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Low dose CT of the lumbar spine compared with radiography: a study on image quality with implications for clinical practice

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Abstract:

Background: Lumbar spine radiography is often performed instead of computed tomography (CT) for radiation dose concerns.

Purpose: To compare image quality of and diagnostic information from low dose lumbar spine CT at an effective dose of about 1 mSv with lumbar spine radiography.

Material and Methods: Fifty-one patients were examined by both methods. Five reviewers scored all examinations on eight image quality criteria using a five-graded scale (0-4) and also assessed three common pathologic changes.

Results: Low dose CT scored better than radiography on the following (odds ratio with 95% confidence interval (CI) limits): sharp reproduction of disc profile and vertebral end-plates (1.8 (1.3, 2.5)), intervertebral foramina and pedicles (4.3 (3.1, 5.9)), intervertebral joints (139 (59, 326)), spinous and transverse processes (7.0 (4.3, 11.2)), sacro-iliac joints (4.2 (3.2, 5.7)), reproduction of the adjacent soft tissues (2.9 (2.1, 4.0)), and absence of any obscuring superimposed gastrointestinal gas and contents (188 (66, 539)). Radiography scored better on sharp reproduction of cortical and trabecular bone (0.3 (0.2, 0.4)). The reviewers visualised disk degeneration, spondylosis/diffuse idiopathic skeletal hyperostosis (DISH) and intervertebral joint osteoarthritis more clearly and were more certain with low dose CT. Mean time to review low dose CT was 204 seconds (95% CI 194-214 s.), radiography 152 seconds (95% CI 146-158 s.). The effective dose for low dose CT was 1.0-1.1 mSv, for radiography 0.7 mSv.

Conclusion: Low dose lumbar spine CT at about 1 mSv has superior image quality to lumbar spine radiography with more anatomical and diagnostic information.

Key words:

Radiation dose; radiography; tomography, X-ray computed; axial skeleton.

Introduction

Despite abundant evidence of the limited value of lumbar spine radiography (1,2), it is still the most common radiologic investigation of the lumbar spine. Many physicians rely on it as a simple, cheap, and widely available preliminary diagnostic modality with relatively low radiation, with effective dose about 1 mSv (3,4).

Computed tomography (CT) has improved musculoskeletal imaging. CT is more sensitive than radiography for evaluation of multiple myeloma (5), is superior to radiography in cervical spine injury (6), and reduces the risk of missing a fracture of the thoracolumbar spine (2). Spiral CT with three-dimensional (3D) reconstructions gives better and more accurate demonstration of different types of fractures and allows for more precise pre-operative surgical planning. On the other hand, the dramatic increase in the number of CT examinations globally has increased the collective radiation dose. The awareness has been raised of both the hazards of medical ionizing radiation and the need to reduce it as much as possible (7). The effective dose of lumbar spine CT has been reported as about 8.7 mSv in Sweden (3), but has been reported as high as 19 mSv (8). To minimize radiation exposure clinicians may try to avoid or minimize the use of unnecessary “standard” CT by using conventional radiography. However, it is possible to perform CT at much lower dose settings than with standard CT, at the expense of increased image noise and reduced image quality; it can even be done using the same relatively low radiation dose as lumbar spine radiography (7,9,10). CT at this low

dose level may have a higher diagnostic value than radiography and may give more information on anatomy as well as on pathologic changes.

The current study was performed to evaluate and compare image quality and anatomic and diagnostic information from low dose CT lumbar spine at about 1 mSv with lumbar spine radiography.

Material and methods

Patients

The study was approved by the regional ethics committee. Inclusion criteria were adults referred for lumbar spine radiography. Exclusion criteria were age below 18 years, pregnancy, coma, dementia or inability to understand oral or written instructions. A power analysis showed that with better image quality than the reference method in 70% of the cases, 51 cases would be needed for 80% power. In a convenience sample 51 patients (16 males, 35 females) gave informed consent and accepted to participate (53 were invited, two declined to participate). Most patients were referred from primary health care (n=48), two were referred from the orthopaedic department, one from the neurological department. The major primary indication was low back pain without known serious underlying conditions (48 cases with back pain; 10 with neurological symptoms, 38 without, one with paraesthesia in the thigh, one for control of osteosynthesis material, one control for a vertebral compression fracture).

