[Imaging]

Confidence in Assessment of Lumbar Spondylolysis Using Three-Dimensional Volumetric T2-Weighted MRI Compared With Limited Field of View, Decreased-Dose CT

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Background: Limited *z*-axis–coverage computed tomography (CT) to evaluate for pediatric lumbar spondylolysis, altering the technique such that the dose to the patient is comparable or lower than radiographs, is currently used at our institution. The objective of the study was to determine whether volumetric 3-dimensional fast spin echo magnetic resonance imaging (3D MRI) can provide equal or greater diagnostic accuracy compared with limited CT in the diagnosis of pediatric lumbar spondylolysis without ionizing radiation.

Hypothesis: Volumetric 3D MRI can provide equal or greater diagnostic accuracy compared with low-dose CT for pediatric lumbar spondylolysis without ionizing radiation.

Study Design: Clinical review.

Level of Evidence: Level 2.

Methods: Three pediatric neuroradiologists evaluated 2-dimensional (2D) MRI, 2D + 3D MRI, and limited CT examinations in 42 pediatric patients who obtained imaging for low back pain and suspected spondylolysis. As there is no gold standard for the diagnosis of spondylolysis besides surgery, interobserver agreement and degree of confidence were compared to determine which modality is preferable.

Results: Decreased-dose CT provided a greater level of agreement than 2D MRI and 2D + 3D MRI. The kappa for rater agreement with 2D MRI, 2D + 3D MRI, and CT was 0.19, 0.32, and 1.0, respectively. All raters agreed in 31%, 40%, and 100% of cases with 2D MRI, 2D + 3D MRI, and CT. Lack of confidence was significantly lower with CT (0%) than with 2D MRI (30%) and 2D + 3D MRI (25%).

Conclusion: For diagnosing spondylolysis, radiologist agreement and confidence trended toward improvement with the addition of a volumetric 3D MRI sequence to standard 2D MRI sequences compared with 2D MRI alone; however, agreement and confidence remain significantly greater using decreased-dose CT when compared with either MRI acquisition.

Clinical Relevance: Decreased-dose CT of the lumbar spine remains the optimal examination to confirm a high suspicion of spondylolysis, with dose essentially equivalent to radiographs. If clinical symptoms are not classic for spondylolysis, 2D MRI is still very good at detecting spondylolysis while remaining sensitive for detection of alternative diagnoses such as disc abnormalities and pars stress reaction. The data suggest that standard 2D MRI sequences should not be entirely replaced by a volumetric T2-weighted 3D sequence (despite promising features of rapid acquisition time, increased spatial resolution, and reconstruction capability).

Keywords: spondylolysis; volumetric; 3D MRI; 2D MRI; CT

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Lumbar spondylolysis, a unilateral or bilateral stress fracture of the pars interarticularis, is a frequent cause of low back pain in adolescent and preadolescent patients.[16] The pars interarticularis is the junction of the pedicle, articular facets, and lamina. Lumbar spondylolysis may be congenital or posttraumatic in etiology. However, the most likely etiology is multifactorial. Spondylolysis occurs most frequently at the L5 level[10] and can progress to spondylolisthesis, which occurs when 1 vertebral body subluxes anteriorly in relation to the more caudal vertebrae. Progression to spondylolisthesis occurs more often in adolescence with a decreased incidence as the patient ages.[6]

Diagnosis of lumbar spondylolysis has traditionally utilized lumbar spine radiographs, with the lateral oblique and coned down lateral views thought to be most helpful.[1] However, spondylolysis can be difficult to diagnose on radiographs, requiring further imaging.[7,11] Limited field of view computed tomography (CT), altering the technique such that the dose to the patient is equal to or less than radiographs,[4] is currently used at our institution. Conventional 2-dimensional fast spin echo magnetic resonance imaging (2D MRI) has no ionizing radiation and provides complementary information to CT such as the presence of reactive marrow edema yet is less specific than CT in diagnosing spondylolysis. Three-dimensional fast spin echo T2 MRI (3D MRI) provides the capability to acquire volumetric datasets that can be reformatted, with better spatial resolution and decreased scan time than conventional 2D MRI. This article summarizes our initial experience at a tertiary care children's hospital in determining whether volumetric 3D MRI can provide equal or greater diagnostic accuracy than decreased-dose CT in the diagnosis of pediatric lumbar spondylolysis without ionizing radiation.

