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3d-Fse Isotropic Mri Of The Lumbar Spine: New Application Of An Existing Technology

Daniel John Blizzard
Yale School of Medicine, daniel.blizzard@yale.edu

3D-FSE Isotropic MRI of the Lumbar Spine: New Application of an Existing Technology

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Daniel John Blizzard

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3D-FAST SPIN-ECHO ISOTROPIC MRI OF THE LUMBAR SPINE: NEW APPLICATION OF AN EXISTING TECHNOLOGY.

Daniel J. Blizzard, Andrew H. Haims, Andrew W. Lischuk, Rattalerk Arunakul, Joshua W. Hustedt, and Jonathan N. Grauer. Department of Orthopaedics and Rehabilitation, Yale University School of Medicine, New Haven, CT.

The purpose of this study was to assess the diagnostic performance of three-dimensional, isotropic fast/turbo spin-echo (3D-TSE) in routine lumbar spine MR imaging.

Conventional 2D-FSE MRI requires independent acquisition of each desired imaging plane. This is time consuming and potentially problematic in spine imaging, as the plane of interest varies along the vertical axis due to lordosis, kyphosis, or possible deformity. 3D-TSE provides the capability to acquire volumetric datasets that can be dynamically reformatted to create images in any desired plane.

Eighty subjects scheduled for routine lumbar MRI were included in a retrospective trial. Each subject underwent both 3D-TSE and conventional 2D-FSE axial and sagittal MRI sequences. For each subject, the 3D-TSE and 2D-FSE sequences were separately evaluated (minimum 4 weeks apart) in a randomized order and

read independently by four reviewers. Images were evaluated using specific criteria for stenosis, herniation, and degenerative changes.

The inter-method reliability for the four reviewers was 85.3%. Modified inter-method reliability analysis, disregarding disagreements between the lowest two descriptors for appropriate criteria (equivalent to "none" and "mild"), revealed average overall agreement of 94.6%.

Using the above, modified criteria, inter-observer variability for 3D-TSE was 89.1% and 88.3% for 2D-FSE ($p=0.05$), and intra-observer variability for 3D-TSE was 87.2% and 82.0% for 2D-FSE ($p<0.01$). The inter-method agreement between 3D-TSE and 2D-FSE was statistically non-inferior to intra-observer 2D-FSE variability ($p<0.01$).

This systematic evaluation showed there is a very high degree of agreement between diagnostic findings assessed on 3D-TSE and conventional 2D-FSE sequences. Overall, inter-method agreement was statistically non-inferior to the intra-observer agreement between repeated 2D-FSE evaluations.

Overall, this study shows that 3D-TSE performs equivalently, if not superiorly to 2D-FSE sequences. Reviewers found particular utility for the ability to manipulate

image planes with the 3D-TSE if there was greater pathology or anatomic variation.

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TABLE OF CONTENTS

INTRODUCTION

Back pain is the number one complaint in primary care office visits and the number two reason for missed days of work in the United States, with 90% of Americans being affected at some point in their lives[1,2]. The mainstay of treatment for lumbar conditions is conservative management. However, if lumbar-related symptoms persist, imaging is often considered. Although radiographs are routinely the initial imaging modality considered for lumbar-related symptoms, further imaging with magnetic resonance imaging (MRI) or computed tomography (CT) is often considered to better define underlying pathology.

Of the advanced imaging modalities, MRI is the most commonly utilized. This allows for the evaluation of neural elements, discs, ligaments, etc. This is in contrast to CT which is better at defining bony anatomy, but less routinely utilized as a primary evaluation tool of the lumbar spine. Despite the increasing frequency of obtaining lumbar MRIs[3], there remain clear limitations with this technology.

Factors intrinsic to the MRI scanner and pulse sequences directly affect image quality. The strength of the MRI magnet is directly proportional to signal strength and signal-to-noise ratio (SNR) and indirectly proportional to three-dimensional (3D) resolution [4,5]. Sequence parameters can also affect image quality [6]. Time to

echo (TE) and pulse repetition time (TR) are primary variables controlling the "weighting" or factor governing image contrast. Specifically, T1 sequences (which primarily enhance fat) have relatively short TE and TR, proton density sequences (which intermediately enhance water) have relatively short TE and long TR, and T2 sequences (which primarily enhance water) have relatively long TE and TR (Figure 1).