Mean age of the patients was 58 years (SD 13.9, range 21-81 years). Mean weight was 79.6 kg (SD 15.6, range 55-125 kg) and height 169 cm (SD 9.3, range 152-194 cm). Mean BMI was 27.7 (SD 4.0, range 20-38). There were no underweight study patients. The patients were classified (11) as being of normal weight (BMI 18.5-24.9), overweight (BMI 25.0-29.9), or obese (BMI > 30.0).

Imaging

Lumbar spine radiography and low dose CT were performed the same day. Radiography was performed on a digital x-ray system (DRX-Evolution, Carestream Health, Rochester, NY, USA) with a flat panel detector (PaxScan CsI, pixel spacing 0.139 mm x 0.139 mm, image

depth 12 bits). Standard clinical settings for lumbar spine were used; 75kV for the anterior-posterior (AP) projection, 85 kV for the lateral and lumbosacral joint projections using automatic exposure control. The average number of exposures was 3.5 (range 2-5) due to clinical status, imaging requirements and possible re-takes.

Low dose CT was performed using a Somatom Definition AS scanner (Siemens, Erlangen, Germany; 40 channels), using settings from a phantom study (10), giving about 1 mSv effective dose; tube potential 120 kV, reference mAs 30, collimation 40x0.6 mm, rotation time 0.5 s, pitch 1.4, FOV 200x200 mm, convolution filter B41f (medium plus), with automatic dose modulation. Axial, coronal and sagittal multiplanar reformations (MPR) with 2 mm thickness and 2 mm increment were sent to the picture archiving and communication system (PACS) (Fig. 1).

Image evaluation

The 102 examinations (51 from each modality) were presented in random order. Five reviewers with 8, 10, 12, 25 and 32 years of experience in diagnostic radiology independently scored all studies blinded to all patient data using the PACS with free use of the PACS tools as follows:

A. Scoring of image quality according to a modification of the European guidelines on image quality for computed tomography (EUR 16262) (12) and diagnostic radiographic images (EUR 16260) (13). Each reviewer scored the following criteria from 0 to 4:

- 1 Sharp reproduction of the disc profile and the upper and lower-plate surfaces of vertebrae
- 2 Sharp reproduction of the cortical (cortex) and the trabecular bone

- 3 Sharp reproduction of the intervertebral foramina and pedicles
- 4 Sharp reproduction of the intervertebral joints
- 5 Sharp reproduction of the spinous and transverse processes
- 6 Reproduction of the adjacent soft tissues
- 7 Sharp reproduction of the sacro-iliac joints (the included part of the joints in the examination)
- 8 Absence of any obscuring superimposed abdominal contents or gastrointestinal gas

The scoring levels for each criterion were 0: Confident that the criterion is not fulfilled, 1: Somewhat confident that the criterion is not fulfilled, 2: Indecisive whether the criterion is fulfilled or not, 3: Somewhat confident that the criterion is fulfilled, and 4: Confident that the criterion is fulfilled. One reviewer scored all examinations again six months later to assess intra-observer agreement.

B) Assessment of pathology. Three common radiologic findings (disk degeneration, intervertebral joint osteoarthritis, and spondylosis/diffuse idiopathic skeletal hyperostosis (DISH)) were evaluated. For each detected type of pathology the vertebral level (or range of levels) was noted. The reviewers also scored how clearly the lesions were seen and how certain the diagnosis was on a three-graded scale.

C) The time needed to review each case.

Radiation dose

For radiography the dose-area product (DAP) was measured with a DAP meter integrated in the equipment and recorded for each projection. The PCXMC computer program v2.0 (Finnish Radiation and Nuclear Safety Authority, Helsinki, Finland) was used to calculate the effective dose for each BMI category with the average DAP of each projection. The field size at the image receptor was 18*42 cm for the AP and lateral projections and 18*30cm for the lumbosacral projection. For CT, the effective tube loading was recorded for each examination and the average value used to calculate the effective dose for each BMI category with the software CT-Expo v 2.3 (SASCRAD, Buchholz, Germany). The scan area covers Th12 to S2 in a virtual phantom.