METHODS

This project was reviewed by our institutional review board and received exempt status given its retrospective nature pertaining to both the CT and MRI components of the study.

As there is no gold standard confirmation for the diagnosis of spondylolysis besides surgery, interobserver agreement and degree of confidence were utilized to determine which modality is preferable. Based on prereview of the MRI images and primary dictations before showing the unknowns to the 3 reviewers, the primary investigator (J.A.D.) recorded 13 cases of spondylolysis, 5 cases of possible spondylolysis, and 24 cases without spondylolysis (total, 42 MRI cases). Prereview of the CT images revealed 4 cases with spondylolysis and 9 cases without spondylolysis (total, 13 CT cases).

There were 2 cohorts for the study: MRI and CT. Inclusion criteria for the MRI cohort included patients with back pain and suspected spondylolysis without a history of prior spinal surgery and patients who were evaluated with both conventional 2D MRI sequences and volumetric 3D MRI sequences (during the same scan) obtained between January 2013 and September 2014, as ordered by an orthopaedic surgeon or sports medicine physician. Forty-five patients were identified who met the inclusion criteria, of whom 3 were excluded for age older than 18 years, leaving 42 patients ranging in age from 5 to 18 years.

Inclusion criteria for the CT cohort included patients with decreased-dose CT between December 2012 and April 2014 as ordered by an orthopaedic surgeon or sports medicine physician for patients in whom they had high clinical suspicion for spondylolysis. Sixteen patients were consequently evaluated by decreased-dose CT during this time, of whom 3 were excluded due to the presence of orthopaedic hardware, leaving 13 patients ranging in age from 11 to 18 years.

Both MRI and CT examinations were assessed anonymously in random order for the presence or absence of spondylolysis by 3 pediatric neuroradiologists with between 3 and 30 years of experience. For MRI, raters first evaluated the conventional 2D MRI sequences alone. Two weeks later, raters reevaluated the same cases using volumetric 3D sequences in addition to the original 2D sequences. The MRIs and CTs were evaluated for spondylolysis using a 5-point Likert-type scale with negative coded as 1, likely negative as 2, equivocal as 3, likely positive as 4, and positive as 5. Agreement was assessed between raters using a Fleiss kappa statistic for multiple raters on an ordinal scale.[5] Kappa classification for strength of agreement includes the following categories: poor, fair, moderate, good, and very good. Good agreement is generally accepted as $\kappa > 0.6$.[8]

Lack of confidence, defined as being scored as 2, 3, or 4, as well as a proportion of patients for whom all raters agreed were compared using an exact chi-square test.

Alternative diagnoses and additional findings were also tabulated in the MRI and CT cohorts regardless of the presence or absence of spondylolysis. Original radiologist MRI reports were also reviewed and tabulated as to whether additional imaging such as CT was recommended.

MRI Technique

All MRI examinations included axial and sagittal T1, axial and sagittal T2, a sagittal fluid-sensitive sequence (T2 fat-saturated and/or STIR), and a volumetric (3D) T2 sequence that could be easily reformatted into multiple planes at the workstation as needed. Images were acquired using a 1.5-T MR system (Philips Medical Systems) with a 3D T2-weighted non–fat-saturated acquisition (repetition time/echo time, 2000 ms/120 ms; flip angle, 15°; matrix, 162 × 144; section thickness, 1.25 mm; no gap; in-plane resolution, 1.25 × 1.39 mm; acquisition time, 4 minutes 22 seconds).

