Three-dimensional turbo spin-echo sequence versus conventional two-dimensional turbo spin-echo sequences in the evaluation of lumbar intervertebral discs

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ABSTRACT

Objectives: The aim of this study was to evaluate the efficacy of a three-dimensional (3D) turbo spin-echo (TSE) sequence for determining lumbar disc protrusions, and to compare the findings with those of conventional two-dimensional (2D) TSE sequences and reveal the interobserver and intermethod agreements of both sequences.

Methods: A total of 127 discs from 84 patients were evaluated by three radiologists. Conventional 2D TSE images and 3D TSE images were independently interpreted with regard to disc pathology and herniation zones and were scored for the degree of spinal stenosis and lumbar neural foraminal stenosis by the three reviewers. To evaluate the lumbar discs, areas of protrusion or extrusion were classified. Interobserver and intermethod reliabilities were calculated using Krippendorff's alpha (Kα) test.

Results: Lumbar disc pathology identification was similar between the 2D TSE and 3D TSE sequences. Interobserver agreements were better for 3D TSE than 2D TSE in the evaluation of disc hernias (Kα ratio; 0.965 vs. 0.944), herniation zones (Kα ratio; 0.894 vs. 0.847), and foraminal narrowing (Kα ratio; 0.965 vs. 0.924). Both 2D and 3D TSE had 100% sensitivity for disc pathologies and spinal stenosis, 81% sensitivity for herniation zones, and 92.5% sensitivity for foraminal stenosis in only operated patients.

Conclusions: The 3D TSE sequence was comparable to conventional magnetic resonance imaging (MRI) sequences in the evaluation of lumbar disc herniation. This approach can be used in radiology departments either alone or combined with routine MRI for lumbar disc hernias as a diagnostic sequence and an approach to overcome problems.

Keywords: Magnetic resonance imaging, spin echo imaging, intervertebral disc, spine

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The lumbar spinal magnetic resonance imaging (MRI) protocol in the evaluation of intervertebral disc pathologies often involves T1-weighted (T1W) and T2-weighted (T2W) sequences in the sagittal and axial planes. Axial spinal images can be obtained as either "stack" images or "through

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disc" sequence images. Stack images are obtained in axial planes with respect to the scanner table, and variable disc angulations owing to natural lordosis of the lumbar spine are not taken into consideration. On the other hand, "through disc" sequence images are obtained by imaging slabs parallel to intervertebral disc spaces,which are set by a radiology technician with a reset of the axial axis at each disk levelfor proper assessment of intervertebral discs [1].

Some radiology departments use three-dimensional (3D) T2W sequences in the evaluation of lumbar intervertebral discs, and a number of them use axial plane images of this MR sequence [2-4]. With variable flip angles, 3D turbo spin-echo (TSE) maintains constant signals by utilizing refocusing radiofrequency pulses and enables very long echo train lengths.Therefore, 3D TSE might allow the acquisition of thin section images within acceptable examination times [5]. It is known that specific 3D TSE and 3D gradient echo sequences, such as constructive interference in steady state (CISS), are very successful in the assessment of nerves. The 3D steady-state refocused gradient echo sequence is a flow-compensated MRI sequence with high contrast and high spatial resolution, enabling detailed visualization of nerve roots and neural structures surrounded by cerebrospinal fluid [6-9]. These sequences are significant examination approaches, which enable visualization of normal nerves in their course, and they are assumed to be adequate imaging approaches for the detection of even small lesions at the initial stage of a disease [6].

In the literature, some papers have indicated the extent of success with the 3D TSE approach. However, the present study attempted to reveal most of the aspects of disc herniation and assess herniation zone by zone using 3D TSE. The aim of this study was to evaluate the efficacy of a 3D TSE sequence for determining lumbar disc protrusions, and to compare the findings with those of conventional 2D TSE sequences and reveal the interobserver and intermethod agreements of both sequences.