Statistical analysis

The data for each image quality criterion were analyzed with the generalized estimating equation (GEE) model (14) due to repeated measurements as each patient was assessed by five observers for each method. The measure of associations was odds ratios (OR) with 95% confidence intervals (CI). An OR of 1 is interpreted as no difference of image quality between methods and an OR higher than 1 is interpreted as low dose CT was assessed as a better method compared with radiography. All statistical analyses were performed using SPSS Statistics for Windows version 22 (IBM Corp., Armonk, NY, USA). The same analysis was performed after stratifying data into BMI subgroups. Inter-observer agreement for all five reviewers according to free-marginal multirater kappa (multirater κ_{free}) was estimated (15). The scoring scale was converted from a 5 grade scale to 3 grades (0-1 as 1, criterion is not fulfilled; 2 as 2, indecisive; and 3-4 as 3, criterion is fulfilled). Data from the first and second observation of one reviewer were used to evaluate the intra-observer agreement. Calculations

were performed with an online kappa calculator (16). Values of free marginal kappa can range from -1.0 to 1.0, with -1.0 indicating perfect disagreement worse than chance, 0.0 indicating agreement equal to chance, and 1.0 indicating perfect agreement. A rule of thumb is that a kappa of 0.70 or above indicates adequate agreement (16).

Results

Image quality was rated significantly higher for CT compared with lumbar spine radiography (Fig. 2) for all criteria except "Sharp reproduction of the cortical and the trabecular bone" which was rated significantly better for radiography according to the GEE model for repeated measurements (Table 1).

When the GEE analysis was performed after stratifying data into BMI subgroups, the result for each subgroup was similar to the results for all data (Table 1), i.e. all criteria were scored significantly better for low dose CT except the criterion "Cortical and trabecular bone". Only the criterion "Disk profile" showed no significant difference between low dose CT and radiography for the obese subgroup.

There were generally high kappa values for inter- and intra-observer agreements for all reviewers' scores for CT according to free-marginal multirater Kappa (Table 2) except for two criteria; "sharp reproduction of cortical and trabecular bone" and "reproduction of adjacent soft tissues". There was a generally low inter- and intra-observer agreement for radiography.

There was no significant difference in detection of pathology between the imaging modalities (Table 3), but the reviewers considered pathology to be visualised more clearly and were more certain on their findings with low dose CT. As an example, a case with unilateral spondylolysis at the L5-S1 level (Fig. 3) was diagnosed by four of five reviewers with low dose CT but only by two reviewers with lumbar spine radiography. In a 71-year-old woman

with unilateral pedicle screws at the L5-S1 level, low dose CT showed an acceptable level of metall artifacts with better visualization of the screw placement in the L5 and S1 vertebrae than radiography (Fig. 4).

The dose estimates are shown in Table 4. The dose from the scanogram was estimated to 0.1 mSv and is included in the calculations. The average time to review the studies was 204 s (95% CI 194-214 s) for low dose CT and 152 s (95% CI 146-158 s) for radiography.

Discussion

The current study has shown that low dose CT improves visualization of most anatomical structures as well as giving observers higher confidence in evaluating some common pathologic lesions compared with radiography. The pathologic findings were more clearly seen with low dose CT and the reviewers were more certain of their findings. Even though these benign lesions are of no clinical concern, the easier detection with CT may reflect the benefit of using low dose CT to visualize small lesions in general, including metastases. Further research on evaluation of the diagnostic accuracy of low dose CT is warranted, especially for the detection of lesions that are highly dependent on visualization of cortical or trabecular bone such as fracture detection.

The GEE model (14) was used since it accounts for the fact that each image was assessed with repeated measurements by five observers for each method. Well-defined criteria, such as the EU criteria (12), are often used, and the score is typically set on a scale with a limited number of steps such as 0 (confident that the criterion is not fulfilled) to 4 (confident that the criterion is fulfilled). Although the values on the scale have a natural ordering, there is no guarantee that the difference between 0 and 1 is equivalent to that between 1 and 2 or between 3 and 4. In statistical terms, the score is defined on an ordinal scale, and this requires adapted statistical methods. This kind of model is a form of logistic regression for repeated measurement with ordinal scaled outcome and is also called proportional odds model for repeated measurement.

Several successful applications of low dose CT in diagnostic musculoskeletal imaging have been reported. Low dose CT has been shown to be a suitable method to implement in the pre- and the postoperative investigation of young patients with scoliosis, where a significant dose reduction compared with standard CT did not convey any negative impact on image quality (17). According to Abul-Kasim et al. (18), low dose CT of the spine is a reliable method to assess the accuracy of pedicle screw placement in patients with adolescent idiopathic scoliosis after posterior corrective surgery, using titanium implants, instead of using other CT protocols with unnecessarily higher radiation doses to young individuals. Low dose cervical spine CT in patients with blunt trauma has acceptable image quality compared with standard dose CT (19). According to Horger et al. (20), low dose whole-body CT, compared with plain radiography, in the staging and monitoring of multiple myeloma patients, is a precise and quick diagnostic tool, with high acceptance among patients and medical personnel, which also enables acquisition of complementary data about other organs.

