Journal of Orthopaedics 77 (2026) 133–141

Contents lists available at ScienceDirect

Journal of Orthopaedics

journal homepage: www.elsevier.com/locate/jor

Balanced Turbo Field Echo MRI as a radiation-free adjunct for spinal bone imaging: A prospective study of 526 patients

Abhishek Soni [a], Akhil Xavier Joseph [a], Vidyadhara S. [a,b,*], Balamurugan T. [a], Ullas V. Acharya [c], Sharath K. Rao [b]

[a] Manipal Comprehensive Spine Care Center, Manipal Hospital, Old Airport Road, Bangalore 560017, Karnataka, India
[b] Department of Orthopaedics, Kasturba Medical College Manipal, Manipal Academy of Higher Education, Manipal, India
[c] Department of Radiology, Manipal Hospital, Old Airport Road, Bangalore 560017, Karnataka, India

ARTICLE INFO

Keywords:
Balanced steady-state free precession
Balanced turbo field echo
Bone imaging
Radiation-free imaging
Spondylolysis
CT-like MRI

ABSTRACT

Study Design: Single-centre, prospective, within-subject observational imaging-quality study with a single experienced reader.
Aims & Objectives: To evaluate whether adding a 3D Balanced Turbo Field Echo (BTFE) sequence to routine 3T spine MRI improves visualization of osseous spinal pathology compared with conventional T1/T2-weighted MRI and plain radiographs.
Materials & Methods: Between March and November 2024, 526 consecutive adults underwent spine imaging including T1/T2-weighted and BTFE MRI on a 3T scanner plus plain radiographs; thin-section CT served as confirmatory reference in a small ligamentum flavum ossification (LFO) subgroup. Six osseous pathologies were scored: disc osteophyte complex, OPLL, LFO, spondylolisthesis, spondylolysis and vertebral fracture. A single senior consultant radiologist (>10 years' experience), blinded to other modalities and clinical details, graded visualization on a 3-point ordinal scale in separate, randomized, washed-out sessions. Modalities were compared per pathology with Friedman's test and Holm-corrected Wilcoxon post-hoc tests.
Results: Mean age was 60.2 ± 11.8 years; 297 (56.5%) were female; thoraco-lumbar scans accounted for 454 (86.3%). Disc osteophyte was most common (n = 229, 43.5%). BTFE scored significantly higher than routine MRI and plain radiographs for every pathology (all $p < 0.001$). OPLL was invisible on radiographs but well delineated on BTFE. For LFO, BTFE meaningfully outperformed routine MRI, representing a radiation-free improvement over standard MRI practice.
Conclusion: Adding a widely available BTFE sequence to routine 3T spine MRI improved visualization of spinal osseous pathology without ionizing radiation. BTFE should be regarded as a candidate bone-imaging adjunct; head-to-head comparison with CT and with established CT-like MRI sequences (ZTE, FRACTURE, 3D FLASH, T1-spoiled gradient-echo, synthetic CT) is needed.

1. Introduction

Magnetic resonance imaging (MRI) is the principal non-invasive modality for evaluating spinal disorders because of its soft-tissue contrast and lack of ionizing radiation. Conventional T1- and T2-weighted sequences are well suited to the spinal cord, intervertebral discs, and paraspinal soft tissues, but they depict cortical bone, calcified structures, and the bone–soft tissue interface poorly.[1,2] Computed tomography (CT) remains the reference standard for spinal bony anatomy, yet its ionizing-radiation burden is a drawback when imaging is repeated and in younger and pregnant patients.[3,4]

Over the past decade several MRI strategies have emerged that aim to produce CT-like bone contrast without ionizing radiation. These can be grouped into four families with distinct evidence bases: (i) ultrashort-echo-time (UTE) and zero-echo-time (ZTE) acquisitions,[5–11] (ii) CT-like gradient-echo methods such as T1-weighted spoiled gradient-echo[12] and 3D fast low-angle shot (FLASH),[13] and dedicated hybrids such as FRACTURE (fast field-echo resembling CT using restricted echo-spacing),[14–16] (iii) AI-generated synthetic CT derived from MRI,[17–22] and (iv) multi-echo or objective lesion-scoring approaches on routine or modified MRI.[23,24] Across cervical foraminal stenosis, OPLL, lumbar facet degeneration, vertebral fractures and pars defects, these methods have shown substantial-to-excellent agreement with CT and, in navigation studies, noninferior screw accuracy.[5,9,12–14,20,21,25–29] Balanced steady-state free precession (bSSFP, marketed as Balanced Turbo Field

* Corresponding author at: Manipal Comprehensive Spine Care Center, Manipal Hospital, Old Airport Road, Bangalore 560017, Karnataka, India.
E-mail address: vidya007@gmail.com (V. S.).

https://doi.org/10.1016/j.jor.2026.05.014
Received 17 April 2026; Accepted 15 May 2026
Available online 1 July 2026

Echo [BTFE], TrueFISP or FIESTA) belongs to a fifth, older family. Its use in the spine has historically been anatomical rather than bone-specific: cervical TrueFISP myelography[30] and lumbar 3D FIESTA for foraminal stenosis.[31] Unlike ZTE, FRACTURE, 3D FLASH and synthetic CT – which in their current form require vendor-specific software, research sequences or dedicated post-processing pipelines – bSSFP is already installed on virtually every modern 3T platform and can be added to a routine protocol in a few seconds. Whether a routinely available bSSFP variant such as BTFE can contribute meaningfully to bone-oriented assessment of the spine has, however, not been tested in a large clinical cohort.

The present study addressed this gap. The primary aim was to quantify the incremental visualization value of BTFE relative to conventional T1/T2-weighted MRI and plain radiographs across a broad prospective cohort. The secondary aim was to describe the performance of BTFE for specific calcified and ossified lesions of clinical surgical relevance – particularly OPLL, LFO and disc osteophyte complexes – and to position the sequence within the contemporary CT-like MRI landscape. We framed BTFE *a priori* as a candidate method to be compared against routine MRI and radiographs, and we report head-to-head benchmarking against CT and other CT-like MRI sequences as a necessary next step rather than a settled question.

2. Materials and methods

2.1. Study design and setting

This was a single-centre prospective observational study conducted at a tertiary spine referral centre between March 2024 and November 2024. Institutional ethics committee approval was obtained before any study activity; written informed consent was obtained from all participants. Reporting follows STROBE for the observational cohort component and the STARD 2015 framework for the LFO subgroup in which CT was available as a cross-modality reference. Completed STROBE and STARD checklists and the patient flow diagram are provided as Supplementary Files S1–S3.