CT Technique

Decreased-dose CTs were performed on a Siemens Somatom 40 CT system, Siemens Biograph 40 PET-CT system (Siemens Healthcare), General Electric LightSpeed VCT (GE Healthcare), and Toshiba Aquilion Premium (Toshiba Healthcare). Studies were performed on varying CT systems as the examinations were frequently performed in conjunction with the patient's clinical evaluation, which occurred either at the main hospital

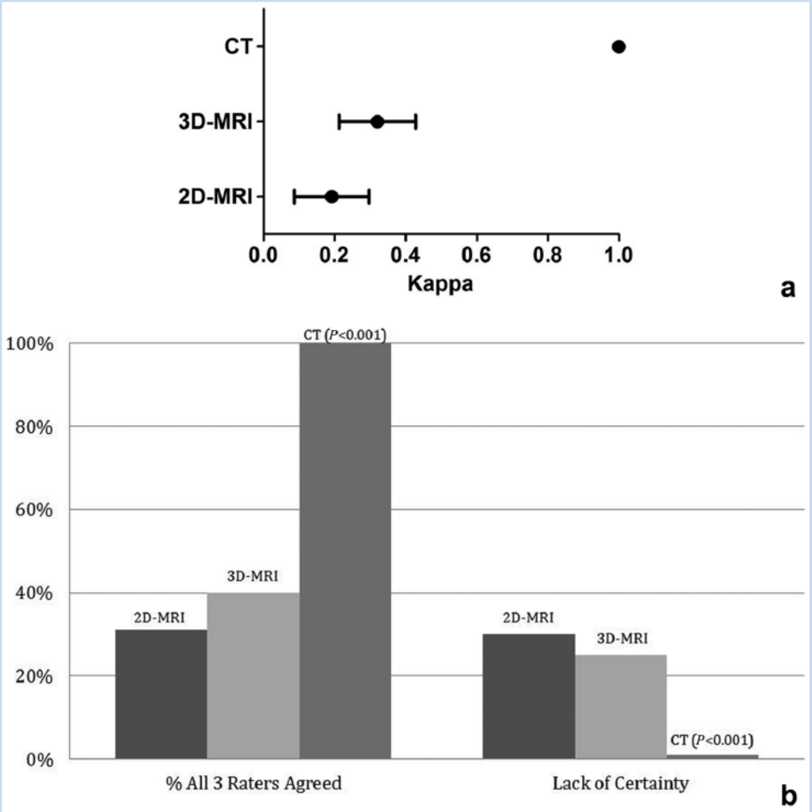

Figure 1. (a) Kappa values for computed tomography (CT) compared with magnetic resonance imaging (MRI). (b) Rater agreement and lack of certainty.

Table 1. Size-specific doses (mGy), effective dose estimates (mSv), and patient dimensions for limited field of view, decreased-dose CT

Age, y	kVp	CTDIvol, mGy	DLP, mGy-cm	AP and Lateral Dimension, cm	Effective Diameter, cm	Conversion Factor	SSDE, mGy	Effective Dose, mSv
14	100	2	33.1	17.6	22	1.65	3.30	0.50
16	100	1.2	24.3	14.4	17	1.98	2.38	0.36
13	100	0.4	7.7	14.6	18.3	1.89	0.76	0.12
12	100	0.4	8.7	15.2	18.3	1.89	0.76	0.13
17	100	2.71	54.38	37	31.7	1.16	3.14	0.82
14	100	1.03	16.82	17.6	22	1.65	1.70	0.25
12	100	1.03	16.36	22.9	18.7	1.86	1.92	0.25
13	80	2.06	41.33	14.4	17	1.98	4.08	0.62
14	100	0.74	10.23	15.6	19.6	1.81	1.34	0.15
11	100	1.49	19.86	14.2	17	1.98	2.95	0.30
16	100	0.91	15.78	16.6	20.8	1.73	1.57	0.24
15	100	0.94	14.51	19.2	23.2	1.58	1.49	0.22
18	80	1.95	38.91	18.8	23.2	1.58	3.08	0.58

AP, anteroposterior; CTDIvol, computed tomography dose index volume; DLP, dose length product; SSDE, size-specific dose estimate.

(Siemens systems) or 1 of 2 satellite centers (Toshiba or GE). On all systems, limited z-axis coverage CT from the inferior portion of L3 through S1 was utilized.