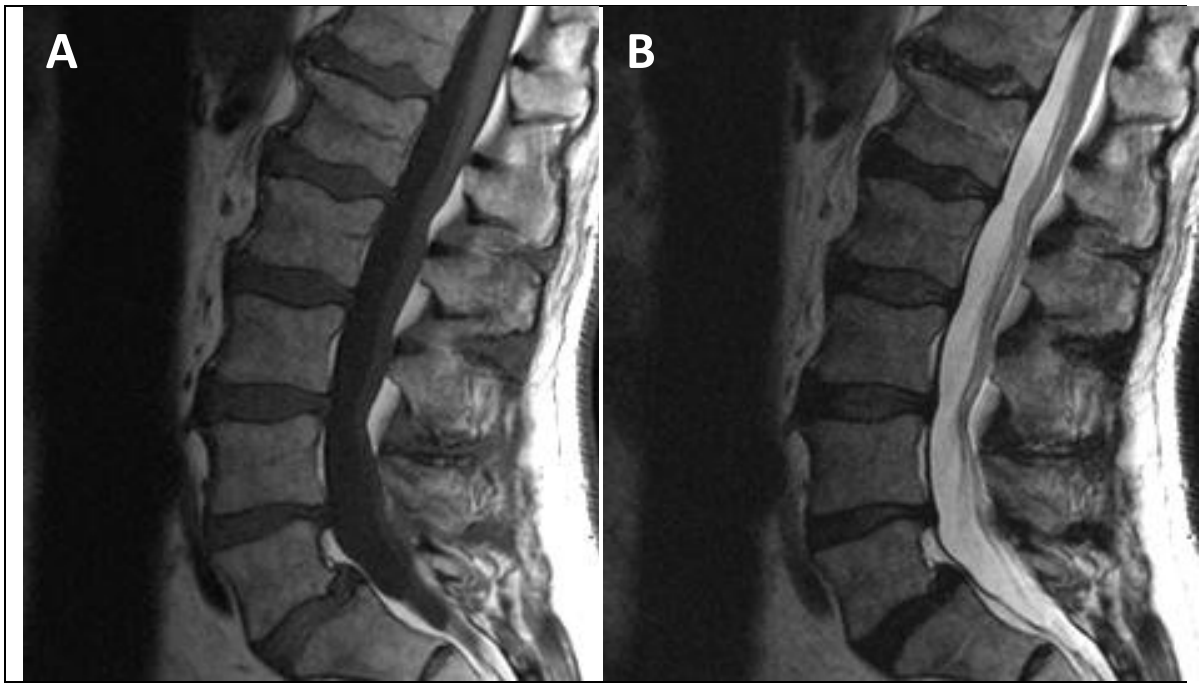

Figure 1: Mid-sagittal MRI sequence of lumbar spine shown with A) T1-weighting and B) T2-weighting. Hyperintensity indicates fat on T1-weighted image and water on T2-weighted image.

In conventional two-dimensional (2D) MRI, axial, coronal, and sagittal images must be acquired independently. In order to best characterize three-dimensional (3D) pathologies, these images may be obtained relative to the axis, or plane, of the

region of interest. This can be challenging for spinal structures where the plane of interest is variable along the course of the area of interest due to lordosis, kyphosis, and/or deformity.

Currently, axial spinal imaging is obtained as either a "stack" or "through disc" sequence. For "stack" sequences, images are acquired relative to the plane of the scanner table, not accounting for the variable angulation of the disc spaces due to the natural lordosis/kyphosis of the spine (Figure 2A). For "through disc" sequences, images are acquired through varied axial planes set by a technician to be orthogonal to a specific disc spaces with resetting of the axial axis at each disc level (Figure 2B). However, the manual selection of axial planes leads to the possibility of selection of suboptimal planes and potential for missing anatomy between discs that could modify clinical decision making.