2.2. Participants

Consecutive adult patients presenting to the spine service who underwent MRI of the spine as part of preoperative or diagnostic workup were included, provided that both T1/T2-weighted and BTFE sequences were obtained in the same session and that plain radiographs of the corresponding region were available within 30 days. Patients with non-diagnostic images due to motion or metallic artefact were excluded. All spinal regions and all adult age groups were eligible.

2.3. Imaging acquisition

All MRI scans were performed on a single 3T MRI system (Philips Ingenia, Philips Healthcare). The standard protocol comprised sagittal T1-weighted and T2-weighted sequences covering the clinically indicated spinal region. The BTFE sequence is a gradient-echo technique that balances all gradient moments and achieves high signal-to-noise ratios, enhancing the visibility of both soft and bony structures. Sequence parameters were: repetition time (TR) 1.2 ms, echo time (TE) 4.1 ms, flip angle 8°, field of view 250 mm, and slice thickness 2 mm, with sagittal orientation and multiplanar axial/coronal reformats reconstructed at the console. BTFE images were reviewed in native contrast without greyscale inversion or bone-window post-processing. Plain radiographs were acquired in standard anteroposterior and lateral projections on digital radiography systems per institutional protocol. In the LFO subgroup, thin-section CT (slice thickness 1 mm, bone kernel) served as the confirmatory bone reference.

Table 1
Prevalence of osseous pathologies in the study cohort (N = 526).

Pathology	Cases, n	Prevalence, %
Disc osteophyte complex	229	43.5
Spondylolysis	27	5.1
Spondylolisthesis	21	4.0
Vertebral fracture	6	1.1
Ligamentum flavum ossification	4	0.8
OPLL	3	0.6

2.4. Pathology assessment

Six osseous pathologies were evaluated: (1) disc osteophyte complex, (2) OPLL, (3) LFO, (4) spondylolisthesis, (5) spondylolysis, and (6) vertebral fracture. For each patient the presence or absence of each pathology was recorded. For patients in whom a pathology was present, visualization quality was scored on each available modality: plain radiograph, routine T1/T2-weighted MRI and BTFE (and CT for the LFO subgroup).

2.5. Image quality scale

Image quality was assessed on a 3-point ordinal scale adapted from prior diagnostic imaging work[5,12,14] (Table 3): grade 1, poor – barely discernible structures precluding diagnosis; grade 2, acceptable – identifiable structures sufficient for a basic diagnostic statement; grade 3, excellent – sharply delineated cortical and trabecular detail suitable for all diagnostic purposes. The scale was calibrated in a 10-case consensus reading session prior to the formal study; cases from this calibration were not included in the main analysis. A deliberately simple 3-point scale was chosen to maximize clinical reproducibility, accepting that finer-grained 5-point Likert or structure-specific ordinal scales (e.g. 0–5 foraminal stenosis severity, 0–4 osteophyte severity, presence/absence and thickness of OPLL per level)[5,12–14] would be preferable in diagnostic-accuracy work and are recommended for the next phase of investigation.

2.6. Observer procedure

All images were reviewed by a single senior consultant radiologist with more than 10 years' experience in spine MRI interpretation. The observer scored each modality in separate reading sessions with a two-week washout between sessions to minimize recall bias. The observer was blinded to (i) any prior or concurrent scores on the other modalities for the same patient and (ii) clinical details beyond the imaging indication. Case order was randomized within each modality session. DICOM headers were anonymized before review. A single-observer design was chosen to obtain a uniform, consistent assessment across a large consecutive cohort; the resulting absence of inter-observer reliability data is acknowledged as a limitation (see Discussion).

2.7. Sample size and statistical analysis

The sample size was determined by clinical feasibility over the study period, with the intent of capturing a broad spectrum of spinal pathology including rare entities such as OPLL and LFO. Descriptive statistics are presented as mean ± SD and median (IQR) for continuous variables and as frequency (%) for categorical variables. Because each patient contributed one score per modality from the same observer, modality comparison was performed within subjects. Paired ordinal visualization scores were compared across the three modalities per pathology with Friedman's test, with post-hoc Wilcoxon signed-rank tests (Holm-corrected). Effect sizes were reported as Kendall's W for omnibus tests and Cliff's δ for pairwise comparisons. Two-sided $p < 0.05$ was considered significant. Analyses were performed in SPSS v21 (IBM

Table 2
Image quality scores (mean ± SD) assigned by the single consultant radiologist for each pathology across imaging modalities. Scores range from 1 (poor) to 3 (excellent). For ligamentum flavum ossification, CT served as confirmatory bone reference; a dash (–) indicates the modality was not applicable for that pathology.

Pathology	n	Radiograph	CT	Routine MRI	BTFE
Disc osteophyte complex	229	1.54 ± 0.49	–	1.52 ± 0.50	3.00 ± 0.00
OPLL	3	–	–	1.00 ± 0.00	3.00 ± 0.00
LFO	4	–	3.00 ± 0.00	1.00 ± 0.00	2.00 ± 0.00
Spondylolisthesis	21	1.90 ± 0.54	–	2.28 ± 0.46	2.90 ± 0.30
Spondylolysis	27	1.77 ± 0.42	–	2.18 ± 0.39	3.00 ± 0.00
Vertebral fracture	6	1.17 ± 0.37	–	1.83 ± 0.40	3.00 ± 0.00

Table 3
Image quality grading scale used by the observer for all modalities.

Grade	Visibility of bony structures	Clarity	Diagnostic reliability
1 – Poor	Barely discernible	Significant blurring and noise; cortical and trabecular detail indistinguishable	Insufficient for diagnostic purposes
2 – Acceptable	Generally visible, identifiable	Some blurring; cortical and trabecular detail reasonably clear but may lack sharpness	Suitable for basic diagnostic purposes
3 – Excellent	Highly visible, well defined	No blurring; cortical and trabecular detail sharply delineated	Suitable for all diagnostic purposes

Corp, Armonk, NY) and R v4.3 (`coin` package for exact Wilcoxon tests). Assessment of inter-observer reliability (weighted Cohen's κ or intraclass correlation) was not possible with a single observer and is planned for a subsequent multi-reader study.

2.8. Ethical approval

The study was approved by the Institutional Ethics Committee (approval number ECR/34/Inst/KA/2013/RR-19) prior to commencement. Written informed consent was obtained from all participants in accordance with the Declaration of Helsinki.