The CT protocols utilized ranges of 80 to 100 kVp, 50 to 99 mA·s, collimations of 0.5 to 0.625 mm, and pitch of 1.0 to 1.39. The effective dose data for the CT portions of the study were based on the standard methods for CT dose estimation, utilizing the system displayed volume Computed Tomography Dose Index (CTDIvol) and Dose Length Product (DLP). DLP to effective dose conversion factors was used from the 2008 American Association of Physicists in Medicine (AAPM) report No. 96,[14] with the methodology in the report initially proposed by the European Working Group for Guidelines on Quality Criteria in Computed Tomography.[3] A size-specific dose estimate (SSDE) was also calculated for each patient using the technique and conversion factors in the 2011 AAPM report No. 204.[12]

RESULTS

With 3 raters, 39 CT assessments were made in 13 patients, 126 2D MRI assessments in 42 patients, and 126 2D + 3D MRI assessments in 42 patients.

Decreased-dose CT provided a significantly greater level of agreement between raters than both 2D MRI ($P < 0.001$) and 2D + 3D MRI ($P < 0.001$). The overall kappa for rater agreement with 2D MRI, 2D + 3D-MRI, and CT was 0.19, 0.32, and 1.0, respectively (Figure 1a). Although adding a volumetric 3D MRI sequence to the standard 2D MRI sequences trended toward improving rater agreement, there was no statistical difference between 2D MRI and 2D + 3D MRI.

With CT, all 3 raters agreed on the presence or absence of spondylolysis in all 13 CT cases (100% of patients) compared with 2D MRI (13/42 or 31%, $P < 0.001$) and 2D + 3D MRI (17/42 or 40%, $P < 0.001$) (Figure 1b).

Lack of confidence, defined as scores of 2, 3, or 4, was significantly lower with CT at 0/39 (0%) than with 2D MRI (38/126, 30%) and 2D + 3D MRI (32/126, 25%) (Figure 1b). Although adding a volumetric 3D MRI sequence to the standard 2D MRI sequences trended toward improving lack of confidence, there was no statistical difference between 2D MRI and 2D + 3D MRI. All CT scores were either 1 (negative) or 5 (positive); none of the raters listed equivocal scores of 2, 3, or 4 with CT. Ratings for 2D MRI were listed as 2 (likely negative), 3 (equivocal), or 4 (likely positive) in 24 (19%), 5 (4%), and 9 (7%) assessments, respectively. Ratings for 2D + 3D MRI were listed as 2 (likely negative), 3 (equivocal), or 4 (likely positive) in 19 (15%), 3 (2%), and 10 (8%) assessments, respectively.

The effective dose data and size-specific dose estimates (SSDE) for the CT examinations are displayed in Table 1. The mean estimated effective dose from a single CT performed with this technique is 0.35 mSv (range, 0.12-0.82 mSv), which is less than the cumulative estimated effective dose associated with the popular combination of radiographs frequently utilized in the diagnosis of spondylolysis (mean, 0.74 mSv; range, 0.59-0.89 mSv). In comparison, a standard CT of the lumbar spine for an adolescent patient performed at our institution ranges from 7 to 17 mSv, depending on patient size.

