Comparison between sagittal sequences in magnetic resonance imaging of the lumbar spine with fat saturation and different phase encoding directions

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ABSTRACT

Background: Comparison of three different sagittal sequences with fat suppression in the lumbar spine magnetic resonance imaging (MRI), evaluating several image characteristics and changing the phase direction. ***Materials and Methods:*** Forty-five subjects (20 males, 25 females, mean age 50 years old) participated in this retrospective study in an MRI machine of 1.5 Tesla (GE Signa Hdx). We compared three fat-saturated sequences {T2 Weighted (T2W) Fast Spin Echo (FSE) Fat Saturation (FS) with phase direction superior-inferior (S/I), T2W Short Tau Inversion Recovery (STIR) with phase direction superior-inferior (S/I) and T2W STIR with phase direction (A/P)}. A qualitative analysis was performed, while two experienced radiologists evaluated the images. The statistical analysis was determined by Kruskal–Wallis non-parametric test. ***Results:*** The T2W FSE FS was superior in almost all studied parameters {total image quality, presence of artifacts, artifacts in 4th lumbar vertebra (L4) - 1st Sacral vertebra (S1), depiction of lesions on vertebral bodies, depiction of lesions on L4-S1 region, sharpness} in comparison with T2W STIR sequences with statistically significant difference ($p<0.001$). The STIR sequences exceeded the T2W FSE FS in the fat saturation effectiveness with a statistically significant difference ($p<0.001$). ***Conclusion:*** The T2 Weighted (T2W) Fast Spin Echo (FSE) Fat Saturation (FS) was superior in the depiction of pathology and normal anatomy, eliminating many artifacts in comparison with T2 Short Tau Inversion Recovery (STIR) sequences, especially in the L4 vertebra– S1 vertebra anatomic region, between three under-study sequences. Choosing the appropriate sagittal fat-saturated sequence in each clinical question is useful to avoid misdiagnosis due to technical artifacts.

INTRODUCTION

Magnetic Resonance Imaging (MRI) is one of the established examinations for the imaging of various pathologies in lumbar spine (1-3). Especially, the sequences with the application of fat saturation techniques have proved very useful for detecting lumbar spinal disorders (4-7). When the signal of fat is suppressed, the image contrast between structures is increased, because of the dynamic range of magnetic resonance (MR) images (4, 6, 8). The suppression of fat tissue could be achieved with different techniques depending on the clinical question, the anatomical structure, and the magnetic field strength (5, 9). The spectral fat saturation technique, the invert pulse, and the opposed phases techniques constitute the most common ways to suppress fat in MR imaging. The spectral fat saturation and the opposed phase sequences belong to the wider category of chemical shift-dependent techniques (4, 5, 10, 11).

The sequences with an inverted pulse, such as short tau inversion recovery (STIR) are commonly used due to their intense fat suppression (11, 12). Furthermore, the STIR sequence is very sensitive to detect ordinary lesions of the lumbar spine. The above sequence is beneficial in edematous conditions either from injury or inflammatory and metastatic origins or tumors' presence (12-14). Except for the fat suppression technique, some other scanning parameters such as phase encoding direction play an important role in the presence of technical artifacts in MR images of the lumbar spine [15]. Usually, the choice of phase direction is based on the dimensions of the depicted anatomical structure. More often the phase encoding direction agrees with the smaller dimension in the anatomy of interest because the most technical/motion artifacts are presented in this direction which is more time-consuming during the data collection [16]. Especially for the lumbar spine the smaller dimension is on the right-left (R-L) axis for the coronal images and the anterior posterior (A-P) axis for the transverse and sagittal images.