METHODS

Patients

After receiving approval from the local ethics committee, 84 patients (35 male and 49 female patients) and 127 intervertebral discs were included in this study. Between March 2016 and January 2017, 96 patients, who accepted and signed an informed consent form, underwent MRI with conventional MR sequences and a 3D TSE sequence. The patients were aged between 17 and 79 years (mean age: 42.62 years). Twelve patients who signed the informed consent form but had normal MRI results (after evaluation and consensus of the interpreters) were excluded from the investigation. Three radiologists (a musculoskeletal radiologist with 11 years of experience, a general radiologist with 15 years of experience, and a neuroradiologist with 16 years of experience) interpreted the MR images. At the time of analysis, the radiologists were blinded to the clinical history of the patients, and they were not provided with any information by clinicians and did not have access to previous reports. The conventional TSE and 3D TSE sequences of a patient were interpreted at different times (at least a 1-week interval) by each researcher. Only the lumbar intervertebral levels of pathologic discs were included in the study for evaluation of the areas of disc protrusion, spinal stenosis, and foraminal stenosis.

Image Analysis

Alterations of intervertebral disc morphology were classified as disc bulging, protrusion, and extrusion. Circumferential symmetric extension of the disk beyond the intervertebral space border was considered as bulging. Focal or asymmetric extension of the intervertebral disc beyond the intervertebral space border was considered as protrusion. Extreme extension of the disc beyond the interspace border with a herniation base, which was wider than the disk of origin or had no connection between the herniated disc material and disk of origin was considered as extrusion [10]. Disc herniation was evaluated in seven areas (central zone and bilateral paracentral, foraminal, and extraforaminal zones). The central zone was considered as the middle region located behind the intervertebral disc that included the anterior aspect of the dural sac. The paracentral zone was considered as the region just adjacent to the central region, and it was at the beginning of the neural foramina. The foraminal zone was considered as the region that included the neural foramen, and the extraforaminal

Table 1. MRI parameters for both conventional 2D TSE and 3D TSE sequences

Parameters	2D TSE sequences			3D TSE sequence	
	Sagittal T1	Sagittal T2	Axial T2	Sagittal	Axial
TR	571	4000	5562	842	842
TE	11	87	88	110	110
Slice thickness (mm)	4	4	4	0.8	0.8
Slice spacing (mm)	0.8	0.8	0.4	0.1	0.1
Number of slices	12	12	6	-	-
Voxel size	1.1×0.7×4.0	1.0×0.7×4.0	1.0×0.7×4.0	0.9×0.9×0.8	0.9×0.9×0.8
Band width	157	181	198	190	190
Flip angle	150	150	150	150	150
Matrix size	260×384	288×384	234×320	220×256	220x256
Field of view	280×280	280×280	230×230	220×220	220×220
Acquisition time (m:sc)	3:05	3:18	4:00	3:08	3:24

MRI = magnetic resonance imaging, 3D TSE = three-dimensional turbo spin-echo, 2D TSE = two-dimensional turbo spin-echo, TE = echo time, TR = repetition time

zone was considered as the region far from the neural foramen, just outside the foraminal zone. If a disc herniation was observed in multiple zones, the interpreters marked all these zones in the worksheet used in the study.

Spinal canal stenosis was evaluated as no stenosis, mild stenosis (0-33% narrowing of the spinal canal space), moderate stenosis (33-66% narrowing of spinal canal space), or severe stenosis (> 66% stenosis of the spinal canal space). The percentages of these measurements were based on the total anteroposterior diameter of the spinal canal.