3. Results

3.1. Cohort characteristics

A total of 526 patients were included over the study period (Supplementary Figure S3, patient flow diagram). The cohort comprised 297 females (56.5%) and 229 males (43.5%), with a mean age of 60.2 ± 11.8 years. Thoraco-lumbar scans accounted for 454 cases (86.3%) and cervical scans for 72 cases (13.7%). The prevalence of each osseous pathology is summarized in Table 1.

3.2. Image quality scores by modality and pathology

Average observer quality scores by modality are summarized in Table 2.

Disc osteophyte complex. Disc osteophyte complex, present in 229 patients (43.5%), was the most common osseous pathology in the cohort (Fig. 1). Quality scores were comparable on plain radiographs (mean 1.54, SD 0.49) and routine MRI (mean 1.52, SD 0.50), whereas BTFE achieved significantly higher scores (mean 3.00, SD 0.00; Friedman $p < 0.001$; post-hoc BTFE vs. routine MRI $p < 0.001$; BTFE vs. radiograph $p < 0.001$). The SD = 0 reflects that the observer graded every disc osteophyte case as grade 3 (excellent) on BTFE, consistent with a ceiling effect of the 3-point scale.

Ossification of the posterior longitudinal ligament. Three patients demonstrated cervical OPLL (Fig. 2). None were visible on plain radiographs, consistent with the limited sensitivity of radiography for posterior longitudinal ligament ossification.[7,13] All three were detected on routine MRI (mean 1.00, SD 0.00). On BTFE, all three were clearly delineated with improved depiction of extent and thickness (mean 3.00, SD 0.00).

Ligamentum flavum ossification. Four patients demonstrated LFO (Fig. 3). In this subgroup, thin-section CT served as a confirmatory bone reference. BTFE meaningfully improved visualization over routine MRI (mean 2.00 vs. 1.00, SD 0.00 for both), representing a radiation-free step forward over the current standard MRI workflow for this pathology. As expected for fine cortical ossification, thin-section CT provided superior delineation (mean 3.00, SD 0.00); this reflects the established role of CT for definitive cortical characterization rather than a limitation of BTFE, which remains the only radiation-free modality to improve on routine MRI in this subgroup.

Spondylolisthesis. Spondylolisthesis was identified in 21 patients (4.0%; Fig. 4). BTFE provided the highest visualization score (mean 2.90, SD 0.30), compared with routine MRI (mean 2.28, SD 0.46) and plain radiographs (mean 1.90, SD 0.54; Friedman $p < 0.001$).

Spondylolysis. Spondylolysis was identified in 27 patients (5.1%; Fig. 4). Visualization was best on BTFE (mean 3.00, SD 0.00), intermediate on routine MRI (mean 2.18, SD 0.39) and lowest on plain radiographs (mean 1.77, SD 0.42; Friedman $p < 0.001$). This finding extends the growing literature on MR-based bone imaging of adolescent and adult pars defects.[9,26–29]

Vertebral fracture. Six patients had vertebral fractures (1.1%; Fig. 5). BTFE provided the clearest depiction of the fracture line (mean 3.00, SD 0.00), routine MRI typically showed cortical break and marrow oedema with moderate clarity (mean 1.83, SD 0.40), and plain radiographs were least informative (mean 1.17, SD 0.37).

3.3. Additional observations

Vacuum disc sign on radiographs was observed in 20 patients (3.8%) and intradiscal hyperintensity on T2-weighted MRI in 48 patients (9.1%). Formal evaluation of BTFE performance for these findings is beyond the scope of the present analysis.

Fig. 1. 64-year-old male with degenerative disc disease of the lumbar and cervical spine and canal stenosis. **(A)** Lateral lumbar radiograph showing lumbar spondylosis with poorly visualized posterior osteophytes. **(B)** Sagittal T2-weighted MRI at the same level showing no discernible osteophytes. **(C)** Sagittal BTFE of the lumbar spine showing well delineated posterior osteophytes at L4–L5 and L5–S1 (arrow). **(D)** Lateral cervical radiograph showing cervical spondylosis with multilevel anterior marginal osteophytes. **(E)** Sagittal T2-weighted MRI showing multilevel marginal osteophytes and disc osteophyte complexes. **(F)** Sagittal BTFE showing a posterior disc osteophyte complex at C6–C7 (arrow).

4. Discussion

In this prospective study of 526 consecutive patients, adding a BTFE sequence to routine 3T spine MRI consistently improved the visualization quality of osseous pathologies – including disc osteophyte complex, spondylolisthesis, spondylolysis, vertebral fractures, OPLL and LFO – as judged by a single experienced consultant radiologist. The principal clinical implication is that BTFE, a bSSFP variant already available on most commercial 3T MRI platforms, can serve as a practical, radiation-free adjunct for bone-oriented assessment of the spine in preoperative settings. We interpret this finding cautiously: BTFE adds visualization value relative to conventional MRI and radiographs, but the present study was not designed to establish BTFE as a CT substitute and the findings have not yet been shown to be reproducible across observers.

4.1. Where BTFE fits within the CT-like MRI landscape

The current literature supports three graded claims about MRI as a radiation-free alternative to CT for spinal bone assessment. First, *well-supported*: when a dedicated CT-like MRI sequence or synthetic-CT workflow is added to routine MRI, diagnostic confidence and agreement with CT improve substantially for cervical foraminal stenosis,[5,6,14,32] OPLL,[7,13,23,24] vertebral fractures,[10,12] lumbar facet