However, it is widely accepted that the sagittal sequences regarding the lumbar spine are acquired with the phase encoding in the craniocaudal, superior -inferior (S/I) axis and not in the A-P axis. This choice of phase direction eliminates the pulsating artifacts originating from cerebrospinal fluid (CSF). Furthermore, the craniocaudal or head-feet phase direction prevents motion artifacts due to respiration, usually presented in phase direction [17, 18]. Nevertheless, while all sagittal sequences are performed with the choice of S-I phase direction, the T2 weighted (T2W) sagittal short tau inversion recovery (STIR) sequence presents more artifacts in this direction. When we tried to change the phase direction into A-P, all the technical artifacts were eliminated, except for a specific artifact in the anatomical region of 4th lumbar (L4) and 5th lumbar (L5), L5, and 1st sacral (S1) vertebras. The great vessels of the anatomic region L4-L5 are the inferior vena cava, part of the aorta, and the common iliac arteries (more often the division is in the level of L4 vertebrae). The above anatomic relation may cause the specific artifact in this area in the T2W fast spin echo (FSE) STIR (A-P direction) which is more sensitive to artifacts [19].

In the present study, we compared three different sequences, a T2W FSE with spectral fat saturation, and two T2W STIR with two different choices of phase encoding direction. The choices of phase encoding direction were: the Superior/Inferior (S/I) in the T2W FSE STIR and the T2W FSE FS and the Anterior/Posterior (A/P) in the T2W FSE STIR. The comparison between these three sequences was performed to find the appropriate technique of fat suppression regarding the clinical question in MR imaging of the lumbar spine. This study also offers a choice of sequence when the widely used T2W FSE STIR (A/P) presents many technical artifacts that complicate the diagnosis.

MATERIALS AND METHODS

General data

From February 2022 to June 2023, 45 subjects (20 males, 25 females, mean age 50 years, range 15-95 years old) participated in this retrospective study (table 1). All the examinations were performed in an MRI machine of 1.5 Tesla General Electric (GE) Signa HDxt, Twin Speed, United Kingdom, 15. x software.

Table 1. The Demographic data of the research participants.

	Demographics of participants		
	N	Mean Age (years)	Range of years
Males	20	49	15-83
Females	25	59	23-95
Total	45	50	15-95

Examination method

The routine MRI protocol included sagittal T2W Fast Spin Echo (FSE) (phase encoding: S/I), sagittal T1W Flow Attenuated Inversion Recovery (FLAIR) (phase encoding: S/I), sagittal T2W Short Tau Inversion Recovery (STIR) (phase encoding: A/P), transverse T2W FSE (phase encoding: A/P) and coronal T1W FLAIR (phase encoding: R/L). Between these routine sequences, we also performed a sagittal T2W FSE (phase encoding: S/I) with spectral fat saturation and a sagittal T2W FSE STIR (phase encoding: S/I) with the same scanning parameters as shown in table 2. We did not repeat the sagittal T2W Short Tau Inversion Recovery (STIR) (phase encoding: A/P), because it was already in the routine protocol of the lumbar spine. Therefore, the evaluation was performed between one of the routine protocol sequences (sagittal T2W Short Tau Inversion Recovery (STIR) (phase encoding: A/P) and two additional sequences (sagittal T2W FSE (phase encoding: S/I) with spectral fat saturation and a sagittal T2W FSE STIR (phase encoding: S/I). In all sagittal sequences, the group of slices was placed parallel to the coronal axis of the lumbar spine, and a saturation band pulse was used. The saturation band was placed anterior to the lumbar spine in a tilt, depending on the phase encoding direction every time.

Evaluation method

We performed a qualitative analysis between the three sagittal T2W fat-saturated sequences (sagittal T2W FSE STIR, phase encoding: S/I; sagittal T2W FSE STIR, phase encoding: A/P; sagittal T2W FSE spectral FS, phase encoding: S/I). More specifically, a qualitative analysis was performed, and seven image characteristics were graded: **a)** overall image quality (0= for the worst general image quality, 4 for the best general image quality), **b)** effective fat saturation (0= for totally ineffective, 4 very effective fat saturation), **c)** presence of artifacts (0=not presented artifacts, 4=presence of many artifacts), **d)** presence of artifacts in L4-L5 and L5-S1 region in front of spine (0=not presented artifacts, 4=presence of many artifacts), **e)** depiction of lesions in vertebral bodies (0=low depiction, 4=the highest depiction) and **f)** depiction of lesions on L4-L5 and L5-S1 region (0=low depiction, 4=the highest depiction), **g)** sharpness (0= unsharp image, 4=very sharp image)

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on a five-level scale. Two qualified radiologists with more than ten years of clinical experience graded all the sagittal images with fat suppression (T2W FSE spectral FS - phase encoding: S/I, T2W FSE STIR - phase encoding: S/I, and T2W FSE STIR - phase encoding: A/P). Specifically, all the images were evaluated independently with an interval of three weeks by two radiologists who reached a consensus. Additionally, the images of three sequences were filmed at optimal window and level settings.