Foraminal stenosis was evaluated using the grading system proposed by Lee *et al*. [11]. Grade 0 represents normal neural foramina, without any foramen obliteration or neural compression. Grade 1 stenosis represents a mild degree of foraminal stenosis (perineural fat obliteration by a thickened ligamentum flavum or by disc osteophytic protrusion in the foraminal zone). Grade 1 foraminal stenosis shows no evidence of a morphologic change in the nerve root. Grade 2 stenosis represents a moderate degree of foraminal stenosis (perineural fat obliteration in four directions, with obliteration of the vertical and transverse axes). Grade 2 stenosis involves narrowing of the foraminal width and height owing to ligamentum flavum thickening, facet arthropathy, disc protrusion, or osteophytic protrusion, without a morphologic change in the nerve root. Grade 3 stenosis represents a severe degree of neural foraminal stenosis, witha morphologic change in the nerve root and nerve root collapse due to disc protrusions, facet arthropathy, ligamentum flavum thickening, or osteophytic protrusion [11].

MRI Procedures

A Magnetom Essenza 1.5T system (Siemens, Erlangen, Germany) was used to obtain images. Lumbar spinal MRI examinations were performed with an 8-channel spinal coil. The time intervals for each 2D TSE sequence were as follows; T1 sequence in sagittal plane: 3 minutes and 5 seconds; T2 sequence in sagittal plane: 3 minutes and 18 seconds; T2 sequence in axial plane: 4 minutes. The time intervals of 3D TSE sequence for each plane were as follows; Sagittal 3D TSE: 3 minutes and 8 seconds, axial 3D TSE: 3 minutes and 24 seconds. The parameters of MRI for both conventional 2D TSE and 3D TSE sequences are presented in Table 1.

Statistical Analysis

After image acquisition and collection of data from the interpreters, all statistical analyses were performed using a commercially available software (Statistical Package for Social Sciences, version 24.0, IBM Corp., Armonk, NY, USA), with the exception of Krippendorff's alpha ratio for which the Recal 0.2/0.3 Alpha program was used (http://dfreelon.org/recal/recal3.php).

For assessing intraobserver agreements, 2D TSE and 3D TSE results were compared using Krippendorff's alpha test (Kα) for each reviewer. Interobserver agreements were revealed by using the same method with comparison of three different data

Table 2. Evaluation of lumbar disc pathologies with 2D TSE and 3D TSE

	Reviewer 1				Reviewer 2				Reviewer 3			
	2D TSE		3D TSE		2D TSE		3D TSE		2D TSE		3D TS	
Bulging (n)	30		25		28		24		26		26	
Protrusion (n)	89		93		91		94		93		92	
Extrusion (n)	8		9		8		9		8		9	
	N	P	N	P	N	P	N	P	N	P	N	
Spinal stenosis (n)	59	68	56	71	61	66	59	68	56	71	61	
Foraminal stenosis (n)	55	72	51	76	52	75	55	72	51	76	52	

3D TSE = three-dimensional turbo spin-echo, 2D TSE = two-dimensional turbo spin-echo, N = not present, P = pres
n = number of patients. Even a single side with foraminal narrowing in a patient was considered as a "present" resul

set from each reviewer for 2D and 3D TSE results. Interobserver and intermethod agreements were calculated using Fleiss' generalized kappa coefficient for each area of disc herniation (zone by zone). For the operated patients, sensitivities of both sequences were calculated by matching the results with surgical outcomes. The level of agreements between 0 and 0.20 accepted as "no agrrement", between 0.21 and 0.39 accepted as "minimal", between 0.40 and 0.54 presented "weak" agreement with regard to kappa values. The kappa values from 0.60 to 0.79 accepted as "moderate", from 0.80 to 0.90 accepted as "strong", and kappa levels > 0.90 indicated "almost perfect" agreement.

RESULTS

Lumbar disc herniation was evaluated by considering disc pathology, herniation area, spinal canal narrowing, and foramina narrowing. There was no disc herniation at levels T12-L1 and L1-2 in the study patients. Table 2 shows the results of interpretations with respect to herniated disc levels. This table also presents the total number of spinal and foraminal stenoses of the disc levels classified as bulging, protrusion, and extrusion.

