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FULL PAPER

Lumbar spine evaluation: accuracy on abdominal CT

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Objective: To determine if the lumbar spine can be accurately evaluated on an abdominal CT.

Methods: The electronic medical records at our institution were searched to find all consecutive patients who had an abdominal CT within 12 months of a lumbar spine MRI obtained between 01 November 2010 and 31 October 2015. The abdominal CT studies were retrospectively reviewed in a blinded fashion for the presence of any significant lumbar spine abnormalities. The prospective lumbar spine MRI reports were used as the standard of reference.

Results: 5,031 patients had lumbar spine MRI studies at our institution during the study period of 01 November 2010 to 31 October 2015. 144 patients met the inclusion criteria of our study. No patients were excluded. 107 patients had 256 abnormal findings on the lumbar spine MRI studies. The sensitivity, specificity, positive

predictive value, negative predictive value and accuracy of abdominal CT in lumbar spine evaluation on a per patient/per finding basis were 89.7/95.3%, 97.3/100%, 99.0/99.2%, 76.6/99.8% and 91.7/99.8%, respectively.

Conclusion: Despite several limitations (e.g. spinal cord assessment, bone marrow assessment and quantum mottle) compared with evaluation of the lumbar spine using MRI, evaluation of the lumbar spine on abdominal CT studies can be accurately performed with current state of the art CT scanners. Additional prospective studies are needed for a more definitive analysis.

Advances in knowledge: With recent advances in CT technology, accurate evaluation of the lumbar spine on abdominal CT studies is feasible, potentially providing significant additional information to patients without additional imaging.

INTRODUCTION

Low back pain is a common ailment. About four in five people will experience low back pain sometime in their lives.¹ CT is a common imaging procedure. Over 62 million CT scans, about one CT for every three Americans, were performed in the US in 2007, one-half of them of the body.^{2–4} Not surprisingly, many CT scans are done in patients who also have low back pain. Although abdominal CT is not done to evaluate the lumbar spine, many patients with low back pain have had a recent abdominal CT for unrelated symptoms. Recently, multidetector CT (MDCT), with post-processed thin section sagittal reformations, has allowed the evaluation of the lumbar spine on abdominal CT studies. Nevertheless, lumbar spine abnormalities are rarely identified on abdominal CT reports.⁵ If the lumbar spine can be accurately evaluated on abdominal CT, then patients with incidental low back pain can have an explanation for their symptoms and may avoid additional costly evaluation. The purpose of this study is to determine if the lumbar spine can be accurately evaluated on an abdominal CT.

METHODS AND MATERIALS

Patients

The local institutional review board approved this retrospective study and waived the informed consent requirement. This study complied with Health Insurance Portability and Accountability Act (HIPAA) guidelines. Our institutional electronic medical records were searched to find all consecutive patients who had a lumbar spine MRI between 01 November 2010 and 31 October 2015 and an abdominal CT within 12 months of that lumbar spine MRI. Exclusion criteria were interval surgery between the MRI and CT, lack of available sagittal CT reformations, missing CT or MRI images and incomplete medical records.

CT technique

Abdominal CT was performed by using a 64-detector row scanner (LightSpeed VCT; GE Healthcare, Milwaukee, WI). CT was performed at 120 kVp with an amperage, averaging 250 mA, which varied according to the patient's body habitus. The helical CT images were obtained with a detector configuration of 64 × 0.625 (40-mm beam width) and a beam pitch of 1.0. The images were reconstructed

at 2.5-mm thickness with a slice interval of 2.5 mm (no gap). Sagittal reformations were obtained using a 2.5-mm section thickness with a 2.5-mm interval. Patients underwent CT during the portal venous phase using Smart Prep with an average delay of 70 s. 125 ml of intravenous contrast material (iohexol, Omnipaque 350, GE Healthcare Inc., Marlborough, MA 01752), was administered via a power injector at 3.5 ml s^{-1} . 11 patients (7.6%) did not receive intravenous contrast material because of contrast allergy, renal failure, clinician request or clinical indication (e.g. renal stone protocol). Oral contrast material was not administered. The scanning range extended from the diaphragm to the ischium. Although the abdominal CT studies were performed for a wide variety of indications (e.g. abdominal pain), none were obtained for spine evaluation. No small field of view targeted reconstructions were available for lumbar spine evaluation on the abdominal CT studies as is used for dedicated lumbar spine CT imaging since the raw image data was no longer available at the time of analysis.