Statistical analysis

The statistical significance (p-value) of the qualitative analysis data was determined by the Kruskal–Wallis non-parametric test. The statistical results were presented with the mean values and the standard deviation (±SD) for every sagittal understudying MR sequence for easier comparison. The median calculation is presented, with the level of significance (p=0.01).

Table 2. Scanning parameters of three compared sequences.

Sequence (Weight of image)	Fat suppression technique	Phase direction	Field Of View (FOV)	Slice thickness	TR	TE	NEX	Scan time
T2W Fast Spin Echo (FSE)	Spectral fat saturation	Superior/inferior (S/I)	30	3mm	3300ms	102	4	2:58
T2W Fast Spin Echo (FSE)	Inversion Recovery pulse	Superior/inferior (S/I)	30	3mm	4300ms	40	4	3:48
T2W Fast Spin Echo (FSE)	Inversion Recovery pulse	Anterior/Posterior (A/P)	30	3mm	4300ms	40	4	3:48

RESULTS

General comparison between three sequences

The results of the qualitative analysis are presented in aggregate in table 3. Generally, according to the above results, the T2W FS (S/I) sequence is superior to the other two STIR sequences in most studied characteristics with statistically significant differences. More specifically, the T2W FS (S/I) sequence proved superior to the T2W FSE STIR (A/P) and the T2W FSE STIR (S/I) in the overall image quality, sharpness, and the depiction of lesions in the L4-S1 region with a statistically significant difference.

Table 3. Summary of the results of the qualitative analysis between the three different sagittal sequences. T2W Fast Spin Echo (FSE) spectral Fat Saturation (FS), phase encoding: Superior/Inferior (S/I), T2W FSE Short Tau Inversion Recovery (STIR), phase encoding: S/I, and T2W FSE STIR, phase encoding: Anterior/Posterior (A/P). The median calculation is presented, with the level of significance (p=0.01) and standard deviation (SD) for all under-study image characteristics, determined by the Kruskal–Wallis non-parametric test.

	MEAN ± SD			p value
	T2 FS S/I	T2 STIR A/P	T2 STIR S/I	
overal image quality	3.6±0.48	3.2±0.35	2.3±0.54	<0.001
effective fat saturation	3.2±0.35	3.9±0.04	3.9±0.04	<0.001
presence of artifacts	0.86±0.72	1.86±0.66	2.44±0.72	<0.001
artifacts in L4-S1 vertebras	0.64±0.67	2±0.67	2.15±0.82	<0.001
depiction of lesions on vertebral bodies	3.26±0.78	2.8±0.72	2.3±0.85	<0.001
depiction of lesions on L4-S1 region	3.44±0.5	2.53±0.75	2.9±0.85	<0.001
sharpness	4±0.0	2.9±0.2	2.8±0.4	<0.001

Moreover, the T2W FS (S/I) surpassed the other two sequences in the presence of artifacts, especially in the elimination of artifacts in L4-S1 vertebras with a statistically significant difference (p<0.001).

The T2W FSE STIR (A/P) presented equal results with T2W FS (S/I), compared to T2W FSE STIR (S/I) regarding the depiction of lesions on vertebral bodies with a statistically significant difference (p<0.001). Finally, the T2W FSE STIR (A/P) and the T2W FSE STIR (S/I) showed better results regarding the effectiveness of fat saturation in comparison with the T2W TSE FS (S/I), also with a statistically significant difference (p<0.001).