Low dose CT is also well established in clinical practice for other regions in the human body. For example, the overall diagnostic accuracy of low dose CT for urolithiasis was calculated as 99.32% according to a systematic review by Niemann et al. (21). Screening for lung cancer using low dose CT reduces mortality compared with radiography by 20% (22). Low dose, dual-source CT coronary angiography in step-and-shoot mode allows, in patients with a regular heart rate, accurate diagnosis of significant coronary stenoses at a low radiation dose compared with conventional coronary angiography (23). Low dose CT colonography has excellent sensitivity for detection of colorectal carcinomas and polyps larger than 6 mm in diameter (24).

Magnetic resonance imaging (MRI) is a good method in spine imaging without ionizing radiation. It has been shown to be superior to radiography and CT in the diagnosis of bone marrow edema, medullary infiltration, and disc herniation. But MRI alone may not be sufficient for a complete understanding of the morphological changes of the skeletal structure, where radiography or CT can add information. Furthermore, the assessment of fracture risk in osteolytic lesions and instability has been proven superior by means of CT (25). MRI is also more costly and more time-consuming, there are some contraindications, and there may be limited availability. All these factors may influence the choice of imaging in the initial imaging of the lumbar spine.

The protocol for low dose CT at 1 mSv level used in the current study was derived from a previous phantom study (10). The effective dose level was set as the average effective dose of lumbar spine radiography in Sweden, 1.1 mSv, according to a report from 2010 (26). Wall et al. reported 0.6 mSv as a typical effective dose in the UK using only two projections (27), but there were large variations between hospitals. Hart et al. reported mean DAP values from lumbar spine examinations in different examination rooms indicating effective doses in the range of approximately 0.2 mSv to 5 mSv (4). The calculations of effective dose are in general hampered by uncertainties and are calculated through multiple steps and depend on a number of approximations (28). In the calculations of effective dose in the current study, the differences in dose level for the different sizes of patients have been taken into account by using average values for each BMI category. However one should be aware of that the organ doses used in the calculations are valid for mathematical phantoms considered equal to a standard patient and should not be used for individual patients and deviations in the different BMI categories is likely lead to different dose distributions and organ doses. The concept effective dose was never meant to be used for individual patients. Any discussion of effective

dose must recognize that it is but a broad, generic estimate of risk, and that differences of a few mSv do not imply any true differences in biologic risk, i.e. there are no meaningful conclusions to be drawn regarding a difference of even several mSv (28-30). Rather risk should be described using broad categories: negligible, < 0.1 mSv; minimal, 0.1–1 mSv; very low, 1–10 mSv; and low, 10–100 mSv (30), which have been implemented by the National radiation protection board in Great Britain (31). Thus the methods evaluated in the current study, low dose CT and radiography, belong to the same risk category, i.e. minimal. CT at the low dose set in the current study, about 1 mSv, has a high possibility to become part of the clinical routine in imaging the lumbar spine. The CT protocol can be further developed by adapting the settings of other parameters than reference mAs, tube potential (kV) and convolution filter, or by applying other reconstruction techniques such as iterative reconstructions (7,32).

The strengths of the current study are that five reviewers took part in this study providing a wide range of experience in evaluating image quality, and that the study included tests of intra-observer and inter-observer agreement and an evaluation of whether BMI was a confounder.

A limitation of study was that the major part of the sample was referred from primary health care with a history of low back pain without any known serious underlying condition. The expectation of pathological findings was thus low compared with more advanced cases such as cases with trauma, known malignancy or skeletal metastasis. Another limitation was that the difficulties in comparing image quality of two different modalities. However the purpose of the current study was to test the capability of the new method to demonstrate different anatomical structures compared with the standard method, radiography, as a minimum

requirement of the diagnostic method. The fact that all observers were consistent in their assessments indicates that this comparison was working.

In conclusion, low dose CT of the lumbar spine at 1 mSv has superior image quality to lumbar spine radiography. Low dose CT may give more anatomical and diagnostic information than lumbar spine radiography and thus can replace it in daily clinical practice.