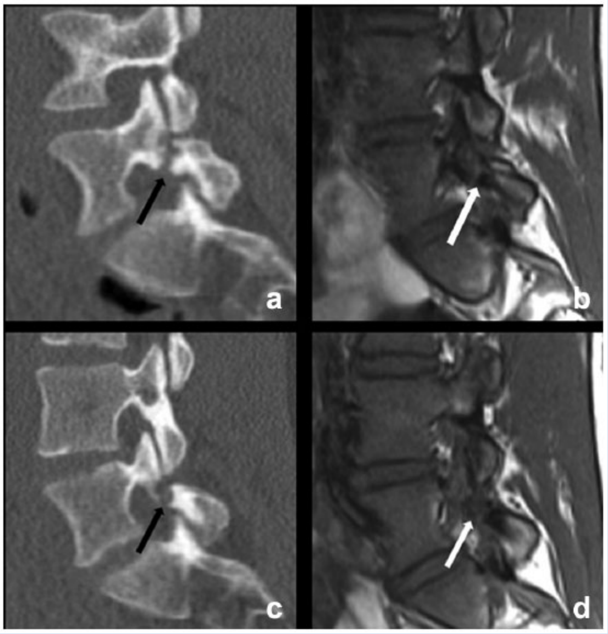

Figure 2. Bilateral L5 pars defects are more conspicuous on decreased-dose CT (a, c) compared with 2-dimensional (2D) MRI T1-weighted sequences (b, d). The conventional 2D MRI was obtained a few weeks before the CT, and only the left defect (d, white arrow) was initially detected on the sagittal T1-weighted sequence. (b) The right pars was called intact on MRI. CT clearly shows bilateral L5 defects (a, c, black arrows), and in hindsight, the right defect becomes more apparent on MRI (b, white arrow). CT, computed tomography; MRI, magnetic resonance imaging.

Alternative diagnoses were identified in 18 of 42 MRI cases and 0 of 13 CT cases. Alternative diagnoses included disc pathology (n = 10), pars stress reaction (n = 3), facet joint effusions (n = 2), soft tissue fluid collection, hip joint effusion, cauda equina schwannoma, and renal malrotation and duplication.

CT correlation was recommended in the original radiologist MRI report in 17 of 42 cases, most often when the diagnosis of spondylolysis was suspected but not certain.

DISCUSSION

Confident diagnosis of spondylolysis can be achieved with CT, but its use has been limited secondary to the resultant dose of ionizing radiation to the patient. Limited field of view CT, optimized to decrease radiation dose, is an improved alternative in the imaging of spondylolysis when compared with general radiography.[13] Radiation dose reduction using this CT technique

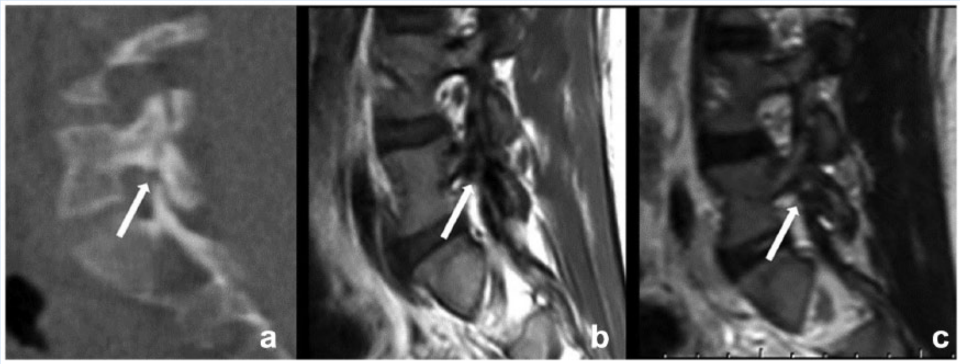

Figure 3. In order of confidence level for detecting left L5 spondylolysis (white arrows), (a) decreased-dose CT was favored over (b) the 2D MRI T1-weighted sequence, which was favored over (c) the 3D MRI T2-weighted sequence. 2D, 2-dimensional; 3D, 3-dimensional; CT, computed tomography; MRI, magnetic resonance imaging.