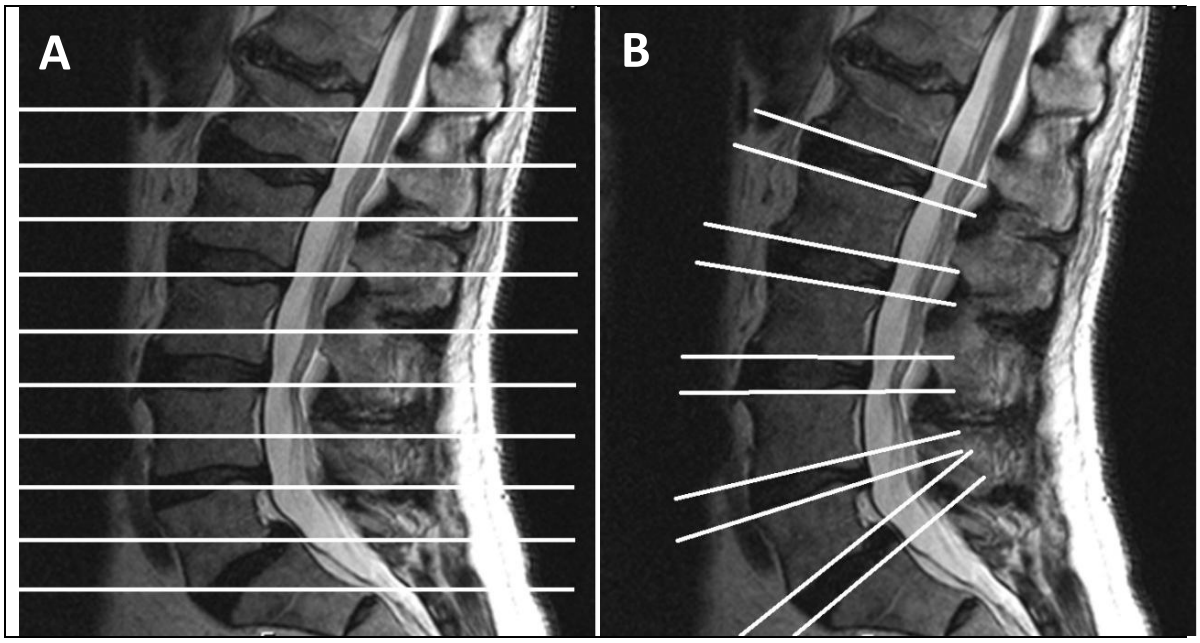

Figure 2: T2-weighted 2D-FSE mid-sagittal MRI depicting different axial imaging slices (white lines) in the lumbar spine. A) "stack" sequence orthogonal to axial plan of the patient. Natural lordosis of spine lead to oblique slices of the lumbar anatomy. B) "through disc" sequence orthogonal to disc spaces. A technician manually defines multiple planes, resetting the axial angle at each disc space level. Interdisc-spaces are not imaged, leading to the potential of missing anatomy of clinical interest.

Using currently available software, it is possible to reconstruct secondary imaging planes from primary planes of acquisition (Figure 3). However, the quality of the reconstructed 2D-MRI images is limited by the inability to obtain an isotropic data set (equivalent resolution in all dimensions).[7] This lack of isotropy renders these images suboptimal for reformation as averaging error is too great (Figure 3B).[7-9] Additionally, the thickness of imaging slices can lead to partial volume artifacts.[10]

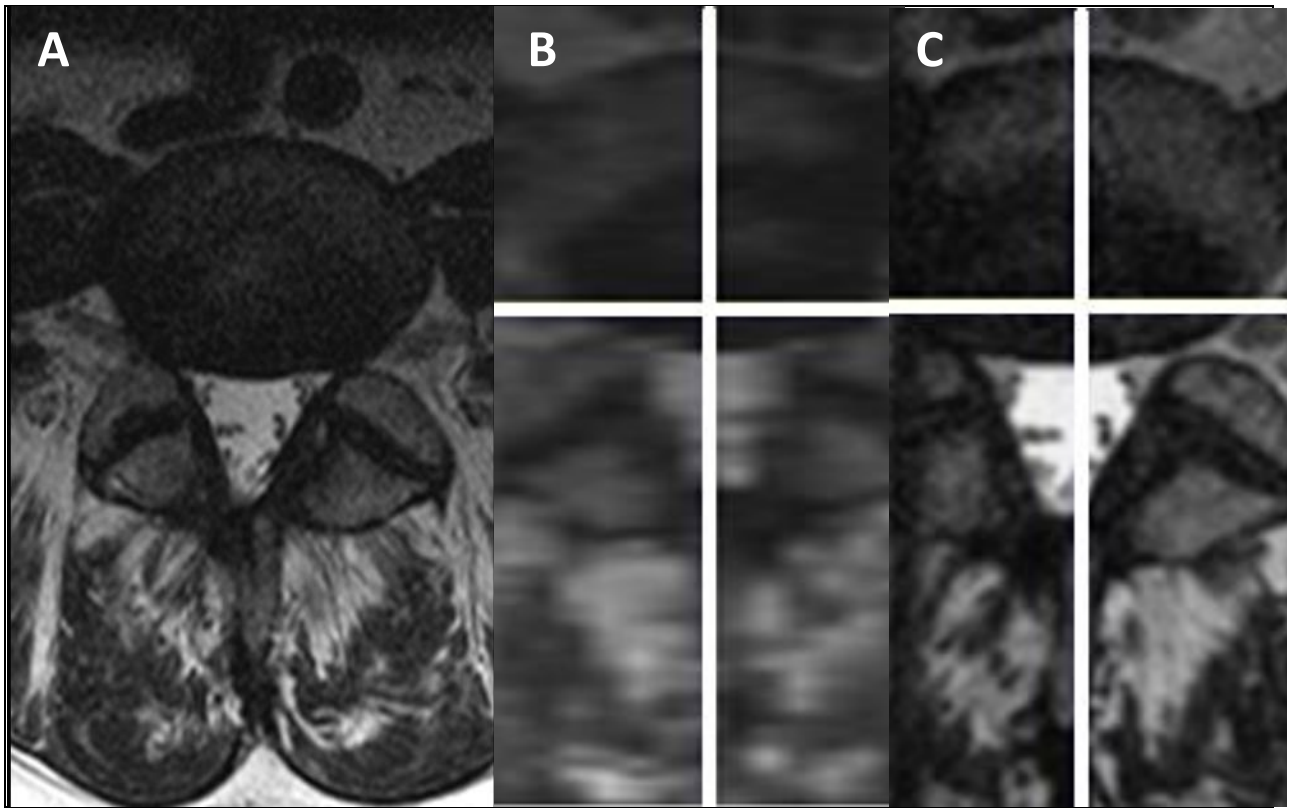

Figure 3: Axial L45 T2-weighted 2D-FSE images of the same subject. A) Traditional axial plane 2D-FSE (gold-standard). B) Reconstructed axial image from traditional 2D-FSE sagittal plane acquisition (poor option). C) Reconstructed axial image from 3D-TSE sagittal acquisition (potential alternative).