Acknowledgments

Conflict of interest

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Tables

Table 1. Image quality scoring for low dose lumbar spine CT compared with lumbar spine radiography. Odds ratios with 95% CI limits according to the generalized estimating equation (GEE) model for repeated measurements.

Criterion	Odds ratio	95% CI limits	Interpretation
1. Disc profile	1.8	1.3 - 2.5	+
2. Cortical & trabecular bone	0.3	0.2 - 0.4	-
3. Intervertebral foramina & pedicles	4.3	3.1 - 5.9	+
4. Intervertebral joints	139	59 - 326	+
5. Spinous & transverse processes	7.0	4.3 - 11.2	+
6. Adjacent soft tissues	2.9	2.1 - 4.0	+
7. Sacro-iliac joints	4.2	3.2 - 5.7	+
8. Absence of superimposed abdominal contents & gas	188	66 - 539	+

+ Significantly superior image quality for low dose CT compared with lumbar spine radiography

- Significantly inferior image quality for low dose CT compared with lumbar spine radiography

Table 2. Inter- and intra-observer agreement in the scoring of eight image quality criteria for low dose CT and radiography according to free-marginal Kappa.

	Inter-observer agreement*		Intra-observer agreement**	
	Low dose CT	Radiography	Low dose CT	Radiography
1. Disc profile	0.87	0.40	0.88	0.29
2. Cortical & trabecular bone	0.11	0.55	-0.15	0.38
3. Intervertebral foramina & pedicles	0.98	0.16	0.91	0.56
4. Intervertebral joints	0.92	0.04	0.94	1.0
5. Spinous & transverse processes	0.84	0.19	0.88	0.47
6. Adjacent soft tissues	0.24	0.12	-0.47	0.97
7. Sacro-iliac joints	0.92	-0.02	0.91	0.47
8. Absence of superimposed abdominal contents & gas	0.94	0.17	1.0	0.18

* Inter-observer agreement was performed for the first observation of all reviewers.

** Intra-observer agreement was performed for the first and second observation of one reviewer.

Table 3. Pathological findings in 255 observations (51 cases x 5 reviewers), including scoring for visibility and certainty.

Diagnosis		Low dose CT	Radiography
Disc degeneration	Number of findings	174	165
	Visibility *	98% (94-99%)	90% (84-93%)
	Certainty **	98% (94-99%)	94% (89-97%)
Intervertebral joint osteoarthritis	Number of findings	168	150
	Visibility	90% (84-94%)	55% (47-68%)
	Certainty	92% (87-95%)	74% (67-81%)
Spondylosis/diffuse idiopathic skeletal hyperostosis (DISH)	Number of findings	178	169
	Visibility	94% (89-97%)	85% (78-89%)
	Certainty	98% (94-99%)	88% (82-92%)

*Proportion of responses that graded the lesion as clearly seen (95% CI limits) which was estimated as proportion of Clear/total (Unclear + Intermediate + Clear).

**Proportion of responses that graded the diagnosis as certain (95% CI limits) which was estimated as proportion of Certain/total (Uncertain + Intermediate + Certain).

Table 4. Dosimetry for low dose CT and radiography according to BMI. For CT the effective dose is for male and female respectively. The average CTDIvol, DLP and effective mAs that were displayed on the scanner is also shown. For radiography the DAP values for each projection is shown as well as the total effective dose.

BMI	CTDIvol (mGy)	DLP (mGycm)	Effective mAs	DAP AP (Gycm ²)	DAP Lat (Gycm ²)	DAP LS (Gycm ²)	Effective dose CT male/female (mSv)	Effective dose radiography (mSv)
Normal weight (n=12)	1.47	47.6	17.80	0.50	1.01	1.17	0.7/0.8	0.4
Overweight (n=23)	1.96	60.7	23.70	0.81	1.48	1.22	0.9/1.0	0.6
Obesity (n=16)	2.63	78.3	31.10	1.50	2.85	2.46	1.2/1.3	0.9
All patients (n=51)	2.03	63.3	24.4	0.94	1.72	1.67	1.0/1.1	0.7