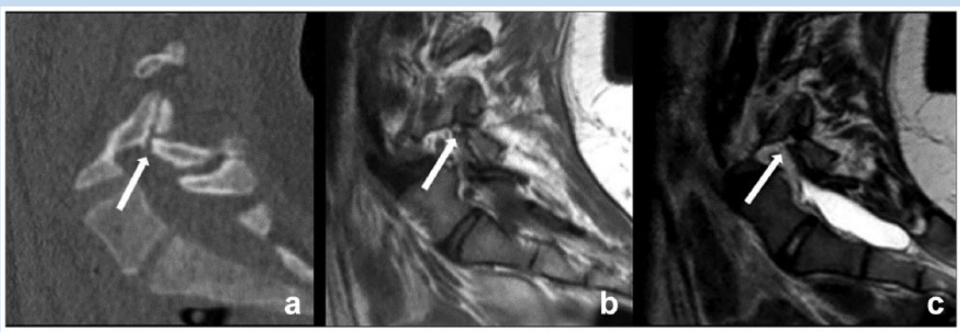

Figure 4. Right L5 pars defect (white arrows) in a patient with a lumbosacral hemivertebra and distorted anatomic planes. In order of confidence level for detecting spondylolysis (a) decreased-dose CT was favored over (b) the 2D MRI T1-weighted sequence, which was favored over (c) the 3D MRI T2-weighted sequence. 2D, 2-dimensional; 3D, 3-dimensional; CT, computed tomography; MRI, magnetic resonance imaging.

eliminates the major disadvantage of standard-dose CT in the diagnosis of spondylolysis.

Conventional 2D MRI has no ionizing radiation and provides complementary information to CT such as the presence of reactive marrow edema yet is considered less specific than CT in diagnosing spondylolysis (Figure 2).[17] Volumetric 3D MRI provides the capability to acquire volumetric datasets that can be reformatted with better spatial resolution and decreased scan time than conventional 2D MRI. Several studies in the adult population have compared 2D MRI with 3D MRI to evaluate degenerative changes in the spine, including neural foraminal stenosis, central spinal stenosis, disc herniation, and nerve compression. These studies demonstrated equivalent if not superior interobserver and intermethod agreement with volumetric 3D MRI compared with traditional 2D MRI for degenerative changes.[2,9,15] One study suggested that 3D MRI was more helpful when evaluating complicated anatomy such as scoliosis and spondylolysis.[15]

Although it was hypothesized that volumetric 3D MRI would offer equivalent diagnostic accuracy compared with decreased dose CT without the harmful effects of ionizing radiation, the data show that diagnostic confidence is greatest using decreased-dose CT compared with both 2D MRI and 2D + 3D MRI for spondylolysis in the pediatric population (Figures 3 and 4). Kappa values, rater agreement, and lack of certainty were all significantly better with CT compared with both 2D MRI and 2D + 3D MRI. Raters were always in agreement when using CT and were confident of their assessment of the diagnosis. In contrast, raters were more likely to assess a patient as likely negative, equivocal, or likely positive with MRI, indicating a degree of uncertainty.

Although adding a volumetric 3D MRI sequence to the standard 2D MRI sequences trended toward improving rater agreement and lack of certainty, there was no statistical difference between 2D MRI and 2D + 3D MRI. The raters indicate that the reconstructive capability of the added

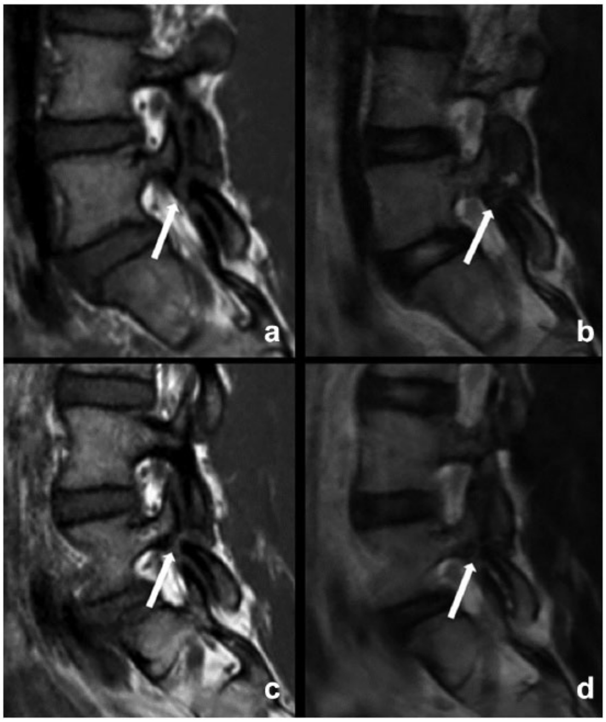

Figure 5. (a, b) Right and (c, d) left L5 pars defects (white arrows). Although improved spatial resolution with 3D MRI T2-weighted sequences would theoretically improve detection of spondylolysis, all raters favored the 2D MRI T1-weighted sequence (a, c) over 3D images (b, d), likely related to improved contrast resolution. 2D, 2-dimensional; 3D, 3-dimensional; CT, computed tomography; MRI, magnetic resonance imaging.