Considering the disc pathologies, Krippendorff's alpha test (Kα) was used to calculate the interobserver agreements, and the Kα ratios were 0.944 and 0.965 for 2D TSE and 3D TSE, respectively, indicating almost perfect agreement for both MR sequences. The intermethod agreement (agreement of the results between 3D TSE and 2D TSE) was calculated using the same method, and the Kα ratios were 0.888 (strong agreement), 0.868 (strong agreement), and 0.902 (almost perfect agreement) for reviewers 1, 2, and 3, respectively (Table 3).

The same method was used to calculate the results of the disc herniation areas for each reviewer with regard to 2D TSE versus 3D TSE, and the seven zones mentioned in the methods section were assessed. The Kα ratios for interobserver agreements were 0.847 for 2D MRI and 0.894 for 3D TSE, both representing strong agreements. The Kα ratios for intermethod agreements (between 2D and 3D TSE sequences) were 0.722 (moderate agreement), 0.868 (strong agreement), and 0.884 (strong agreement) for

Table 3. Interobserver agreements for 2D TSE, interobserver agreements for 3D TSE, and intermethod agreements between 2D and 3D TSE for each observer in all patients.

	Interobserver agreements for 2D TSE	Interobserver agreements for 3D TSE	Intermethod agreements between 2D and 3D TSE for each observer		
			RW 1	RW 2	RW 3
Disc pathology	0.944	0.965	0.888	0.868	0.902
Areas of disc herniations	0.847	0.894	0.722	0.868	0.884
Spinal canal stenosis	0.970	0.894	0.926	0.868	0.902
Foraminal stenosis	0.924	0.965	0.951	0.884	0.897

3D TSE = three-dimensional turbo spin-echo, 2D TSE = two-dimensional turbo spin-echo. RW 1, RW 2, and RW 3 represent reviewer 1, reviewer 2, and reviewer 3 respectively. The numbers presented above, which were calculated using Krippendorff's alpha test, represent the levels of agreement in Table 2.