Figure legends

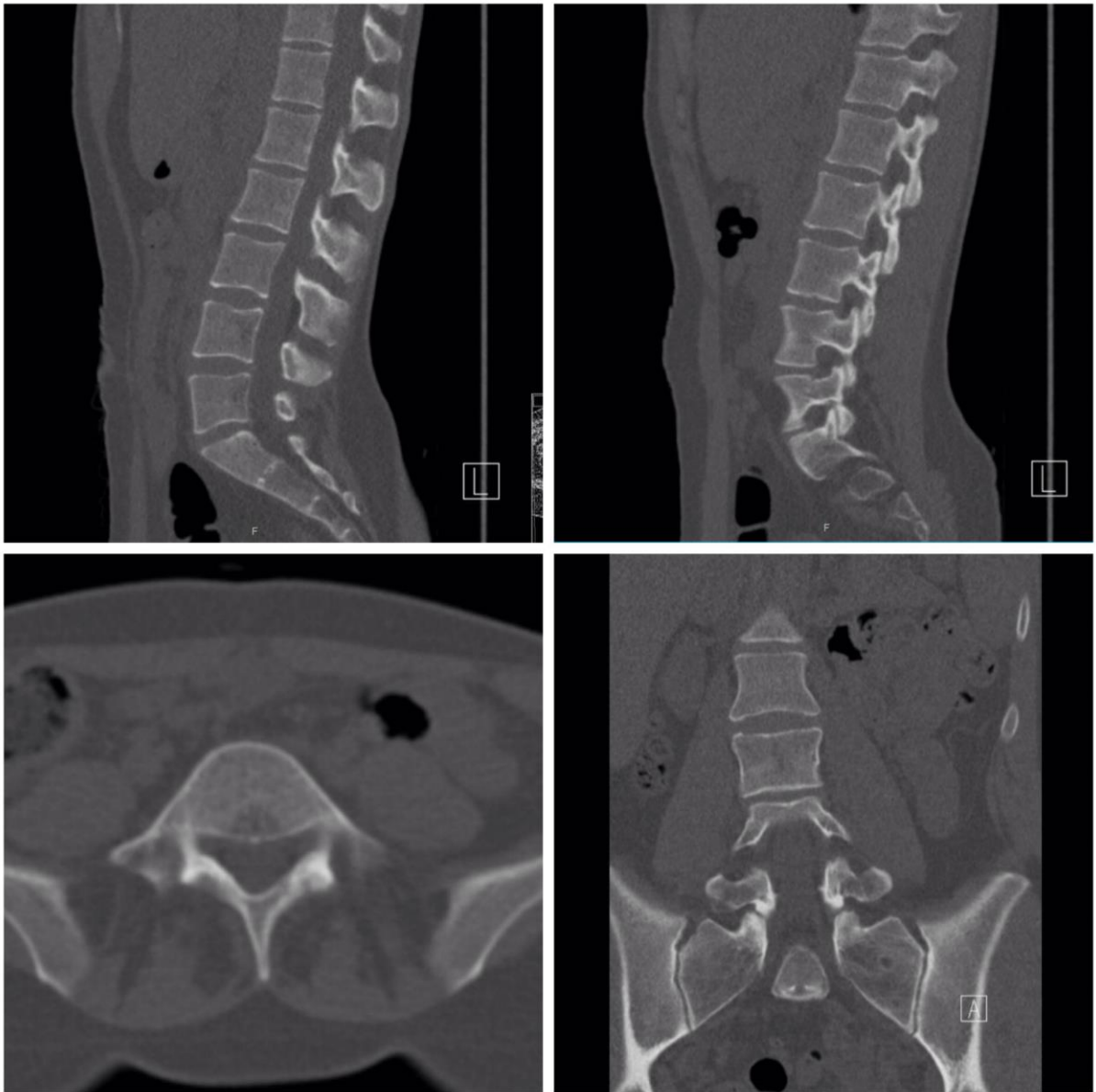


Fig. 1. Low dose CT of a 27-year-old woman of normal weight with good image quality, which demonstrates the sharp reproduction of different anatomical structures of the lumbar spine.