volumetric 3D sequence was helpful for problem solving a few of the cases with difficult anatomy, which may explain the trend toward improvement but not statistical significance.

Despite the shortfalls in confidently diagnosing spondylolysis, MRI offered more insight into potential alternative diagnoses in spondylolysis-negative cases. Most of the alternative diagnoses are typically occult by CT. To reiterate, 43% (18/42) of MRI cases had findings other than discrete pars interarticularis fractures, including disc pathology, pars stress reaction, facet joint effusions, soft tissue fluid collection, hip joint effusion, and a cauda equina schwannoma. No alternative diagnoses were identified in the CT cohort.

Of interest, the pediatric neuroradiologists who provided the reports on the original MRI examinations suggested CT correlation in 40% of cases even though 3D MRI sequences were available, most often when the diagnosis of spondylolysis was suspected but not certain. This supports the findings that diagnostic confidence is greater with CT.

In the study, raters were statistically more confident using CT compared with MRI in detecting spondylolysis. When only MRI was available, all raters anecdotally favored the 2D sagittal T1-weighted sequence over the volumetric 3D T2-weighted sequence, despite the improved spatial resolution of the 3D sequence. This postanalysis observation suggests that improving contrast resolution may be of better diagnostic utility to distinguish the pars from surrounding tissues (Figures 5 and 6). Because of this observation, it is hypothesized that a fairly rapid sagittal T1 mDixon sequence (which includes thin section T1, T1 with fat saturation, T1 in-phase, and T1 out-of-phase sequences) may improve the detection of spondylolysis compared with the standard 2D T1-weighted sequence. This sequence has not been routinely added to our spondylolysis MRI examinations as of yet; therefore, we have no conclusive supportive data. Further analysis may be warranted with prospective or larger retrospective studies.

This study was limited by its retrospective nature, lack of a true operative gold standard, as well as number of patients examined by CT compared with MRI (13 vs 42 patients, respectively). Unfortunately, only 2 of the 13 patients with decreased-dose CT also had a comparison MRI, another significant limitation. In both of those cases, CT followed the MRI, possibly supporting the definitive nature of the CT compared with MRI. Perhaps some of the data differences are attributable to inherently different MRI and CT cohorts regarding the ordering physicians' pretest probability for suspected spondylolysis.

Rater agreement of 100%, or kappa of 1.0, pertaining to the diagnosis of spondylolysis on decreased-dose CT sounds questionable, as statistics are usually not so absolute. However, the raters were given identical instructions and were appropriately blinded during the evaluations. This is thought to reflect the superior rater confidence level and diagnostic capability of decreased-dose CT over 2D MRI and 2D + 3D MRI in evaluating spondylolysis.

Studies were performed on different CT systems due to the clinical appointments taking place at different locations. Rather than exclude the cases performed at alternate sites, we took this as an opportunity to show that the simple modifications in CT technique can easily be applied to CT scanners produced by different vendors.

CONCLUSION

For diagnosing spondylolysis, radiologist agreement and confidence trended toward improvement with the addition of a volumetric 3D MRI sequence to standard 2D MRI sequences compared with 2D MRI alone; however, rater agreement and confidence remain significantly greater using decreased-dose CT when compared with either MRI acquisition. The data suggest that standard 2D MRI sequences should not be entirely replaced by a volumetric T2-weighted 3D sequence (despite promising features of rapid acquisition time, increased spatial resolution, and reconstruction capability). The high-contrast resolution of a standard T1-weighted sequence is very helpful in contributing to the diagnosis of spondylolysis on MRI; the volumetric 3D sequence is a helpful adjunct in a few of the cases with difficult anatomy.