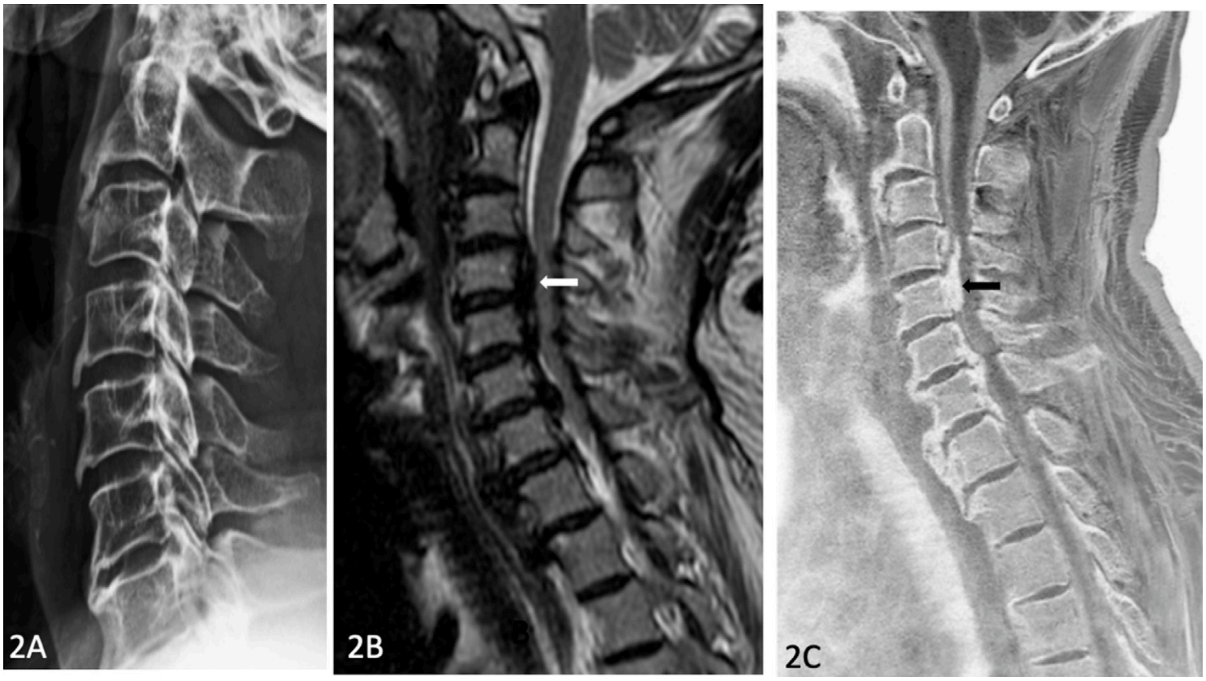

Fig. 2. 72-year-old male with cervical OPLL and compressive myelopathy. **(A)** Lateral cervical radiograph – no evidence of ossified posterior longitudinal ligament. **(B)** Sagittal T2-weighted MRI showing OPLL and multiple osteophytes (arrow). **(C)** Sagittal BTFE showing the OPLL with sharper delineation of extent and thickness (arrow).

and transitional anatomy,[25] and pars defects.[9,26–29] Synthetic-CT derivatives have additionally shown noninferior geometric and navigation accuracy for pedicle-screw planning in the lumbar and cervical spine.[17,18,20–22] Second, *partly supported*: routine MRI alone is typically insufficient for reliable assessment of calcified or cortical lesions, and the incremental value of a bone-oriented sequence over routine MRI is consistent across reader studies.[6,12–14,24,32] Third, *not yet well supported*: classic bSSFP by itself has not been shown across the spine literature to replace CT for the full range of preoperative bone tasks; older steady-state studies support anatomical and foraminal depiction[30,31] rather than replacement of CT for cortical bone, sclerosis, facet morphology, calcified disc, OPLL or vertebral fracture. We therefore position BTFE, for now, as a candidate bone-imaging sequence whose place alongside ZTE, FRACTURE, 3D FLASH, T1-spoiled gradient-echo and synthetic CT is for future comparative studies to decide, not a substitute for CT.

4.2. Why evaluate BTFE when other CT-like MRI methods exist?

The principal rationale is accessibility. ZTE, FRACTURE, 3D FLASH and deep-learning synthetic CT, despite compelling evidence, are to date restricted to specific vendors, research licences or bespoke post-processing pipelines and are not available on most community and mid-sized hospital 3T platforms.[5,13,14,18–20] bSSFP, in contrast, is installed by default on GE (BTFE/FIESTA), Siemens (TrueFISP) and Philips (Balanced-FFE) systems and adds a few seconds of acquisition to a routine exam. A positive signal from BTFE in a large prospective cohort therefore has immediate translational value for centres that cannot deploy vendor-specific CT-like MRI packages, while leaving open the question of how BTFE performs relative to those packages head-to-head.

4.3. Comparison with ZTE and other CT-like studies

Two recent studies are particularly relevant. Tran and colleagues, in 42 cervical degenerative disease patients, reported that ZTE improved detection of bone involvement in neural foraminal narrowing (47%) and canal stenosis (25%) and increased reader confidence, though without improved OPLL detection over routine MRI.[6] Caffard and colleagues showed that post-processed ZTE could confirm suspected OPLL identified on routine MRI, supporting CT-avoidance workflows.[33] The prospective cervical FRACTURE study by Wang and colleagues demonstrated noninferiority to CT for osteophytes, bony foraminal stenosis and OPLL with better confidence and reliability than routine MRI.[14] For OPLL specifically, the 3D FLASH add-on study of Kim and colleagues improved detection and inter-observer agreement, with the greatest gains for thin lesions.[13] Our OPLL findings, though based on only three patients, are qualitatively concordant with these reports: routine MRI showed the lesion, but BTFE sharpened delineation of extent and thickness. The broader message is that bone-oriented MRI sequences meaningfully narrow the gap between routine MRI and CT, and BTFE contributes to this trend on widely available platforms.

4.4. Clinical relevance for preoperative planning

Accurate characterization of calcified and ossified lesions before spine surgery has direct implications for operative planning and patient safety. Calcified disc herniations, OPLL and LFO can adhere to the dura, complicate neural decompression and increase the risk of dural tears, cerebrospinal-fluid leak and intraoperative neurological injury.[34–38] For the spondylolysis subgroup, MR-based bone imaging has matched CT in adolescent and pediatric cohorts,[9,26–29] and our data extend this signal to a predominantly adult population. Preoperative recognition of these features allows the surgeon to select an appropriate approach, anticipate microscopic dissection, and counsel the patient regarding risk. A bone-oriented MRI sequence that can be added to the routine MRI examination consolidates this workflow and removes the radiation exposure associated with CT.