MR technique

MRI of the lumbar spine was performed with a 1.5 T MRI unit (Magnetom Espree, Siemens Medical Solutions, Erlangen, Germany or Signa HDX twin speed, GE Healthcare, Milwaukee, WI) and a dedicated receive-only spine coil. The imaging protocol included sagittal and transverse T_1 weighted (TR/TE, 400/13)

and T_2 weighted (TR/TE, 4000/102) turbo spine-echo sequences, and a sagittal fast short inversion time inversion-recovery (TR/TE/TI, 4000/40/150) sequence, with the following parameters: echo train length, 3–17; number of signals acquired, 1–3; slice thickness, 4–5 mm; gap, 1 mm; FOV, 200–280 mm and matrix, $320\text{--}448 \times 208\text{--}336$. Contrast enhanced T_1 weighted images were also obtained in 18 patients (12.5%) using the intravenous administration of 0.1 mmol (0.2 ml) per kg of body weight of a gadolinium-based contrast agent (Magnevist, gadopentetate dimeglumine, Bayer HealthCare LLC., Whippany NJ 07981; or Multihance, gadobenate dimeglumine, Bracco Diagnostics Inc., Monroe Twp., NJ 08831). Contrast was used when the patient had prior lumbar spine surgery, a history of cancer or possible infectious spondylodiscitis. The parameters were the same as those used for unenhanced T_1 weighted imaging (except for the addition of fat suppression).

Image interpretation

A board certified, fellowship-trained radiologist, with over 20 years of cross-sectional imaging experience in abdominal CT evaluation, retrospectively reviewed the abdominal CT studies in a blinded fashion, without any knowledge of the patients' histories or lumbar spine MR findings, for the presence of any significant lumbar spine abnormalities. Each abnormality identified on the abdominal CT was classified as definite, probable

Figure 1. A 54-year-old male with *Streptococcus constellatus* infectious spondylodiscitis and paraspinal abscess. (a) Sagittal fast short inversion time inversion-recovery image shows increased signal intensity in L3/4 disc space (arrow) and adjacent L3 and L4 vertebral bodies with associated vertebral body and endplate destruction. (b) Sagittal T_1 weighted fat suppressed contrast enhanced Turbo spin-echo image shows enhancement in the L3/4 disc space, subjacent endplates (arrow) and L3 and L4 vertebral bodies with associated vertebral body and endplate destruction. (c) Sagittal contrast enhanced reformatted CT image shows vertebral body and endplate destruction (arrow) subjacent to the L3/4 disc space, concordant with MRI findings. Also seen is artefact from interbody metal cages at L4/5 and L5/S1. (d) Transverse T_1 weighted fat suppressed contrast enhanced Turbo spin-echo image shows a large right psoas abscess (arrow) as well as endplate and vertebral body enhancement (star). (e) Transverse contrast enhanced CT image shows a large right psoas abscess (arrow), concordant with MRI findings.

Figure 2. An 85-year-old male with *Streptococcus bovis* infectious spondylodiscitis, bacteremia and aortic valve endocarditis. (a) Sagittal fast short inversion time inversion-recovery image shows vertebral body and endplate (arrows) destruction with increased signal intensity in L4/5 disc space and adjacent L4 and L5 vertebral bodies. Similar changes are seen at the L3/L4 and L1/2 disc spaces. (b) Sagittal T_1 weighted fat suppressed contrast enhanced Turbo spin-echo image shows destruction of the L4 and L5 vertebral bodies and endplates (arrows) subjacent to the L4/5 disc space. Enhancement of the L4/5 disc, subjacent endplates and vertebral bodies and paraspinal soft tissue is also present. Similar changes are present at L3/4 and L1/2. (c) Sagittal reformatted CT image shows L4/5 disc space widening with vertebral body and endplate (arrows) destruction subjacent to the L4/5 disc space, concordant with the MRI findings. Similar changes are present at L3/4 and L1/2, also concordant with the MRI findings.

or possible. The prospective lumbar spine MRI report was used as the standard of reference. The MRI studies were all read by board certified, fellowship trained radiologists with expertise in spine imaging. All prospective abdominal CT reports were then reviewed to determine if the lumbar spine abnormalities were prospectively diagnosed.