Single-plane CT scanning yields sufficient data for reconstruction of high quality images in other planes of interest. In helical CT imaging, the patient is evenly translated through the gantry while the x-ray tube rotates continuously creating a precessional, volumetric scan [11]. The raw helical data can then be processed through interpolation algorithms to create a volume of voxels (3D points representing x-ray attenuation) that can be reformatted into images in any plane [12].

Although routine for CT scans, this has not become an accepted practice for MRI due to a lack of sufficient image density to allow for analogous, high-quality transformations.

High resolution 3D-MRI sequences have been available for many years, however the requisite time to acquire these images made them clinically infeasible. For fast spin-echo (FSE) sequences, exam times for 3D scans were approximately thirteen to twenty-six times longer than 2D scans with additional requisite time for post-processing.[10] Additionally, the resultant data was anisotropic, limiting post-acquisitional reformations.[9,13,14] Using parallel imaging and refocusing flip-angle modulation, 3D-fast/turbo spin-echo (3D-TSE) sequences acquire thin, continuous slices yielding volumetric datasets that can be used to create multi-planar reformations with comparable contrast, resolution, and tissue enhancement to traditional two-dimensional fast spin-echo (2D-FSE) scans (Figure 3C, 4).[9,15-18] With this sequence it is now possible to attain large volumetric images with 0.7mm isotropic resolution with scan times of 3-6 minutes with a significant reduction in post-processing time.[16,18] That is, a 3D-TSE sequence can be acquired in approximately the same amount of time as any single T2 sequence (axial, sagittal, or coronal). This sequence can be run on most modern 1.5 and 3.0T scanners as it does not require any specific hardware or software modifications to the scanner.

Implementing these advancements, 3D-TSE has been preliminarily investigated in the knee and ankle. Stevens et al. found that cartilage and muscle SNR were significantly higher in isotropic 3D-TSE compared to 2D-FSE imaging the ankle, but found no significant difference in subjective image quality.[7] Several studies comparing 3D-TSE to 2D-FSE on the knee found similar diagnostic performance of the two modalities, but much shorter overall scan times with 3D-TSE suggesting potential throughput improvement on the imaging machine.[9,13,19] Ristow et al. expanded upon these studies, quantifying diagnostic performance for different anatomical components of the knee.[20] They found superior diagnostic sensitivity, but inferior specificity of cartilaginous lesions with 3D-TSE, in addition to superior visualization of high contrast objects, but inferior visualization of low contrast objects and lower image quality of 3D-TSE compared to 2D-FSE.

Preliminary utilization of 3D MRI in the spine has been reported in two studies. In 2009, Meindl et al. reported their results from phantom and in vivo testing.[21] Fifteen volunteers were scanned and the resultant studies were evaluated for simple visualization of anatomical structures in the cervical spine (spinal cord, gray and white matter, intraspinal nerve roots, CSF, neural foramen, and vertebral bone). Visibility was assessed qualitatively using a five-point confidence scale: 1, not visible; 2, barely visible; 3, adequately visible; 4, good visibility; 5, excellent

visibility. The authors concluded that the 3D-TSE sequence yielded better visibility compared to the 2D sequences for all structures except cord anatomy and vertebral bone. Although these initial results were positive, the authors provided no objective criteria for their visibility confidence scale and did not include any evaluation of potential pathology. Given the subtleties of distinguishing benign pathologies and normal variants from operable and potentially progressive pathologies, it is essential to more robustly assess the quality and utility of the imaging studies prior to introduction of a new sequence into clinical practice.

In 2012, Kwon et al. published a similar study comparing the visibility of anatomical structures in the cervical spine with both 3D-TSE and 2D-FSE in 14 volunteers.[22] They concluded that the 3D-TSE sequence was superior to conventional 2D sequences for the "delineation of intradural rootlets and neural foramina[22]." However, this study similarly lacked assessment of performance in diagnosing clinical pathologies and was further limited by a visual assessment scoring scale that lacked any objective, defined criterion.

To date, there are no published studies evaluating the clinical utility of using 3D-TSE for routine lumbar spine imaging. The aim of this study is to assess the performance and diagnostic capabilities of 3D-TSE in routine imaging of the lumbar spine. It is hypothesized that this new sequence will produce greater

image versatility from the capability to reconstruct data in varying planes. Additionally, given the comparable resolution of the 3D-TSE, it is hypothesized that 3D-TSE sequence will yield equivalent diagnostic findings to those found with the 2D-FSE sequences.