Analysis of the results

Nevertheless, while all the sagittal sequences are performed with the choice of (S/I) phase direction, the sagittal T2W FSE STIR sequence presented more artifacts in this direction. When we tried to change the phase direction into (A/P), all the technical artifacts were eliminated, except for a specific artifact in the anatomical region of L4, L5, and S1 vertebras as shown in (figures 1 and 2), something that was confirmed in other similar studies like Pui's *et al.* [6].

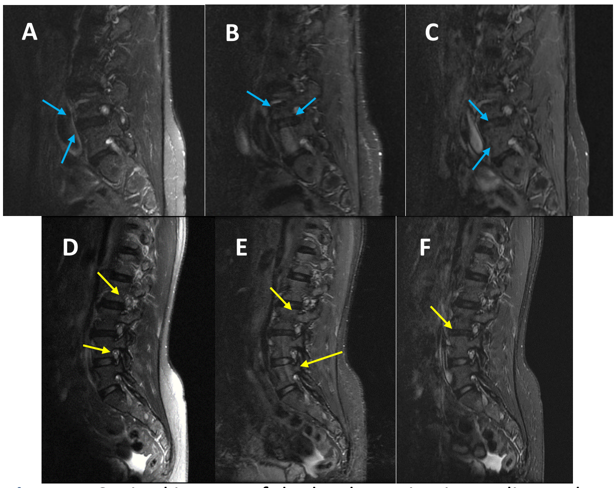

Figure 1. Sagittal images of the lumbar spine in reading order, T2W FSE FS sagittal with phase encoding (S/I), T2W FSE STIR sagittal with phase encoding (A/P), T2W FSE STIR sagittal with phase encoding (S/I). The STIR images (**B** and **C**, E and **F**) present multiple technical artifacts and many of these hide some anatomical regions such as the whole L5 vertebra body (**B**, blue arrows). On the other hand, image A presents the same region without artifacts and pathology (blue arrows). The STIR images (**E** and **F**) present very often artifacts compared to image D. Either the STIR (A/P) or the STIR (S/I) shows artifacts depending on the anatomy (vessels) and the pathology's topography. In this case, image E presents more artifacts than the other two images, and the ghost artifacts may be presented in the upper vertebras (yellow arrows).

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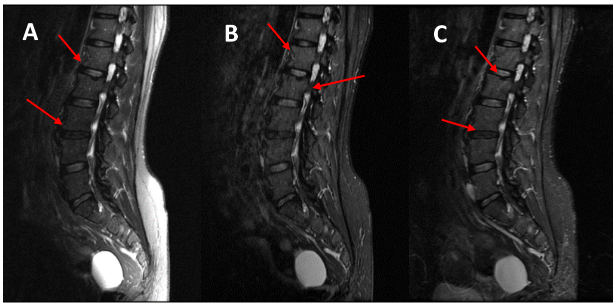

Figure 2. Sagittal images of lumbar spine **A)** T2W FSE FS sagittal with phase encoding (S/I), **B)** T2W FSE STIR sagittal with phase encoding (A/P), **C)** T2W FSE STIR sagittal with phase encoding (S/I). In this case, image C presents more artifacts than the other two images, and the ghost artifacts may be presented in the upper vertebras (red arrows), due to vessel topography, cystic lesion, or respiration motion. On the other hand, the image A eliminates the technical artifacts and presents better image quality.

The great vessels of the anatomic region L4-L5-S1 are the inferior vena cava, part of the aorta, and the common iliac arteries (more often the division is in the level of L4-L5 vertebrae). Marchi et al. performed a morphometric study and concluded that the above anatomic relation may cause the specific artifact in this area in the T2W FSE STIR (A/P direction) which is more sensitive to these artifacts [19, 20, 21]. Especially in cases of pathology, the technical artifacts could lead to misdiagnosis and false positive results not only in this region (L4-S1) but also in upper vertebras as illustrated in (figure 3 and 4) [22].