4.5. Strengths

Strengths include the prospective design, a large consecutive cohort spanning a clinically representative spectrum of spine pathology, within-subject modality comparison (each patient acting as their own control across radiograph, routine MRI and BTFE), blinded separate

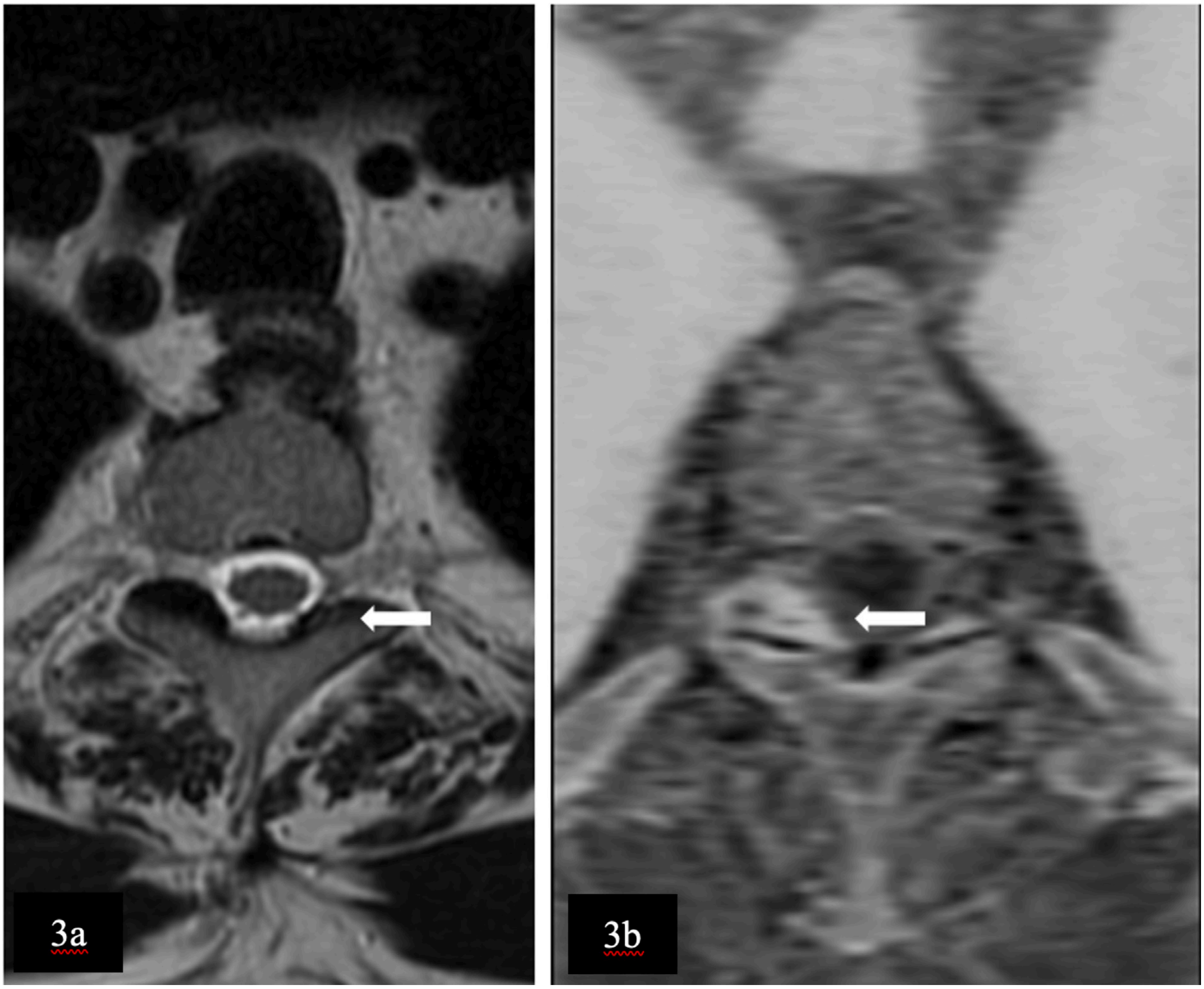

Fig. 3. 53-year-old female with degenerative disc disease of the lumbar spine and lumbar canal stenosis. **(A)** Axial T2-weighted MRI with poorly visualized ligamentum flavum ossification. **(B)** Axial BTFE reformat at the same level showing bilateral ligamentum flavum ossification.

reading sessions with a two-week washout and randomized case order, and the use of a single experienced senior radiologist to ensure a uniform and consistent standard of interpretation across the cohort. The cohort size is one of the largest reported for any bone-oriented MRI sequence in the spine to date.

4.6. Limitations

Several limitations must be acknowledged. *First and most important*, all images were scored by a single experienced observer; we therefore cannot report inter-observer reliability and cannot demonstrate that the visualization advantage of BTFE is robust across radiologists of differing experience or across disciplines (spine surgery, neuroradiology). Recent prospective CT-like MRI studies have used two to three independent readers with site- and level-based scoring and weighted-κ/ICC analyses,[5,12–14,32] and replication of our findings in such a multi-reader design is an immediate next step. *Second*, CT was used as a confirmatory reference only for the small LFO subgroup; for the remaining pathologies no bone reference standard was available, so our findings speak to visualization quality rather than to formal sensitivity and specificity against a reference standard. *Third*, the 3-point ordinal quality scale was intentionally simple and clinically intuitive, but its limited range produced a ceiling effect (SD = 0) for several pathologies on BTFE; structure-specific ordinal scales (e.g. 0–5 foraminal stenosis, 0–4 osteophyte severity, presence and thickness of OPLL per level), a reader-confidence rating, and objective quantitative metrics such as the OPLL lesion-quality ratio[24] or measurements of lesion thickness, foraminal diameter and pedicle width should be used in subsequent work.[5,12–14] *Fourth*, we did not directly compare BTFE with other CT-like MRI sequences (ZTE, UTE, FRACTURE, 3D FLASH, T1-spoiled gradient-echo, synthetic CT); head-to-head prospective comparisons are required to position BTFE within this family of sequences.[12–14,20,21] *Fifth*, the very low prevalence of some clinically important pathologies (OPLL $n = 3$, LFO $n = 4$, fractures $n = 6$) limits the inferences that can be drawn for these subgroups, which should be regarded as descriptive. *Sixth*, the study was based at a single centre and on a single 3T Philips platform; generalizability to other vendors (Siemens, GE, Canon) and to 1.5T systems warrants further study. *Seventh*, we did not capture surgical-outcome correlation, a change-in-management endpoint (as recommended for CT-like MRI studies),[14,32] or patient-level radiation-dose savings; these remain fruitful directions for further protocol development.