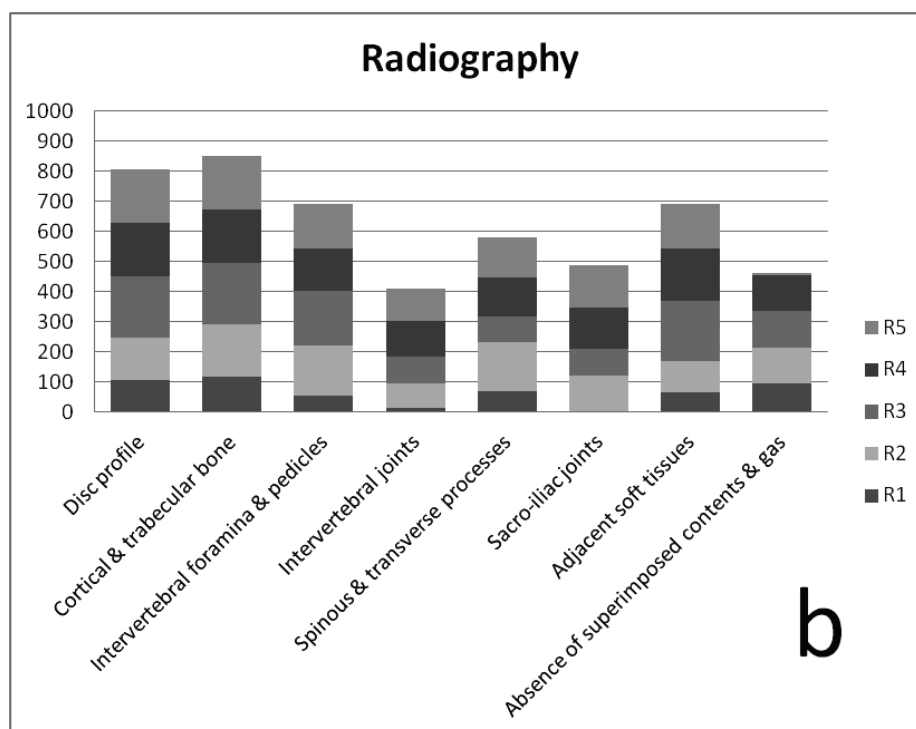
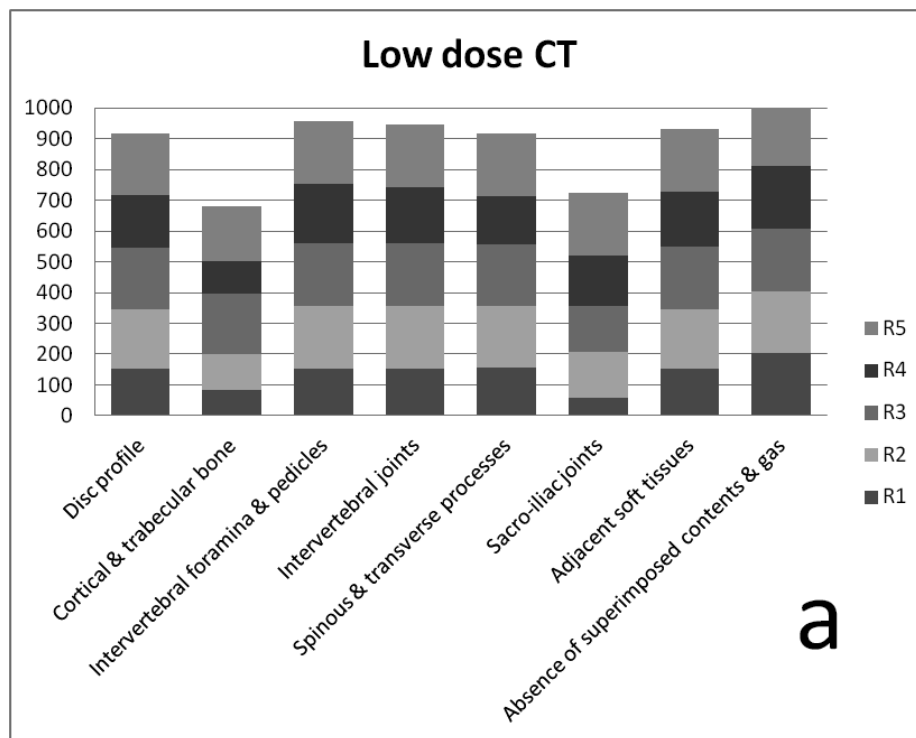


Fig. 2. Scores for all reviewers (R1-5) on all criteria for a) low dose CT and b) lumbar spine radiography. Full score for each criterion is 1020 (4 max score x 5 reviewers x 51 cases). CT was scored higher on all criteria except on “Sharp reproduction of cortical and trabecular bone”.