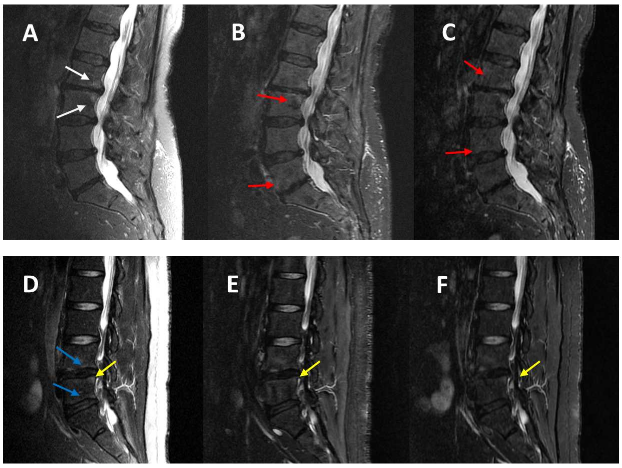

Figure 3. Sagittal images of the lumbar spine in reading order, T2W FSE FS sagittal with phase encoding (S/I), T2W FSE STIR sagittal with phase encoding (A/P), T2W FSE STIR sagittal with phase encoding (S/I). The STIR images **B** and C although they depict the pathology, the multiple artifacts (red arrows), especially in the image **C**, do not allow a clear depiction of the lesion's boundaries. On the other hand, image **A** depicts the Modic lesion with much better perspicuity and fewer artifacts (white arrows). The multiple artifacts in STIR images (**E** and **F**) reduce the accuracy of the method. Image A is the only one that depicts the bone edema in the lower part of the L4 and L5 vertebra (blue arrows). Also, image **D** depicts the pathology in the upper part of the L5 vertebra (yellow arrows), while images E and F are full of artifacts in this area.

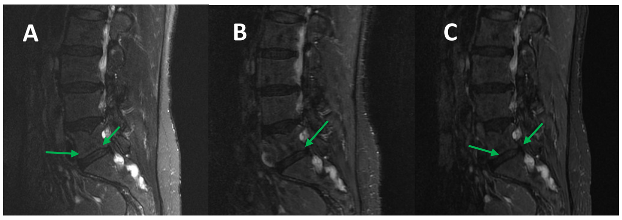

Figure 4. Sagittal images of lumbar spine **A)** T2W FSE FS sagittal with phase encoding (S/I), **B)** T2W FSE STIR sagittal with phase encoding (A/P), **C)** T2W FSE STIR sagittal with phase encoding (S/I). A case with sciatica and the suspicion of a compression fracture in the L5 vertebra. Image A illustrates that there is not a fracture in this vertebra, something that the STIR images (B and C) do not confirm due to technical artifacts. In addition, the Modic lesion in the lower part of the L5 vertebra is depicted in image A and less clearly in image C, while in image B is lost due to multiple artifacts (green arrows).

In the present study, we compared three different sagittal sequences for the lumbar spine, a T2W FSE with spectral fat saturation, and two T2W STIR with two different choices of phase encoding direction. The choices of encoding were the T2W FSE STIR in the (S/I) direction and the T2W FSE STIR in the (A/P) direction. The comparison between these three sequences was performed to find the appropriate technique of fat suppression regarding the clinical question in MR imaging of the lumbar spine.

According to the statistical results, the T2W FSE FS (S/I) sequence reduces the technical artifacts, especially in the lower lumbar spine region (lumbar 4 - sacral 1). In addition, T2W FSE FS (S/I) presents a satisfying overall image quality with fewer technical artifacts in all the lumbar vertebras with higher resolution in comparison with T2W FSE STIR, as depicted in figure 5.

