high signal lesions were more common in T2W Dixon images (74.2% (95% vs. 68.2%, p=0.029)) and false negatives were less common (25.9% vs. 31.7%, p=0.035) when compared to STIR. The kappa value for grading signal intensity between T2W Dixon and STIR was found to be 0.34 (95% CI=0.25-0.42) after being dichotomized into a 0-1 score, suggesting a weak initial agreement. This was especially true for the 545 "true" lesions. While 169 out of 545 lesions (31.0%) had full agreement, T2 Dixon-based readings revealed 5.8% more high signal areas than STIR readings (p=0.04). The kappa value varied between -0.36 and -0.44 under collapse conditions. The agreement was found to be independent of age, as all four age groups had Kappa values of -0.4.

Athira et al. [8] WO images, in contrast to STIR and T1W-FS-PC sequences, had the highest mean CNR of the largest lesions (296.35 ± 208.28). The image sets WO and T1W-FS-PC were significantly different from each other, as were the WO and STIR image sets (p-value < 0.001 and p-value = 0.002, respectively). Additionally, STIR, T1W-FS-PC, and WOW pictures made bone marrow lesions due to acute sacroiliitis obvious. The WO images outperformed the STIR and T1WFS-PC images in quantifying BME/osteitis. Although contrast was not associated with the identification of any additional cases when sacroiliitis analysis was conducted using the T2W multipoint Dixon sequence. When compared to the conventional imaging method, WO images were superior at detecting acute bone marrow lesions; IP images were equally effective as traditional T1W sequences at detecting subchondral sclerosis; and OP images followed by FO images were superior to T1W images at detecting periarticular fat deposition. When compared to T1W images, IP and FO image sets were equally good at detecting cortical erosions. The Dixon sequences were not very helpful in diagnosing ankylosis.

Maeder et al. [31] WO images, in contrast to STIR and T1W-FS-PC sequences, had the highest mean CNR of the largest lesions (296.35 ± 208.28). The image sets WO and T1W-FS-PC were significantly different from each other, as were the WO

and STIR image sets (p-value < 0.001 and p-value = 0.002, respectively). Additionally, STIR, T1W-FS-PC, and WOW pictures made bone marrow lesions due to acute sacroiliitis very obvious. The WO images outperformed the STIR and T1WFS-PC images in quantifying BME/osteitis. Although contrast was not associated with the identification of any additional cases when sacroiliitis analysis was conducted using the T2W multipoint Dixon sequence. For the detection of acute bone marrow lesions, WO images outperformed the standard imaging method; for the detection of subchondral sclerosis, IP images were just as effective as traditional T1W sequences; and for the detection of periarticular fat deposition, OP images followed by FO images outperformed T1W images. In terms of detecting cortical erosions, IP and FO image sets were on par with T1W images. Ankylosis could not be easily diagnosed using the Dixon sequences.

Özgen et al. [18] determined that there was good interrater agreement for the diagnosis of sacroiliitis, with a kappa value of 0.91 (95% CI, 0.78-1.03). Two patients in the group with unilateral joints, eleven patients with active sacroiliitis, eight patients with chronic sacroiliitis, and ten patients with signs of both types of sacroiliitis were detected on magnetic resonance imaging (MRI). Both observers found no evidence of active or chronic sacroiliitis in the other fifteen patients. The analysis of the T2-weighted multipoint Dixon images did not reveal any newly diagnosed cases of active or chronic sacroiliitis. For every lesion exhibiting active sacroiliitis, there was remarkable concordance between the T2-weighted images containing fat saturation and those containing only water.

A κ value of 1.00 (95% CI, 1.00-1.00) was thus obtained for the diagnosis of active sacroiliitis among the raters. The multipoint Dixon images that were fat-saturated T2-weighted and water-only T2-weighted were considered to be of better quality than the contrast-enhanced fat-saturated T1-weighted images. A statistically significant difference was found between the groups, specifically between the water-only T2-weighted multipoint Dixon images and the fat-saturated T2-weighted images ($p < 0.01$), as well as between these images and the contrast-enhanced fat saturated T1-weighted images ($p < 0.01$). The groups were clearly differentiated from one another ($p = 0.00001$), but the Tukey test proved that this difference was limited to those two groups. No additional cases were diagnosed with active sacroiliitis after examining the contrast-enhanced fat-saturated T1-weighted images [18].

T2W Dixon and STIR sequences for focused examinations have been compared in multiple studies with adults, with the aim of improving diagnostic performance. The average age of the 22 patients in their study was 80.9 years , Heynen et al. [15] used a 3-T scanner to examine femoral neck fractures that could not be seen on radiographs by comparing T2W Dixon, T1W, and STIR images. Both the STIR and T2W Dixon images had significantly lower interobserver agreement, with kappa values ranging from 0.70 to 0.79 and 0.87 to 0.93, respectively. In comparison to STIR, T2W Dixon water-only images were less sensitive and inaccurate for crack identification when information for all accessible sequences was used as an alternative gold standard.

For instance, in the evaluation of the lumbar spine, their findings are at odds with those of others [32], the hand [33], and the sacro-iliac joints [18].

In comparison to other fat saturation techniques, Dixon's advantage is that it produces homogeneous fat suppression because it is not affected by local magnetic field inhomogeneities. Quantification of fat is another possible application of these methods [13].

Gradient echo and spin-echo sequences are both technically capable of implementing Dixon techniques. On the other hand,

when using the Dixon technique, images with metallic artifacts from larger prosthetics tend to have low quality [25]. In this setting, STIR remains the preferred technique [16, 25].

It is not suitable for use as a postcontrast sequence, though, due to its low SNR in comparison to Dixon sequences. This means that Dixon, thanks to its higher SNR, is the way to go for knee arthrodesis, ankle arthrodesis, or spinal arthrodesis involving small metallic components. Furthermore, it is employed in cases where there is a high level of The routine fat suppression sequences are surpassed in image quality and CNR by the Dixon sequences [28].

Because of its reduced acquisition time and improved CNR, it is considered as good as, if not better than, other conventional modalities for postcontrast image suppression, which is necessary in cases like inflammatory or infectious changes close to metallic implants. It also has the advantage of being applicable to both T1W and T2W sequences [25].

Despite providing quantitative data demonstrating statistically significant differences between pulse sequences, the study's limitations included a small patient population and an inadequate sample size. Although we made every effort to acquire all sets of images at approximately the same time, any change in imaging parameters could impact the CNR of a lesion in a specific pulse sequence, which could impact the statistical results. Therefore, we cannot guarantee a fair comparison of pulse sequences. Not only that, we disregarded laboratory results, clinical examinations, and patient follow-up in favour of conventional MRI without contrast material as our reference standard. Additional insights could be provided by future studies with larger subject numbers. Lastly, the T2-weighted multipoint Dixon images were reviewed by a single observer.

Conclusion

To identify indications of BME in the knee joint, a single MRI sequence employing multi-point T2-weighting can be utilized rather than the more traditional T1-weighted, fat-saturated T2-weighted, and contrast-enhanced fat-saturated T1-weighted imaging techniques. Avoiding the use of contrast medium during a single procedure can save time, money, and reduce the likelihood of adverse effects.

Because of this, the majority of these studies back the use of Dixon as a standalone sequence rather than the conventional combination protocol of morphologic sequences. This needs to be confirmed by additional large-scale studies, and to avoid bias and mistakes, future research needs to make proper use of matching and blinding techniques. Finally, it is important to investigate the Dixon technique's function in follow-up cases.

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Conflicts of interest

No conflicts of interest

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