All cases were reviewed at a dedicated picture archiving and communication system unit (IMPAX 6; Agfa Healthcare, Mortsel, Belgium). Findings were concordant if the final classification was either normal or abnormal (for pathology and location) on both the retrospective abdominal CT reading and the prospective lumbar spine MRI report and discordant if the retrospective abdominal CT classification, as normal or abnormal, was different from the prospective lumbar spine MRI report. Evaluations were also analysed on a per patient basis.

Lumbar spine abnormalities

The following lumbar spine abnormalities were sought on the abdominal CT: foraminal stenosis (moderate-severe only), herniated disc, central canal stenosis (moderate-severe only), spondylodiscitis, fracture, spondylolesthesis, spinal cord/canal abnormality and bone tumour. A total of 51 potential findings were possible for each patient since, except for the spinal cord/canal, each disk level or vertebral body from T12 to S1 was independently evaluated for the abovementioned abnormalities.

Moderate to severe foraminal (including lateral recess) stenosis was diagnosed when the foraminal fat surrounding the exiting nerve was effaced, the foraminal area was less than 2/3 of the

Figure 3. A 68-year-old male with metastatic non small cell lung cancer. (a) Sagittal T_1 weighted Turbo spin-echo image shows L4 vertebral body (star) bone metastasis with decreased signal intensity. Multiple other similar appearing bone metastases are seen throughout the spine. (b) Sagittal contrast enhanced reformatted CT image shows mixed lytic (down arrow) and sclerotic (up black arrow) bone metastases, concordant with MRI findings. An acute L3 vertebral body inferior endplate fracture (up white arrow) is present, also concordant with findings on MRI.

expected area, or the subarticular recess height was less than 2 mm. Moderate to severe central canal stenosis was diagnosed when the spinal canal area was less than 2/3 of the expected spinal canal area, the AP dimension of the spinal canal was less than 10 mm, the cross-sectional area of the spinal canal was less than 100 mm² or the cauda equina was qualitatively crowded. Spondylodiscitis was diagnosed when ill-defined or irregular endplates with vertebral body destruction subjacent to a

Figure 4. A 71-year-old male with acute back pain, lower extremity weakness, areflexia and an old T12 vertebral body compression fracture. (a) Transverse T_2 weighted Turbo spin-echo image shows a right lateral disc protrusion (arrow) at L4/5 contacting and displacing the exiting right L4 nerve root (arrowhead). (b) Transverse CT shows a right lateral disc protrusion (arrow) at L4/5 contacting and displacing the exiting right L4 nerve root (arrowhead), concordant with the MRI findings.

Figure 5. A 60-year-old male with lumbar spine degenerative disc disease. (a) Transverse T_2 weighted Turbo spine-echo image shows moderate to severe central canal stenosis at L4/5. Right facet synovial cyst (arrow). (b) Transverse CT image shows moderate to severe central canal stenosis at L4/5 concordant with the MRI findings. Right facet synovial cyst (arrow).

narrowed (or widened) disc space were present with or without an associated paraspinal fluid collection.

All discordant findings between the abdominal CT and lumbar spine MRI studies were analysed by direct comparison of the two studies. All available information, such as other imaging studies (e.g. follow up lumbar spine MRIs) and clinical data, was used in this analysis to determine the reasons for the discordant findings.

Two-by-two tables were used to calculate sensitivity, specificity, accuracy, positive predictive value (ppv) and negative predictive value (npv) with 95% CI for both findings and patients.

RESULTS

Patients

5,031 patients had lumbar spine MRI studies at our institution during the study period of 01 November 2010 to 31 October 2015. 144 (2.9%) of these patients met the inclusion criteria of our study. No patients were excluded. There were 141 males and 3 females (average age 65.5 years, range 26–95 years). 107 (74.3%) of the 144 patients had an abnormal lumbar spine MRI. Each patient with an abnormality had an average of 2.4 abnormal findings.

Figure 6. A 68-year-old male with low back pain and lower extremity weakness. (a) Sagittal T_1 weighted Turbo spine-echo image shows severe left foraminal stenosis at L4/5 (arrow). (b) Sagittal reformatted CT image shows severe left foraminal stenosis at L4/5 (arrow), concordant with the MRI findings.