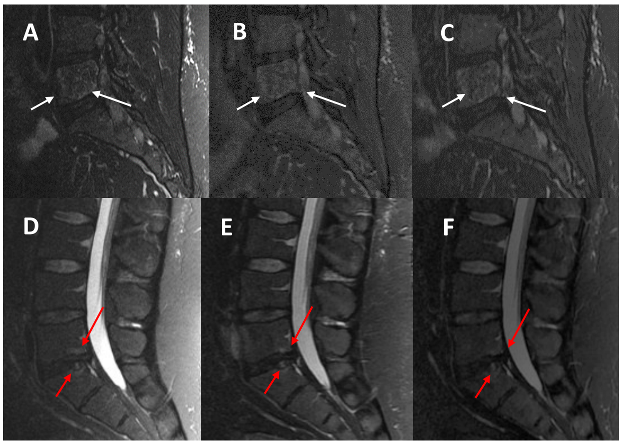

Figure 5. Sagittal images of the lumbar spine in reading order, T2W FSE FS sagittal with phase encoding (S/I), T2W FSE STIR sagittal with phase encoding (A/P), T2W FSE STIR sagittal with phase encoding (S/I). Images **B** and **C** show the pathologic region of hemangioma, but the multiple artifacts hide some information about the safest diagnosis. On the other hand, image **A** depicts the pathologic area with fewer artifacts and much better resolution. In that way, the boundaries of the hemangioma are depicted with more perspicuity (white arrows). Image **D** presents less technical artifacts than images **E** and **F**. As a result, in conjunction with the high resolution of T2W FSE FS the pathology in image D is illustrated more perspicuous in the lower part of L5 and the upper part of the S1 vertebras (red arrows).

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Different studies by Dalto *et al*. and Guerini *et al.* corroborate our conclusions that the sequences with spectral fat suppression techniques are superior in several features to those sequences with a clear invert pulse, such as STIR. Not only while imaging the lumbar spine, but also while imaging the pelvis, in most cases [4, 23].

On the other hand, if metallic objects and inhomogeneities are presented, the suppression of fat in this sequence is not homogenous such as T2W FSE STIR. The T2W FSE FS would be used in cases of metallic objects in the lumbar spine for a specific pathology in a specific anatomical region because in this case (inhomogeneities) would present more artifacts than T2W FSE STIR [4, 24, 25].

In the STIR sequences, the fat suppression is more certain than in the other sequences (especially in burly patients), but with a greater percentage of blurring as shown in figure 6, (if we used a larger matrix as well as in T2W sequences to reduce burring, the scan time would be unacceptable). This result is in agreement with other related studies like Grande *et al.*, and Piu *et al*. who compared the fat suppression between chemical shift techniques and STIR [6, 10].

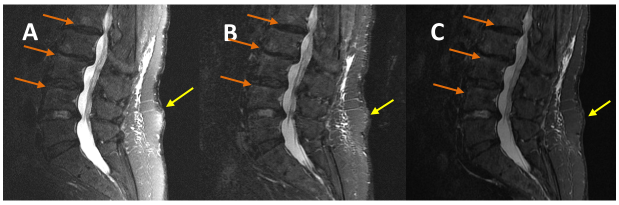

Figure 6. Sagittal images of the lumbar spine in reading order, T2W FSE FS sagittal with phase encoding (S/I), T2W FSE STIR sagittal with phase encoding (A/P), T2W FSE STIR sagittal with phase encoding (S/I). In obese patients, the noise is increased in all these images. Despite that, while the STIR images (images **B** and **C**) achieve more homogenous fat saturation (yellow arrows), the T2W FS (image **A**) depicts the pathologic regions because of the fewer artifacts (green arrows).

DISCUSSION

Magnetic Resonance Imaging (MRI) constitutes one of the most basic examinations for the illustration of many pathologies in the lumbar spine [1, 2]. Especially, the sequences with the application of fat suppression techniques have proved very useful for detecting lumbar spinal disorders [5, 6]. When the signal of adipose tissue is suppressed, the image contrast between structures is increased, because of the dynamic range of magnetic resonance (MR) images [4, 6, 13]. More specifically, the fatty tissue that is depicted as dark in the sequences with suppression, permits others, more aqueous tissues to receive the brightest shades of the final image. In that way, the scale of shades is less wide and the image contrast is ameliorated [26].