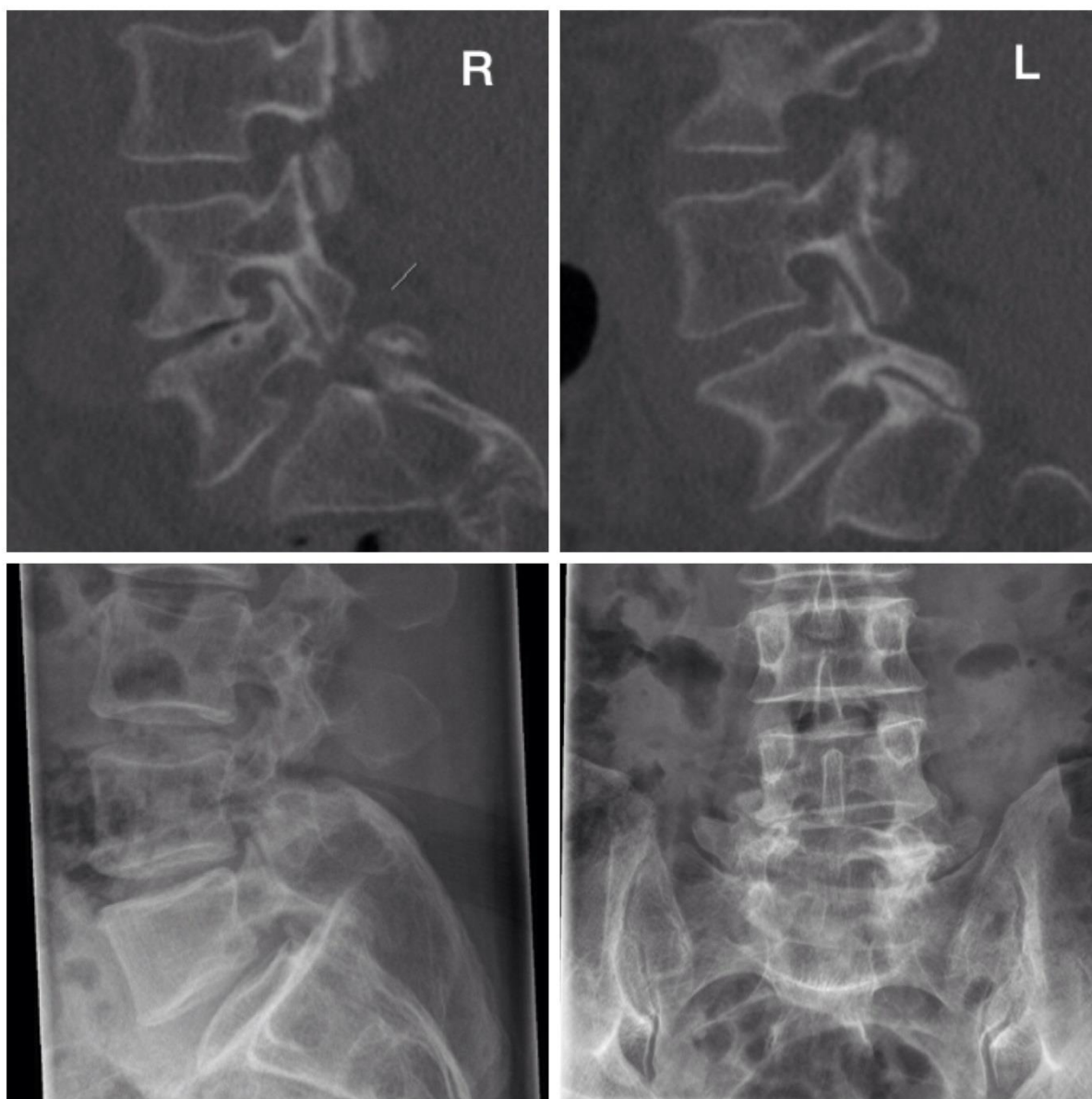


Fig. 3. A 64-year-old man with unilateral spondylolysis at the L5-S1 level, well demonstrated at low dose CT (line). This finding was difficult to detect and to determine if it was uni- or bilateral on lumbar spine radiography.



Fig. 4. A 71-year-old woman with unilateral pedicle screws on the right side at the L5-S1 level. Metal artifacts at low dose CT were acceptable with clear visualization of the screw placement in the L5 and S1 vertebrae. This was more difficult to determine on lumbar spine radiography.