Figure 7. A 55-year-old male with metastatic pancreatic cancer. (a) Sagittal T_1 weighted contrast enhanced fat-suppressed Turbo spin-echo image shows a small 7-mm enhancing bone metastasis in the L1 vertebral body (arrow). (b) Sagittal contrast enhanced reformatted CT, obtained 1 month prior to the MRI, does not show the L1 vertebral body metastasis (arrow).

Table 1. Accuracy of abdominal CT in lumbar spine evaluation

	Findings	Patients
TP	244	96
TN	7086	36
FP	2	1
FN	12	11
Total	7344	144
D+	256	107
D–	7088	37
Sensitivity	95.3% (94.8–95.7%)	89.7% (84.7–94.6%)
Specificity	100% (99.9–100%)	97.3% (94.6–99.9%)
ppv	99.2% (98.9–99.3%)	99.0% (97.3–100%)
npv	99.8% (99.7–99.9%)	76.6% (69.6–83.5%)
Accuracy	99.8% (99.7–99.9%)	91.7% (87.1–96.1%)

D+, abnormal; D–, normal; FP, false positive; FN, false negative; npv, negative predictive value; ppv, positive predictive value; TN, true negative; TP, true positive.

Findings

There were 256 total abnormal findings on the lumbar spine MRI studies: 9 (3.5%) spondylodiscitis (Figures 1 and 2), 21 (8.2%) bone tumours (Figure 3), 23 (9.0%) spinal fractures (Figure 3), 44 (17.2%) herniated discs (Figure 4), 51 (19.9%) moderate to severe central canal stenoses (Figure 5), 91 (35.5%) moderate to severe foraminal stenoses (Figure 6), 12 (4.7%) spondylolesthesis and 5 (2.0%) spinal cord/canal abnormalities.

244 of the 256 total abnormal findings were identified on the blinded retrospective evaluation of the abdominal CT. 71% (173/244) of the abnormal findings were diagnosed as definitely present. 25% (61/244) of the abnormal findings were diagnosed as probably present. 4% (10/244) of the abnormal findings were

diagnosed as possibly present. Only 36 (14.1%) of the 256 total abnormal findings were diagnosed prospectively on the abdominal CT report.

The average number of months between the lumbar spine MRI and abdominal CT was 3.1 months.

On the abdominal CT studies, 14 discordant findings were found in 12 patients: 2 false positive foraminal stenoses, 5 false negative bone tumours (Figure 7), 3 false negative cord/central canal masses, 1 false negative spondylodiscitis and 3 false negative herniated discs. The average age of the patients with discordant findings was 63.4 years. The average number of months between the CT and MRI for the discordant findings was 3.4 months. The reasons for discordant findings were of four types: MRI superiority, severity grading differences between readers, non-contrast imaging and interval change between studies.

The sensitivity, specificity, accuracy, ppv and npv with 95% CI for both findings and patients are listed in Table 1.

DISCUSSION

Evaluation of the lumbar spine on abdominal CT became feasible in 2004 with 64 slice MDCT, which allows reconstruction of axially acquired data into thin section sagittal reformations with virtually isotropic resolution.⁶ Small field of view targeted reconstruction of the lumbar spine, which improves spatial resolution and is routinely performed on dedicated lumbar spine CT, is not typically used with abdominal CT since the lumbar spine is not the region of interest on abdominal CT.^{7,8} Small field of view targeted reconstruction of the lumbar spine can be done retrospectively on abdominal CT studies, but only for a limited time.⁹ Data storage limitations prevent indefinite saving of the raw data on the abdominal CT, which is necessary for targeted reconstruction. Retrospective targeted reconstruction was not done on any of our abdominal CT studies. This targeting is different from magnification, which can be done at any time, but does not improve spatial resolution like targeted reconstruction.⁸ Also, radiation reduction strategies can produce significant image noise in the lumbar spine on abdominal CT studies, reducing CT quality.¹⁰

3 mm is the maximally acquired slice thickness needed for diagnostic sagittal reformations for spine evaluation.^{11,12} The scanned axial slice thickness used in our study, which is typical for most state-of-the-art MDCT scanning, was 0.625 mm, significantly thinner than that needed for diagnostic sagittal reformations. Although the scanned axial slice thickness used by most imaging centres is less than 3 mm, spine pathology is rarely identified and reported on abdominal MDCT studies.⁵ Multiple studies found that fractures of the spine are rarely identified on MDCT studies of the chest and abdomen despite state of the art imaging, with only 0–16% of spine fractures being reported.^{5,11,13,14} In one study, only 9% of spine abnormalities including degenerative disc disease, facet joint osteoarthritis, scoliosis, bone tumours and vertebral fractures were mentioned in the official CT report on MDCT of the chest and abdomen despite images being acquired with 0.75-mm thin sections with subsequent 3-mm thin sagittal

reformations.⁵ In our study, only 14.1% (36/256) of the abnormal findings in the lumbar spine were identified prospectively on the original abdominal CT report, which is consistent with antecedent studies.