The suppression of fat tissue could be achieved with different techniques depending on the clinical question, the anatomical structure, and the magnetic field strength [5, 11]. The spectral fat saturation technique, the technique with an inverted pulse, and the opposed phases techniques constitute the most common ways for fat suppression in MR imaging. The spectral fat saturation and the opposed phase sequences belong to the wider category of chemical shift techniques [4, 10]. Sequences with inverted pulse, such as the short tau inversion recovery (STIR) are commonly used due to their intense fat suppression [12, 14]. Effective and homogeneous fat suppression is very important to avoid misdiagnosis, especially in regions with incomplete fat suppression mimicking pathologies [22, 24, 27].

Furthermore, the T2W FSE STIR sequence is very sensitive to detecting many ordinary lesions of the lumbar spine. The above sequence is beneficial in edematous conditions either from injury or from inflammatory diseases. Also, the high signal of the T2W FSE STIR sequence in lesions from metastatic origins or tumors' presence could be an important diagnostic tool in conjunction with the other routine pulse sequences [12-14].

However, except for the fat suppression technique, other scanning parameters such as the phase encoding direction play an important role in the presence of technical artifacts in MR images of the lumbar spine [15, 28]. Usually, the choice of phase direction is based on the dimensions of the depicted anatomical structure. More often the phase encoding direction agrees with the smaller dimension in the anatomy of interest. This is because most technical/motion artifacts are presented in the phase direction which is more time-consuming during the data collection [16, 25].

Especially for the lumbar spine the smaller dimension is on the right-left (R/L) axis for the coronal images and on the anterior-posterior (A/P) axis for the transverse and sagittal images. However, it is widely accepted that the sagittal sequences regarding the lumbar spine are acquired with the phase encoding on the craniocaudal (S/I) axis and not on the (A/P) axis. This choice of phase direction eliminates the pulsating artifacts originating from cerebrospinal fluid (CSF). Furthermore, the craniocaudal or head-feet phase or (S/I) direction prevents the motion artifacts due to respiration which are usually presented in phase direction [17, 18, 29].

Additionally, while STIR sequences in the cervical and thoracic spine have great results according to the bibliography, the lumbar spine may present artifacts dangerous for misdiagnosis [30].

Thus, if the clinical question is about bone lesions, the choice of sequence could be changed depending on the spine kurtosis. Especially, regarding above and below the last two intervertebral disks (lumbar 4-lumbar 5, or lumbar 5 – sacral 1) the ghost artifacts

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are more presented in these bony tissues. Indicatively, in the cases of lumbar spine alignment, the choice of sequences with S/I phase direction could be wiser. In that way, the presence of artifacts in the craniocaudal axis can be eliminated by placing the saturation band obliquely right above the bladder. Additionally, the bladder is suggested to be empty during the examination because its peristalsis and urine are sources of ghost artifacts [20].

Our study had some limitations. The matrix of T2W FSE was larger (512×288), while T2W FSE STIR's matrix was (320×256). The matrix size, of course, affects the spatial resolution and by extension the sharpness. Thus, the sharpness of T2W FSE FS was much greater than the STIR sequences (with a significant statistical difference), but the use of a larger matrix in STIR as well as in T2W sequences to reduce burring, would increase the scan time to unacceptable values. We placed the saturation band in a different direction, anterior of the lumbar spine during the planning of T2W FSE STIR (A/P). If we try to change the phase direction in this sequence from (A/P) to (S/I) more technical artifacts will be presented in all the range of the lumbar spine, because this sequence is more sensitive in technical artifacts than the T2W FSE.

To conclude, the T2W FSE FS was superior in the depiction of the pathology and normal anatomy, eliminating many artifacts in comparison with T2W FSE STIR sequences, especially in the L4-S1 anatomic region, between the three understudied sequences. However, further investigation should be performed to choose the best suppression technique and the appropriate sequence depending on the clinical circumstances and diagnostic questions.

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Ethical consideration: From the director of the private clinic "Animus Kyanoys Stavros"

Author contribution: L.E., Inspirer and coordinator of the study; P.M., Manuscript writing, protocol configuration, collection of data; T.A. and P.N., Evaluation and grading of images; R.V., Statistical analysis and manuscript revision; S.G.K. and L.P., Copy-editing; M.P. and B.A.: Image quality control; D.E., Copy-editing and clinical consideration.

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