SPECIFIC AIMS AND HYPOTHESIS

Assess the diagnostic performance of three-dimensional, isotropic fast/turbo spin-echo (3D-TSE) in routine lumbar spine MR imaging. We hypothesize that the 3D-TSE sequence will have comparable diagnostic utility to traditional 2D sequences. Furthermore, wee hypothesize that 3D-TSE will provide greater image versatility from the capability to reconstruct data in varying imaging planes.

METHODS

The patient population for this study was identified through a search of our institution's Department of Radiology imaging database for all patients undergoing musculoskeletal-protocoled lumbar MRI between December 2009 and August 2010. The start date was chosen as the date our facility instituted a trial protocol of T1-weighted (sagittal and axial stack), T2-weighted (sagittal and axial stack), and PD-weighted (axial stack) 2D-FSE sequences as well as the 3D-TSE sequence to evaluate the relative role of varied sequences. Exclusion criteria for this study were prior lumbar instrumentation or fusion. All imaging studies were completed on one of three Siemens (Siemens Medical Solutions USA Inc., Malvern, PA) MRI scanners: Verio (3T), Avanto (1.5T), or Esprit (1.5T). Each study used the Siemens spine matrix coil dedicated to each scanner. Images were viewed using our institution's digital radiography software, SYNAPSE v3.2.1 (FUJIFILM, Tokyo, Japan) with the Obliquus MPR (FUJIFILM, Tokyo, Japan) software plug-in to dynamically view the 3D images.

For each subject, the T2-weighted 3D-TSE and 2D-FSE sequences were separately and independently reviewed by four reviewers (two orthopaedic spine surgeons and two musculoskeletal radiologists). The reviewers were not formally trained with the Obliquus MPR software. For each patient, evaluation of the

sequences was separated by a minimum of four weeks (to reduce recall bias) in a randomized order (to avoid systematic bias).

For each study, the 3D-TSE and 2D-FSE sequences were evaluated using specific criteria for stenosis, herniation, and degenerative changes (57 data points per study). Disc anatomy and pathology was evaluated for the L1/L2 to L5/S1 intervertebral discs. Vertebral pathology was evaluated for the L1 to L5 vertebrae. The specific criteria and corresponding severity scores were as follows (Figures 4 & 5).

- Disc hydration was evaluated as either normal, partially reduced, or completely black.
- Disc space height was evaluated as either normal, reduced < 50%, or reduced > 50% and was graded at the point of greatest reduction on the disc.
- Transitional vertebrae at the L5/S1 junction were evaluated as either present or not present.
- Endplate changes were graded as not present, bright, or dark.
- Spondylolisthesis was evaluated as either absent, retrolisthesis or anterolisthesis with reduction of adjacent vertebrae overlap of 0-25%, 25-50%, 50-75%, or 75-100%.

- Central canal stenosis was evaluated as either not present, mild (0-33% reduction of the canal space), moderate (33-66% reduction of the canal space), or severe (66-100% reduction of the canal space).
- Foraminal stenosis was evaluated as either not present, present, or present with compression of neural elements.
- Disc herniation was evaluated at four locations: central (midline), posterolateral (between midline and the facet joints), foraminal (under the facet joints), or far lateral (lateral to the facet joints). Severities were evaluated as either not present, diffuse disc bulge or present without compression of canal, present with <50% compression of the central canal, or present with >50% compression of the central canal.
- Facet joint degeneration was evaluated as either not present or present.
- Marrow changes (other than at the endplates) were evaluated as not present, diffuse marrow abnormalities, focal marrow abnormalities (including hemangiomas), or suggestion of fracture.

SAGITTAL IMAGES

Anatomy/Pathology

Disc Space Hydration	Normal	Partially reduced	Black disc			
	0	**1**	**2**			
Disc Space Height (at most severe point)	Normal	Reduced < 50%	Reduced > 50%			
	0	**1**	**2**			
Transitional Vertebrae	No	Yes				
	0	**1**				
Endplate Changes	Normal	Bright	Dark			
	0	**1**	**2**			
Spondylolisthesis	Absent	Grade 1: 0-25%	Grade 2: 25-50%	Grade 3: 50-75%	Grade 4: 75-100%	Retrolisthesis
	0	**1**	**2**	**3**	**4**	**5**
Marrow Changes (other than at endplate)	Absent	Diffuse marrow abnormality	Focal marrow abnormality	Suggestion of fracture		
	0	**1**	**2**	**3**		

AXIAL IMAGES

Anatomy/Pathology

Stenosis				
Central	Normal	Mild (0-33%)	Moderate (33-66%)	Severe (66-100%)
	0	**1**	**2**	**3**
Foraminal	Normal	Present	Compression of neural elements	
	0	**1**	**2**	
Disc Herniation	Absent	Present, but no compression of canal or diffuse disc bulge	Present with mild compression of canal (< 50%)	Present with marked compression of canal (> 50%)
	0	**1**	**2**	**3**
Facet joint (Assessment of degeneration)	Absent	Present		
	0	**1**		

Figure 4: Grading criteria. Each diagnostic finding is listed with an explanation of each respective severity gradation.