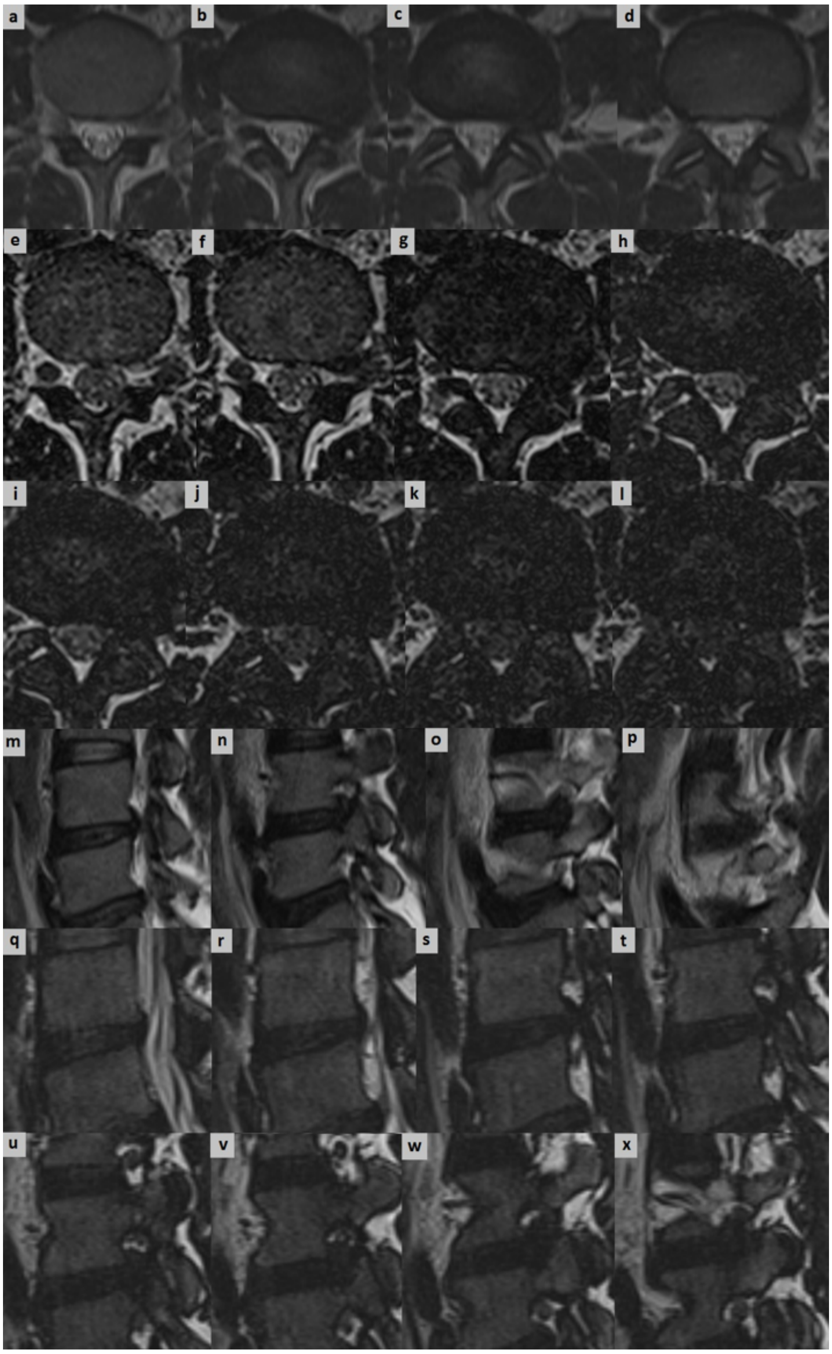

Figure 1. Consecutive images of a 34-year-old woman with L4-5 disc protrusion at the left foraminal and extraforaminal zones. Conventional MRI sequences in (a-d) T2-weighted (T2W) axial images and (m-p) T2W sagittal images. The 3D TSE sequence in (e-l) axial images and (q-x) sagittal images.

reviewers 1, 2, and 3, respectively (Table 3).

When the interobserver agreements of disc herniation areas were calculated separately (zone by zone), the outcomes of the analysis revealed that the left paracentral zone was the best zone and the right extraforaminal zone was the worst zone of agreement for 2D TSE and 3D TSE sequences with regard to Fleiss' generalized kappa coefficient (Table 4).

Spinal stenosis was also assessed with Kα ratios, and the interobserver differences were 0.970 (almost perfect agreement) for 2D TSE and 0.894 (strong agreement) for 3D TSE. Intermethod agreements (using the same analysis) were 0.926 (almost perfect agreement), 0.868 (strong agreement), and 0.902 (almost perfect agreement) for reviewers 1, 2, and 3, respectively (Table 3).

Table 4. Interobserver agreements for each herniation zone for 2D and 3D TSE with respect to Fleiss' generalized kappa coefficient values

Zone	MRI	3D TSE
Central	0.894	0.969
Left paracentral	0.962	1.000
Right paracentral	0.926	0.930
Left foraminal	0.926	0.969
Right foraminal	0.895	0.954
Left extraforaminal	0.747	0.872
Right extraforaminal	0.653	0.798

3D TSE = three-dimensional turbo spin-echo, 2D TSE = two-dimensional turbo spin-echo

With regard to foraminal stenosis, interobserver differences were measured with Kα ratios, and both the 2D and 3D TSE sequences showed almost perfect agreement (0.924 and 0.965, respectively). Intermethod differences were 0.951, 0.884, and 0.897 with regard to foraminal stenosis for reviewers 1, 2, and 3, respectively (Table 3; Figure 1).

Of the 84 patients included in this study, 18 (21 discs) were operated. If we only consider the operated patients, the sensitivities of both 2D and 3D TSE for discal pathologies, herniation zones, spinal stenosis, and foraminal stenosis were 100%, 81%, 100%, and 92.5%, respectively.