4.7. Directions for future work

The most immediate next step is a multi-reader replication of the present findings, using two to three independent observers with complementary training (e.g. senior neuroradiologist, junior radiologist, spine surgeon), blinded independent reads with washout, and weighted-κ/ICC analyses against a CT reference where available, following the designs used in contemporary CT-like MRI reader studies.[5,12–14,32] A parallel priority is a prospective head-to-head study of

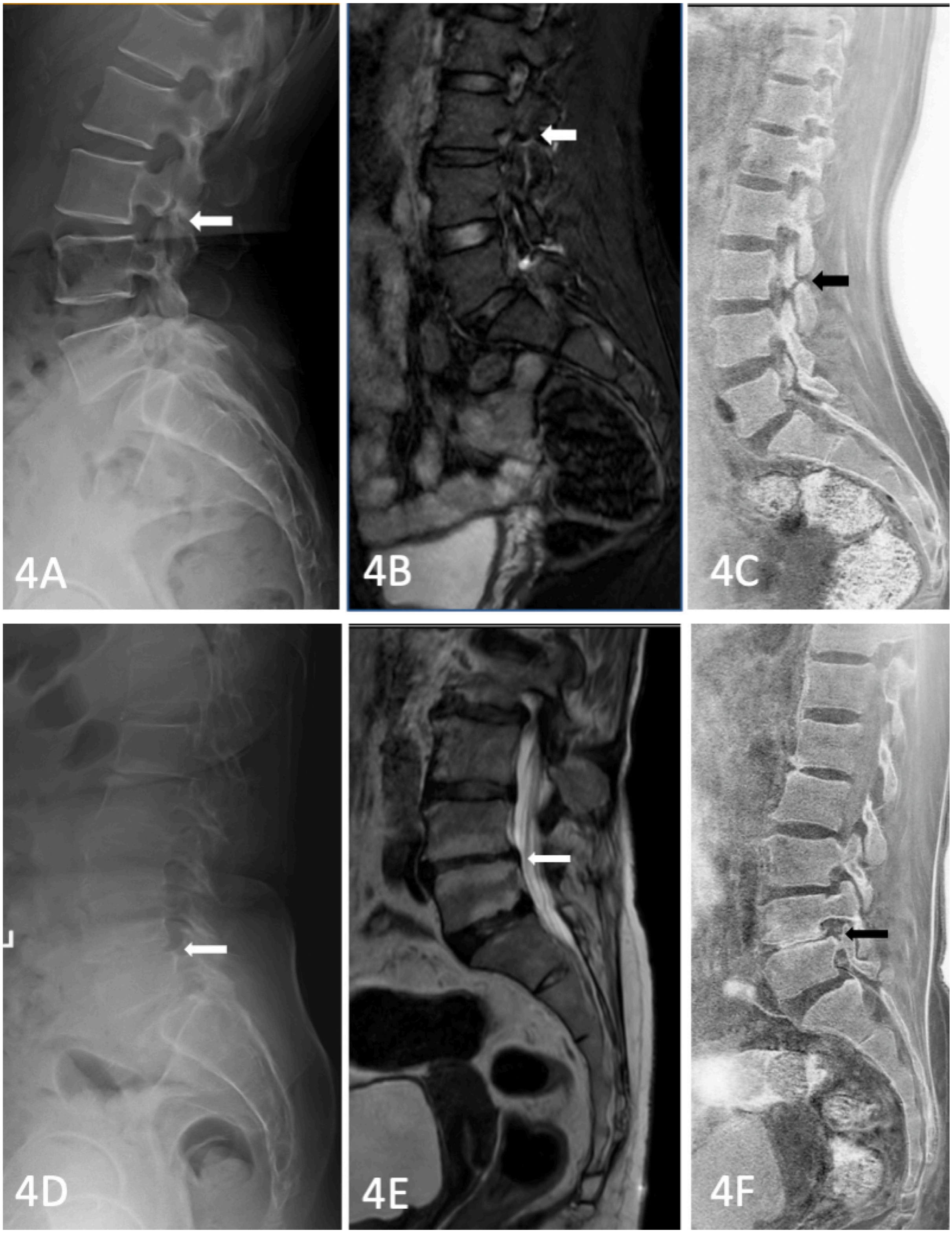

Fig. 4. **(A)** Lateral lumbar radiograph showing spondylolysis at L3. **(B)** Sagittal T2-weighted MRI of the same patient. **(C)** Sagittal BTFE showing the pars defect with improved delineation (arrow). **(D)** Lateral lumbar radiograph showing L4–L5 Grade I spondylolisthesis. **(E)** Sagittal T2-weighted MRI of the same patient. **(F)** Sagittal BTFE showing Grade I L4–L5 spondylolisthesis with improved depiction of the bony endplates and pars (arrow).

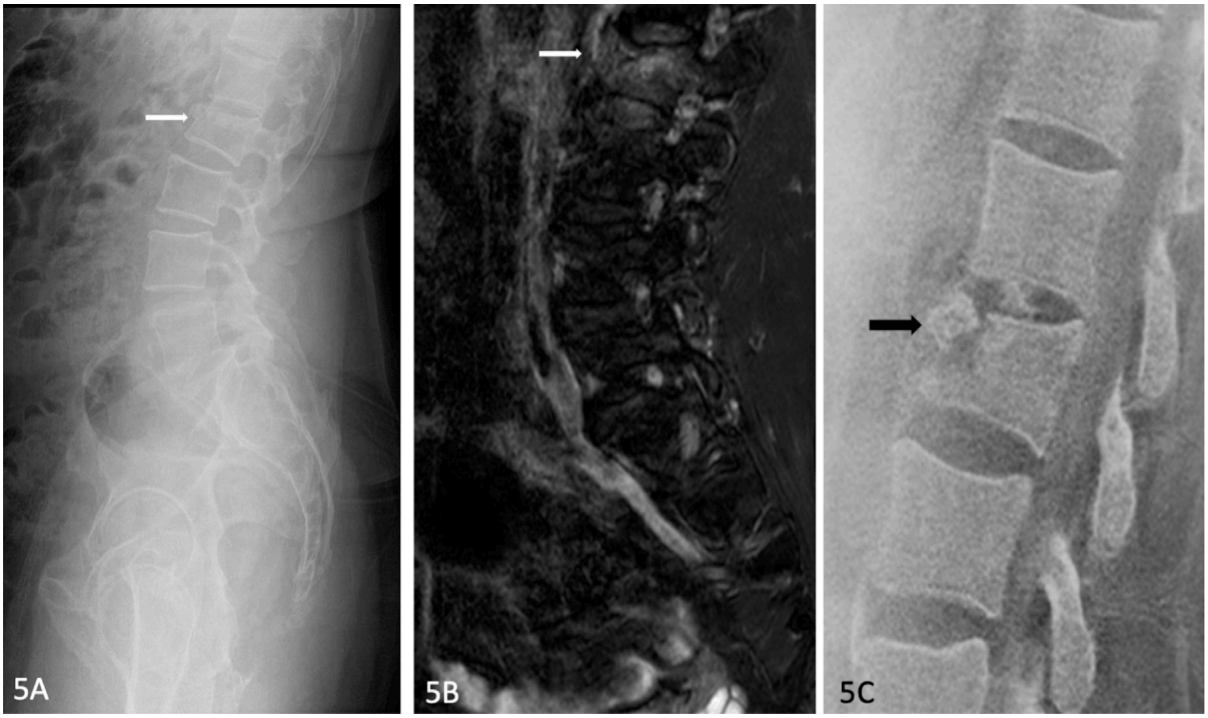

Fig. 5. 45-year-old male with traumatic fracture of the L2 vertebral body. **(A)** Lateral lumbar radiograph showing the L2 vertebral body fracture. **(B)** Sagittal T2-weighted MRI showing cortical break and bone oedema. **(C)** Sagittal BTFE showing a wedge compression fracture of the L2 vertebral body, with the fracture line through the antero-superior corner better visualized (arrow).