Sagittal Images

Transitional Vertebrae	L5/S1

Endplate Changes					

Spondylolisthesis					

Marrow Changes (other than at endplate)	Any Level

Axial Images

Anatomy/Pathology	L12	L23	L34	L45	L5/S1
Stenosis					
Central					
Foraminal					
Disc Herniation					
Central (midline)					
Posterolateral (between midline & facet)					
Foraminal (under facet)					
Far lateral (lateral to facet)					
Facet Joint (Assessment of degeneration)					

Figure 5: Grading sheet . All diagnostic findings are graded at each intervertebral space with the exception of transitional vertebrae (which is evaluated only at L5/S1) and marrow changes (which are evaluated globally for all lumbar vertebrae).

These criteria, and corresponding severities, were developed and repeatedly pilot-tested by the authors of this study for the specific purpose of evaluating performance of imaging sequences as they are used in routine clinical practice. The evaluation criteria were limited to anatomy and pathology that is routinely evaluated using T2-weighted sequences.

Intra-observer reliability was assessed for each sequence through repeated evaluation of the first twenty patients enrolled in the study. Both sequences for these patients were evaluated approximately six months after the initial evaluations. For the second evaluation, sequences for each respective patient were again separated by a minimum of four weeks and all four reviewers again evaluated the sequences independently.

Statistical analysis was performed using JMP© version 9 (SAS Institute, Cary, NC, USA). Reliability was assessed using paired t-tests. This study was approved by our institution's Human Investigations Committee.

My contribution to this project included development, pilot-testing, and multiple revisions of the grading scheme used to evaluate the studies. As there was no widely accepted standard for evaluating and grading spine MRI, our group developed a grading scheme that focused specifically on clinically relevant pathologies and quantified, or graded, the pathologies using clinically tangible severities.

In addition to aiding in the development of the grading scheme, I queried the Radiology Department at our institution for access to the list of patients that had

undergone imaging since the institution of a new MRI lumbar spine protocol that included both 2D-FSE and 3D-TSE sequences. I used the results of this query to create a database of patients indexed by exam date. After personally viewing all of the studies of the respective patients, I revised the database to only include patients that had saved and accessible 2D-FSE and 3D-TSE sequences and excluded patients that had clear evidence of prior lumbar spine surgery. Following revision of the database, I worked with Dr. Grauer to determine both the total number of patients necessary to evaluate in the study as well as the number of studies to re-examine to assess intra-observer reliability.

Following evaluation of all of the studies by all of the other authors, I inputted the resultant data into a database. I subsequently analyzed all of the data and completed all of the statistics independently.

RESULTS

A total of 130 patients were identified by the radiology database search. Of these, 12 patients were postoperative from lumbar instrumentation and/or fusion and 22 patients were found not to have had the 3D-TSE sequence performed due to technician omission early in the protocol refinement period at our institution. The exclusion of these patients resulted in a total of 96 patients eligible for the study. These patients were sorted into chronological order based upon the imaging date, and the first 80 patients were enrolled in the study based on *a priori* power calculations.

The study population consisted of 38 (48%) males and 42 (52%) females. The average age of the study population was 50.2 years (range: 14-82 years).

Inter-method reliability, 3D-TSE vs. 2D-FSE, was calculated through point-by-point comparison of reviewers' findings for each sequence between respective criteria. The average overall agreement for the four reviewers was 85.3% (range: 84.0-87.3%) (Table 1). Evaluation of the disagreements between the sequences showed no trend for more severe findings to be appreciated on one sequence relative to the other.

Analysis of the point-by-point inter-method reliability test revealed that the most frequent disagreements between sequences occurred between the lowest severity gradings–disagreements between "normal" and "mild" abnormalities. Modified point-by-point, inter-method reliability analysis, not counting disagreements between the lowest two severity scores (where applicable), revealed average overall agreement of 94.6% (range: 94.2-94.9%)(Table 1).

	Overall	Modified
Inter-method reliability	**85.3%** (range: 84.0-87.3%)	**94.6%** (range: 94.2-94.9%)

Table 1. Inter-method reliability is calculated for each reviewer as the point-by-point agreement between evaluations of each sequence across each of the 57 criterion. The average and range of reliability of the four reviewers is reported. The modified reliability excludes disagreements between "normal" and "mild" abnormalities.

Intra-observer reliability was calculated for both sequences through point-by-point comparison of reviewers' findings at each of the evaluation time points between respective criteria. The average overall agreement for the 3D-TSE sequence was 87.2% (range: 85.3%-90.0%). The average overall agreement for the 2D-FSE sequence was 82.0% (range: 78.6%-83.5%). The intra-observer reliability was statistically higher for 3D-TSE relative to 2D-FSE ($p<0.01$) (Table 2).