DISCUSSION

MRI is a common diagnostic tool for evaluating the pathologies of lumbar intervertebral discs. The results of 3D TSE were promising in this study. We found that 3D TSE was comparable with 2D TSE, and in many aspects, it was better than conventional TSE sequences for evaluating disc pathologies.

Back pain is one of the most common complaints in patients admitted to neurology and neurosurgery departments. Lumbar spinal MRI is one of the most common imaging approaches performed by clinicians and surgeons for the assessment of patients with neurological examination findings consistent with radiculopathy. Conventional T1W and T2W sequences are used to analyze disc herniation, the spinal canal, and the neural foramina in most radiology departments. Radiologists have extensive experience in the interpretation of routine images in daily practice, and MRI has proven to be appropriate for analyzing lumbar disc herniation and other pathologies relevant to herniation, such as neural root or thecal sac indentations and neural root edema, and for determining the exact location of the primary pathology.

On the other hand, MRI has some limitations in the evaluation of disc pathologies. It may be difficult to fully characterize complex anatomy and pathology by using traditional sequences. The borders of lumbar discs may not be visualized clearly, especially in the foraminal regions. Additionally, it can be difficult to determine the relationship between the disc and neural structures that are close to the disc border, such as the thecal sac and nerve roots. In order to overcome these difficulties, new MRI sequences are applied to patients. The TSE T2W 3D sequence, which involves sampling perfection with application-optimized contrast using different flip-angle evolution (SPACE), is an MRI approach that uses variable flip angles for refocusing instead of the conventional 180° refocusing pulse. Tins *et al*. [2] claimed that a 3D SPACE sequence in conjunction with sagittal T1W images was sufficient for routine spinal imaging with increased diagnostic confidence. Aydin *et al*. [12] studied a CISS sequence, which is a gradient-echo technique with steady-state free precession, and quantitative diffusion-weighted imaging for routine lumbar disc imaging, and the authors found that these sequences may be alternative imaging approaches to conventional MRI approaches for assessing lumbar disc hernias [12].

The 3D TSE approach is a relatively new MRI technique, which is available in certain MR machines. This sequence has the potential to supplement (as a problem solver) or replace routine 2D fast spin-echo (FSE) sequences for lumbar imaging [13-15]. Moreover, it has some additional properties, including dynamic modification of the imaging plane using an add-on program to the standard image-viewing software [14, 16]. In the literature, some studies have compared the technical image quality of 3D MRI sequences with that of 2D MRI sequences for the cervical spine [17, 18].

Tins *et al*. [2] tried to use the SPACE sequence in 62 MRI examinations with two examiners in order to determine the suitability of the 3D SPACE sequence for routine imaging of the spine. In their study, with high interobserver agreement for the SPACE sequence, the depiction of anatomy was very good in 84% of cases. For artifact assessment of SPACE, the kappa value was 0.92 and the confidence interval was between 0.92 and 1.00. They mentioned that the SPACE sequence was superior to routine MRI sequences for the depiction of anatomy and artifact resistance according to their results [2]. Blizzard *et al*. [1] applied the 3D TSE sequence to 80 patients and correlated the results with the 2D FSE sequence. Intermethod reliability was calculated for each interpreter as the point-by-point agreement using 57 criteria, including central canal stenosis and disc herniation. In their study, the intermethod reliability was 85.3% overall and 94.6% according to modified reliability, which excludes disagreements between normal and mild abnormalities. Additionally, intraobserver reliabilities were 82.0% for 2D FSE and 87.2% for 3D TSE, and interobserver reliabilities were 77.4% for 2D FSE and 78.4% for 3D TSE (overall) and 88.3% for 2D FSE and 89.1% for 3D TSE according to calculations for modified reliability [1]. Our interobserver agreements were higher for 3D TSE according to disc pathologies, disc herniation areas, and foraminal stenosis. On the other hand, the 2D TSE sequence showed better agreement with regard to spinal canal stenosis,although the agreement result was classified as strong for 3D TSE.