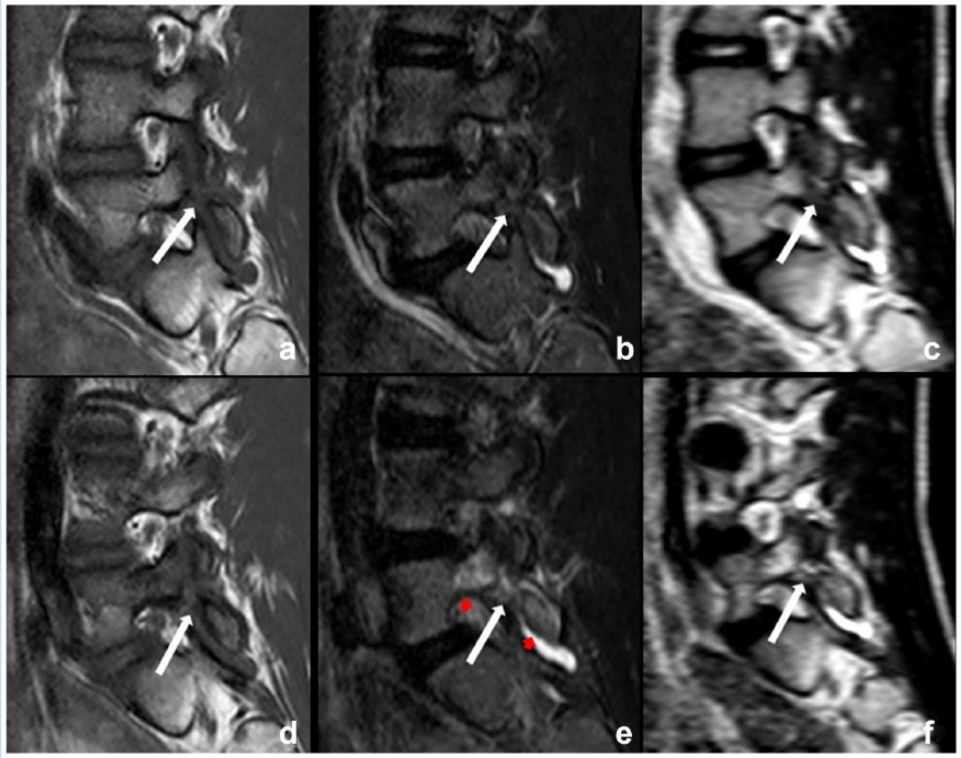

Figure 6. (a, b, c) Right and (d, e, f) left L5 pars defects. The defects (white arrows) are best defined on the 2D MRI T1-weighted sequence (a, d) compared with the 2D STIR sequence (b, e) and 3D T2-weighted sequence (c, f). An advantage of MRI over CT (not obtained in this case) is identification of edema associated with the left defect (e, red arrowheads), indicating a subacute or symptomatic defect, compared with the nonedematous chronic right defect (b). MRI is also helpful in detecting pars stress reaction, which may be symptomatic prior to the appearance of a defect on CT. 2D, 2-dimensional; 3D, 3-dimensional; CT, computed tomography; MRI, magnetic resonance imaging; STIR, short tau inversion recovery.

Recommendation

Decreased-dose CT of the lumbar spine is the optimal examination to confirm high clinical suspicion of spondylolysis with the greatest diagnostic confidence and with dose essentially equivalent to radiographs. If CT is negative for spondylolysis, then subsequent MRI examination is recommended to evaluate for other sources of back pain such as disc abnormalities and pars stress reaction. If there is a more nebulous clinical scenario or a larger area of the back needs to be imaged (negating the low radiation benefit of small field of view CT), starting with a standard 2D MRI may be of greater benefit given that it is still very good at detecting spondylolysis while remaining sensitive for detection of alternative diagnoses. If needed, a more focal low-dose CT study may be subsequently acquired to problem solve equivocal spondylolysis cases.

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