Inter-observer reliability was calculated for both sequences through point-by-point comparison of paired-reviewer agreement for all six permutations of the four reviewers. The average agreement for the 3D-TSE sequence was 78.4%. The average agreement for the 2D-FSE sequence was 77.4%. A paired t-test revealed the difference between the reliabilities was not statistically significant (p=0.07). Using the previously described modified analysis, the inter-observer reliability for the 3D-TSE sequence was 89.1% and 88.3% for the 2D-FSE sequence (paired t-test, p=0.05) (Table 2).

	2D-FSE	3D-TSE	p-value*
Intra-observer reliability	**82.0%** (range: 78.6-83.5%)	**87.2%** (range: 85.3-90.0%)	**<0.01**
Inter-observer reliability			
Overall	**77.4%**	**78.4%**	**0.07**
Modified	**88.3%**	**89.1%**	**0.05**

Table 2. Reliability results. Intra-observer reliability is calculated for each reviewer as the point-by-point agreement between repeated evaluations of each sequence across each of the 57 criterion. The average and range of reliability of the four reviewers is reported. The overall inter-observer reliability is calculated as the point-by-point agreement between all six permutations of the four reviewers. The modified inter-observer reliability is similar, but excludes disagreements between "normal" and "mild" abnormalities.(*Paired t-test)

Most notably, the average inter-sequence reliability between 3D-TSE and 2D-FSE sequences (85.3%) was higher than the average intra-observer reliability of the 2D-FSE sequence (82.0%). A one-sided t-test showed the agreement between the 3D-TSE and 2D-FSE sequences was statistically non-inferior to the intra-observer reliability of the 2D-FSE sequence ($p<0.01$).

DISCUSSION

Lumbar spine MR imaging is one of the most common tests ordered in the assessment of patients being evaluated for lumbar-related conditions. The interpretation of these images plays an instrumental role in directing further diagnostic workup and potential treatment algorithms. Accordingly, advancements in imaging modalities and techniques should be both welcomed and thoroughly assessed prior to clinical implementation.

Although axial and sagittal T2-weighted 2D-FSE sequences are the most commonly used (with complementary information from additional sequences), many limitations still exist. Complex anatomy and pathology may be difficult to fully characterize using traditional sagittal and axial views. The relative merits of "stack" and "through disc" axial sequences may be debated, but they both have limitations that cannot be overcome with post-acquisition image processing.[23]

3D-TSE is a relatively new MRI sequence available on certain scanners that has the potential to supplement or replace conventional 2D-FSE sequences for routine imaging.[9,13,16] With this sequence, the reviewer is able to dynamically modify the plane of imaging to produce images in any desired plane using an add-on program to standard image-viewing software.[16,18] The add-on program to view the

3D images does not require any special training to effectively utilize. At our institution, there is no incremental increase to the overall study cost from addition of the 3D sequence to the standard 2D sequences (T1, T2, and PD) in the imaging protocol. Furthermore, the incremental increase in study time (4-6 minutes) from the inclusion of the 3D sequence is nominal in relation to the total study time (45-60 minutes). Although technical image quality of 3D-MRI sequences has been compared to 2D sequences in the cervical spine,[21,22] no