BTFE against CT in patients with suspected OPLL or LFO, with a finer-grained, structure-specific image-quality scale, per-level and per-side assessment of cortical margins, osteophyte size, foraminal diameter and OPLL thickness, and objective quantitative lesion metrics modelled on the cervical OPLL lesion-quality score.[24] A third priority is a multi-arm comparison of routine MRI, BTFE and one established CT-like MRI sequence (ZTE, FRACTURE, 3D FLASH, T1-spoiled gradient-echo or AI-generated synthetic CT) against CT as the reference.[5,12–14] Multi-centre, multi-vendor validation and translation to 1.5T platforms will further clarify whether BTFE can be adopted as a routine radiation-free bone-imaging adjunct.

5. Conclusions

In a large prospective cohort of 526 consecutive spine MRI studies assessed by a single experienced senior consultant radiologist, adding a Balanced Turbo Field Echo sequence consistently improved visualization of spinal osseous pathologies – including disc osteophyte complex, spondylolisthesis, spondylolysis, vertebral fractures, OPLL and LFO – compared with routine T1/T2-weighted MRI and plain radiographs. Because BTFE is already installed on virtually every commercial 3T MRI platform, it represents a practical, radiation-free adjunct for bone-oriented spine imaging. BTFE should, however, be regarded as a candidate bone-imaging sequence rather than a validated CT substitute: multi-reader replication studies, prospective head-to-head studies against CT, and head-to-head comparisons against established CT-like MRI sequences (ZTE, FRACTURE, 3D FLASH, T1-spoiled gradient-echo, synthetic CT) – using structure-specific ordinal scales, objective quantitative metrics and weighted-κ/ICC analyses – are the necessary next steps.

CRediT authorship contribution statement

Abhishek Soni: Conceptualization, Methodology, Investigation, Writing – original draft. **Akhil Xavier Joseph:** Data curation, Investigation, Writing – review & editing. **Vidyadhara S.:** Conceptualization, Supervision, Project administration, Writing – review & editing. **Balamurugan T.:** Investigation, Writing – review & editing. **Ullas V. Acharya:** Methodology, Formal analysis, Writing – review & editing. **Sharath K. Rao:** Supervision, Validation, Writing – review & editing.

Patient/guardian consent statement

Written informed consent was obtained from all participants prior to study enrolment, in accor- dance with the ethical principles of the Declaration of Helsinki. Patient data were anonymized before imaging review. The privacy rights of all participants have been observed throughout.

Ethical statement

This prospective observational study was approved by the Institutional Ethics Committee of Manipal Hospital, Bangalore, India (Approval number: ECR/34/Inst/KA/2013/RR-19). The study was conducted in accordance with the ethical principles of the Declaration of Helsinki and all applicable institutional guidelines.

Written informed consent was obtained from all participants prior to enrolment. Patient data were anonymized before imaging review. No patient identifiers are included in this manuscript.

Funding statement

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Declaration of competing interest

All authors declare that they have no conflicts of interest relevant to this manuscript. None of the authors have received honoraria, consultancy fees, research funding, or any other financial or non-financial support from any commercial entity that could be construed as a conflict of interest with respect to the findings reported in this work.

Acknowledgements

The authors have no acknowledgements to declare.

Appendix A. Supplementary data

Supplementary material related to this article can be found online at https://doi.org/10.1016/j.jor.2026.05.014.

Data availability

The data that support the findings of this study are available from the corresponding author upon reasonable request.