In 1990, Grenier *et al*. [19] claimed that foraminal and extraforaminal lumbar disk herniations were less frequent than intraspinal herniations and they were more difficult to diagnose. They underlined the difficulty of distinction between disc fragments and enlarged foraminal veins in far lateral zone herniation. They recommended flow sensitive sequences or contrast enhancement, which may aid in the diagnosis and overcome this issue. Within the same year, Epstein *et al*. [20] studied 60 patients with far lateral lumbar disc herniation. Myelo-computed tomography (CT) was found to be more effective and superior to noncontrast CT and MRI in their study. Lejune *et al*. [21] analyzed a series of 83 patients, who were operated specifically for foraminal lumbar disc herniation.They used the same classification for herniation zones as presented in our study. Although they used CT, they mentioned that foraminal herniations might be overlooked because even a moderate bulge of the intervertebral disc could impinge the nerve root in the narrow space of the neural foramen [21]. The limitations of evaluating the foraminal region have long been known. However, because of innovations in MRI technology, magnetic field forces are much stronger and new sequences have been used lately to overcome the limitations and difficulties. Lee *et al*. [22] studied lumbar spinal MRI using a 3.0T MR machine. They compared 2D T2W TSE with 3D T2W SPACE sequences for lumbar neural foraminal stenosis, central spinal stenosis, and nerve compression,with two interpreters. The 3D T2W TSE and 2D T2W SPACE sequences had similar sensitivity ratios for detecting foraminal stenosis at 32 foramen levels (78.9% vs. 78.9%). For spinal stenosis both sequences had 100% sensitivity at 42 spinal levels, and for nerve compression, the sensitivity ratios were 92.9% and 81.8% for 3D T2W TSE and 2D T2W, respectively, at 59 spinal nerves. The kappa values of interobserver agreements (3D T2W TSE vs. 2D T2W TSE) were 0.849 vs. 0.451 for foraminal stenosis, 0.809 vs. 0.503 for spinal stenosis, and 0.681 vs. 0.429 for nerve compression [22]. Our study revealed almost perfect agreements for 2D TSE and 3D TSE. Intermethod agreements were almost perfect for one reviewer and strong for the other two reviewers with regard to foraminal stenosis.

3D TSE provides good visualization for lumbar imaging but is not perfect in all aspects. It is mentioned that wrap around artifacts may occur in reformatted images of a 3D TSE sequence, which does not have an effect on the diagnosis; however, in this research, reformatted images were not used [11]. Reformatted images were not a component of this study due to correlate "the same MRI planes" with conventional sequences in order to reveal and analyze the possibilities and disadvantages of this MRI technique. Although we obtained good results with 3D TSE, most of our patients were not operated after MRI examinations, and this was a limitation of our study. Thus, it was not possible to correlate these two sequences with regard to surgical outcomes in all patients included in this study.

CONCLUSION

In conclusion, the 3D TSE sequence was very useful and the images obtained by this approach were comparable to images obtained with conventional MRI sequences in the evaluation of lumbar disc herniation. We recommend this sequence for use in radiology departments either alone or combined with routine MRI for lumbar disc hernias.

Author Contributions

Study concept and design: VK, HA; Acquisition of data: VK, SSK, CHY; Analysis and interpretation of data: VK, SSK, HA; Drafting of the manuscript:VK, AKS; Critical revision of the manuscript for important intellectual content: HA, VK, AKS, UM; Statistical analysis: VK, AKS; Administrative, technical, and materialsupport: VK, SSK, CHY; Study supervision: VK; Guarantor of integrity of entire study: VK; Literature research: VK, AKS, UM, CHY

Conflict of interest

The authors disclosed no conflict of interest during the preparation or publication of this manuscript.

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