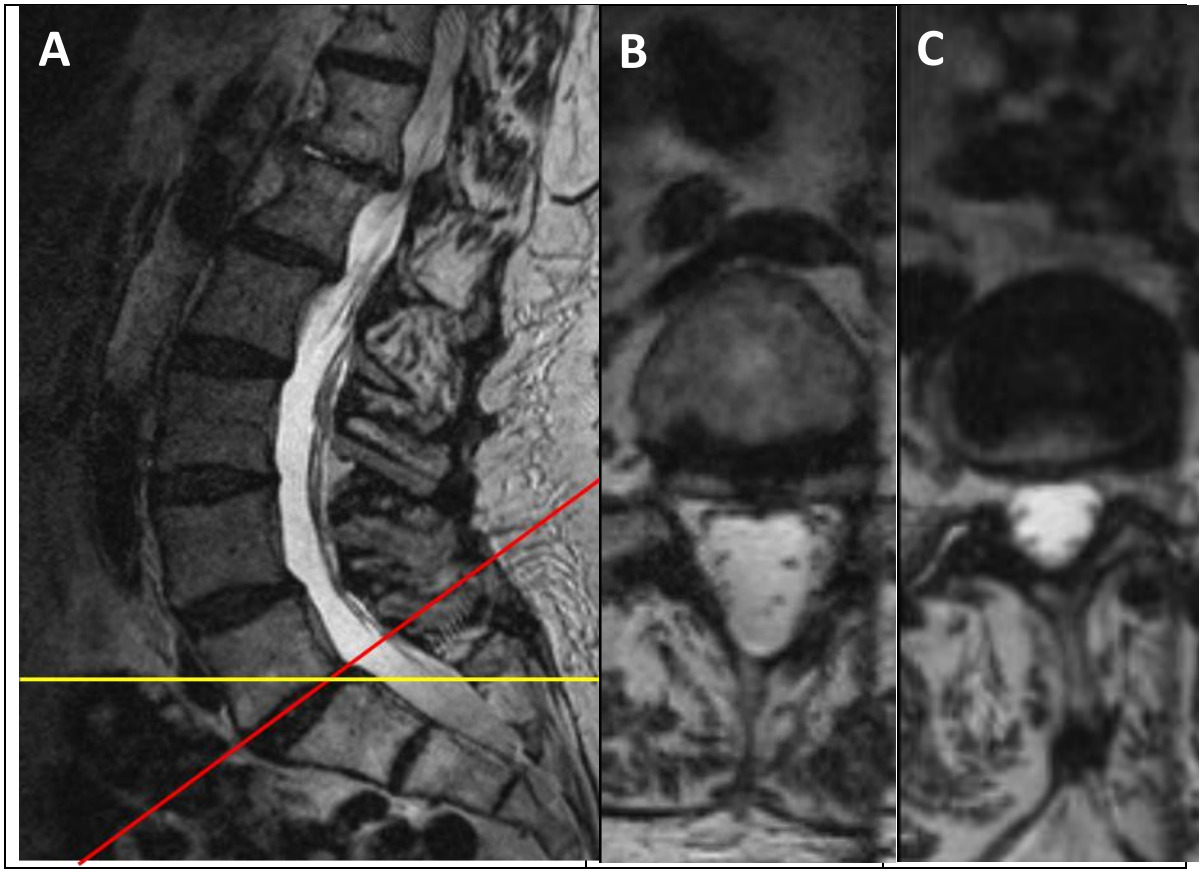

Figure 6: Reconstructed images from 3D-TSE sequence. A) image from sagittal 3D-TSE acquisition. B) reconstructed image corresponding to slice denoted by yellow line in the sagittal image. C) reconstructed image corresponding to slice denoted by red line in the sagittal image. The oblique slice clearly provides a superior view of the disc space.

published study has comprehensively evaluated clinical diagnostic performance of 3D-MRI in the spine.

This systematic evaluation showed there is a very high degree of agreement between diagnostic findings assessed on 3D-TSE and conventional 2D-FSE sequences. Specifically, it was found that the overall point-by-point agreement between 3D-TSE and 2D-FSE (85.34%) was statistically non-inferior to the agreement between repeated evaluations of standard 2D-FSE image sequences (82.02%). This non-inferiority indicates that 3D-TSE yields equivalent diagnostic information. Additionally, the intra-observer reliability was statistically higher for 3D-TSE compared to 2D-FSE. This suggests that the 3D-TSE sequence yields more precise results. Finally, inter-observer reliability of 3D-TSE was found to be statistically non-inferior to 2D-FSE sequences.

There are several clear advantages to the 3D-TSE sequence. Anecdotally, reviewers found that the sequence was of particular utility when there was greater anatomic variation in the sagittal or coronal plane (Figure 6). Additionally, since the 3D-TSE sequence produces a volumetric dataset in the same amount of time required to obtain a single 2D-FSE sequence, it is possible to obtain the same amount of information gleaned from an axial and sagittal 2D-FSE set of images in approximately half the time.

Although the 3D-TSE sequence introduces the potential to render additional views and images, the increased number of images that can be produced introduces the possibility of increasing the total amount of time required for a reviewer to evaluate the sequence. Furthermore, although the reviewers in this study self-reported a consistent amount of time spent reviewing each sequence for each patient, they had already gained familiarity with the 3D-TSE and the required software prior to the initiation of the study.

This study is limited by the inherent inability to verify the accuracy of imaging findings in all patients. That is, in instances where 3D-TSE and 2D-FSE findings differ, it is not possible to verify which findings are correct. This limitation was addressed in the design of the study–rather than assessing accuracy of the 3D-TSE sequence, it was instead compared to 2D-FSE, the current gold-standard, to assess whether it would yield equivalent diagnostic information. Additionally, only sagittal stack 2D-FSE axial images were used in this study, as this is the current practice at our institution.

Of additional note, only the T2-weighted 2D-FSE and 3D-TSE image sets were compared in this study. Imaging for specific suspected pathology can necessitate reliance upon other weighted image sets (such as T1, STIR, PD). However, this

study was designed specifically to assess the performance of T2-weighted sequences, as these are the most commonly utilized sequences for the evaluation of the most common pathologies in the lumbar spine.

Given the continued escalation of healthcare costs and the concurrent development of new technologies, it is essential to assess potential advancements in the field rigorously prior to attempted introduction into the clinical setting. This rigorous assessment of demonstrates 3D-TSE to perform equivalently, if not superiorly to 2D-FSE sequences with specific potential advantages of post-image acquisition processing.

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