References

1. Ruiz Santiago F, Láinez Ramos-Bossini AJ, Wáng YXJ, López Zúñiga D. The value of magnetic resonance imaging and computed tomography in the study of spinal disorders. *Quant Imaging Med Surg*. 2022;12(7):3947–3986.
2. Modic MT, Ross JS. Lumbar degenerative disk disease. *Radiology*. 2007;245(1):43–61.
3. Florkow M, Willemsen K, Mascarenhas V, Oei E, Stralen Mv, Seevinck P. Magnetic resonance imaging versus computed tomography for three-dimensional bone imaging of musculoskeletal pathologies: a review. *J Magn Reson Imaging*. 2022;56:11–34.
4. Chong L, Lee K, Sim FY. 3D MRI with CT-like bone contrast - An overview of current approaches and practical clinical implementation.. *Eur J Radiol*. 2021;143:109915.
5. Argentieri E, Koff M, Breighner RE, Endo Y, Shah P, Sneag D. Diagnostic accuracy of zero-echo time MRI for the evaluation of cervical neural foraminal stenosis. *SPINE*. 2017;43:928–933.
6. Tran C, Yang HR, Ahmad ZY, et al. Utility of zero-echo time sequence as an adjunct for MR evaluation of degenerative disease in the cervical spine. *Skelet Radiol*. 2023;53:899–908.
7. Ma Y, Chang E. Ossification of the posterior longitudinal ligament on zero echo time MRI with "CT-like" contrast.. *AJR Am J Roentgenol*. 2021.
8. Hou B, Liu C, Li Y, et al. Evaluation of the degenerative lumbar osseous morphology using zero echo time magnetic resonance imaging (ZTE-MRI). *Eur Spine J*. 2022:1–9.
9. Finkenstaedt T, Siriwanarangsun P, Achar S, et al. Ultrashort time-to-echo magnetic resonance imaging at 3 T for the detection of spondylolysis in cadaveric spines: comparison with CT. *Invest Radiol*. 2019;54:32–38.
10. Feuerriegel G, Kronthaler S, Boehm C, et al. Diagnostic value of water-fat-separated images and CT-like susceptibility-weighted images extracted from a single ultrashort echo time sequence for the evaluation of vertebral fractures and degenerative changes of the spine. *Eur Radiol*. 2022;33:1445–1455.
11. Afsahi A, Lombardi A, Wei Z, et al. High-contrast lumbar spinal bone imaging using a 3D slab-selective UTE sequence. *Front Endocrinol*. 2022;12.
12. Schwaiger B, Schneider C, Kronthaler S, et al. CT-like images based on T1 spoiled gradient-echo and ultra-short echo time MRI sequences for the assessment of vertebral fractures and degenerative bone changes of the spine. *Eur Radiol*. 2021;31:4680–4689.
13. Kim S, Lee GY, Chung BM. CT-like image based on 3D fast low-angle shot: Superior diagnostic performance of ossification of the posterior longitudinal ligament. *Skelet Radiol*. 2025;54:1905–1913.
14. Wang Q, Xing X-y, Zhang Z, et al. Added value of 3D fast-field-echo (FRACTURE) sequences for cervical spondylosis diagnosis: A prospective multi-reader non-inferiority study. *Insights Into Imaging*. 2025;16.
15. Okazaki T, Doi K, Shibamoto K, et al. Zero-echo time (ZTE) and fast field echo resembling a CT using restricted echo-spacing (FRACTURE) on 3-T MRI for the cervical spine.. *J Med Investig : JMI*. 2025;72 3.4:266–271.
16. Manek H, Gala F. Comparing CT-like bone images based on fast field echo resembling a CT using restricted echo spacing (FRACTURE) MR with CT in pediatric congenital vertebral anomalies. *Am J Neuroradiol*. 2024;46:1471–1477.
17. Morbée L, Chen M, Herregods N, Pullens P, Jans L. MRI-based synthetic CT of the lumbar spine: Geometric measurements for surgery planning in comparison with CT. *Eur J Radiol*. 2021;144:109999.
18. Staartjes V, Seevinck P, Vandertop W, Stralen Mv, Schröder M. Magnetic resonance imaging-based synthetic computed tomography of the lumbar spine for surgical planning: A clinical proof-of-concept. *Neurosurg Focus*. 2021;50 1:E13.
19. Kolk BVDvd, Slotman DJ, Nijholt I, et al. Bone visualization of the cervical spine with deep learning-based synthetic CT compared to conventional CT: a single-center noninferiority study on image quality. *Eur J Radiol*. 2022;154:110414.
20. Lafranca P, Rommelspacher Y, Muijs S, et al. Safety and accuracy of cervical pedicle screw navigation using artificial intelligence-generated, MRI-based synthetic CT versus conventional CT. *J Neurosurg Spine*. 2025:1–7.
21. Lafranca P, Rommelspacher Y, Walter SG, et al. The safety and accuracy of radiation-free spinal navigation using a short, scoliosis-specific BoneMRI-protocol, compared to CT. *Eur Spine J*. 2025;35:298–304.
22. Altorfer MFCS, Burkhard MMD, Kelly MMJ, et al. Robot-assisted lumbar pedicle screw placement based on 3D magnetic resonance imaging. *Glob Spine J*. 2024;15:1243–1250.
23. Lee S-Y, Shin Y, Park H, Rho M, Chung E. Usefulness of multiecho fast field echo MRI in the evaluation of ossification of the posterior longitudinal ligament and dural ossification of the cervical spine. *PLoS One*. 2017;12.
24. Hsung W, Lin H-Y, Lin H-H, Yao Y-C, Wang S-T, Chang M-C, Chou P-H. MRI-based lesion quality score assessing ossification of the posterior longitudinal ligament of the cervical spine.. *Spine J : Off J North Am Spine Soc*. 2024.
25. Kaniewska M, Kuhn DM, Deininger-Czermak E, Wolharn L, Finkenstaedt T, Guggenberger R. 3D zero-echo time and 3D T1-weighted gradient-echo MRI sequences as an alternative to CT for the evaluation of the lumbar facet joints and lumbosacral transitional vertebrae. *Acta Radiol*. 2023;64:2137–2144.
26. Altorfer F, Yan JJ, Abel F, et al. Lumbar spine bone MRI: a radiation-free approach utilizing CT-like imaging for diagnosing pars defects in the adolescent spine. *Am J Neuroradiol*. 2025;46:2195–2199.
27. Kinoshita Y, Sakai T, Sugiura K, et al. Can MRI replace CT in the diagnosis and staging of lumbar spondylolysis in pediatric patients? a validation study using MR bone imaging.. *J Pediatr Orthop*. 2025.
28. Okuyama K, Aoki Y, Matushita Y, et al. Evaluation of fracture lines in adolescent lumbar spondylolysis using MR bone imaging as an alternative to computed tomography. *Eur Spine J*. 2025;34:1971–1976.
29. Kitakado A, Fukuda T, Kobayashi J, Ojiri H. Diagnostic utility of double-echo steady-state (DESS) MRI for fracture and bone marrow edema detection in adolescent lumbar spondylolysis. *Diagnostics*. 2023;13.
30. Baskaran V, Pereles F, Russell E, et al. Myelographic MR imaging of the cervical spine with a 3D true fast imaging with steady-state precession technique: Initial experience.. *Radiology*. 2003;227 2:585–592.
31. Nemoto O, Fujikawa A, Tachibana A. Three-dimensional fast imaging employing steady-state acquisition MRI and its diagnostic value for lumbar foraminal stenosis. *Eur J Orthop Surg Traumatol*. 2014;24:209–214.
32. Deininger-Czermak E, Gascho D, Franckenberg S, et al. Added value of ultra-short echo time and fast field echo using restricted echo-spacing MR imaging in the assessment of the osseous cervical spine. *La Radiol Medica*. 2023;128:234–241.
33. Caffard T, et al. Diagnosis and evaluation of cervical ossification of the posterior longitudinal ligament with zero-echo time MRI. *Glob Spine J*. 2024. Online ahead of print. emphPlease verify volume / pages before submission..
34. Epstein NE. The surgical management of ossification of the posterior longitudinal ligament in 43 North Americans. *Spine*. 1998;23(17):1924–1930.
35. Hirabayashi S. Ossification of the posterior longitudinal ligament of the cervical spine: surgical strategy and clinical outcomes. *Asian Spine J*. 2018;12(4):713–726.
36. An HS, Al-Shihabi L, Kurd M. Surgical treatment for ossification of the posterior longitudinal ligament in the cervical spine. *J Am Acad Orthop Surg*. 2014;22(7):420–429.
37. Kumar N, et al. Surgical techniques and perioperative considerations for thoracic ossification of the ligamentum flavum. *Glob Spine J*. 2024. emphPlease verify volume / pages before submission..
38. Haleem A, et al. Calcified thoracic disc herniation: surgical outcomes and lessons learnt. *Eur Spine J*. 2024. emphPlease verify volume / pages before submission..