What are the possible explanations for spine pathology not being reported on abdominal MDCT? Better scanners produce more images. Abdominal MDCT studies typically are composed of about 750 images. Owing to the large number of images to be reviewed, spine evaluation may be excluded in order to save time.¹⁵ Lumbar spine pathology has traditionally not been reported on abdominal CT studies, bone window settings and sagittal reformations, which are needed for spine evaluation, may not be reviewed, radiologists trained in body imaging, although experts in evaluating abdominal CT studies, may not feel comfortable evaluating the lumbar spine and only findings determined to be clinically pertinent (which for abdominal CT is not the lumbar spine) may be reported, are additional considerations.^{5,13,15}

Our study suggests that abnormalities of the lumbar spine can be accurately detected on abdominal CT studies. The sensitivity, specificity, ppv, npv and accuracy of abdominal CT in lumbar spine evaluation on a per patient/per finding basis were 89.7/95.3%, 97.3/100%, 99.0/99.2%, 76.6/99.8% and 91.7/99.8%, respectively.

The reasons for discordant findings between the abdominal CT and lumbar spine MRI included MRI superiority, severity grading differences between readers, non-contrast imaging and interval change between studies. Two patients had diffuse bone marrow infiltration, seen on MRI but not on CT. These were probably true negatives as MRI is more sensitive than CT in evaluating bone marrow pathology.^{16,17} A 7-mm enhancing vertebral body metastasis was seen on lumbar spine MRI, but not on abdominal CT (Figure 7). The CT and MRI were obtained within 1 month of each other, so interval development is unlikely. Even in retrospect, the bone metastasis could not be seen on CT, consistent with the dictum that MRI is more sensitive than CT in the detection of non-cortical bone metastases.¹⁶ Three false negative CT findings were owing to small cord/central canal masses. Evaluation of the spinal cord and canal on CT is significantly limited compared with MRI so this discordance would be expected.^{17,18} Moderate to severe foraminal stenosis was diagnosed on the abdominal CT, but called mild stenosis on the lumbar spine MRI, resulting in two false positive foraminal stenoses in one patient based on severity grading differences between readers. A patient with spondylodiscitis and paraspinal abscess was also discordant between CT and MRI. The discitis and an enlarged paraspinal muscle were seen on the abdominal CT, with a suspected underlying abscess, but no abscess was visualized. The CT was, however, done without intravenous contrast while the MR was done with intravenous contrast, demonstrating that intravenous contrast is essential for abscess identification.¹⁸ Although spondylodiscitis was correctly diagnosed on CT in this case, spondylodiscitis is detected earlier on MRI than on CT.^{17,18} The average number of months between the CT and MRI for the discordant findings was slightly greater than for the group as a whole (3.4 vs 3.1

months, respectively). The longer the time interval between the two studies, the greater chance that a discordant finding could be caused by interval change rather than by diagnostic inaccuracy. Two patients had extensive bone metastases that were not seen on abdominal CT. These metastases probably developed in the 2–6 month interval between the MR and CT studies in each patient since it is implausible that such extensive disease seen on the MRI would not be seen, even in retrospect, on the abdominal CT studies. Herniated discs in three patients were seen on lumbar spine MRI but not on abdominal CT. These discrepancies could be due either to interval development of herniated discs in the 4–9 months between the two studies or false negative CT studies owing to the small size of the herniated discs.

Although abdominal CT was shown to be accurate in lumbar spine evaluation, diagnostic confidence for abnormal findings was reduced to probable in 25% (61/244) and possible in 4% (10/244) owing to increased quantum mottle or image noise. Increased image noise, with a degradation of image quality, results from voluntary radiation dose reduction techniques.¹⁹ The goal of radiation reduction techniques on CT is to reduce the radiation dose as much as possible without causing diagnostic confidence reduction, non-diagnostic studies, repeat imaging or diagnostic errors. Unfortunately, as shown in this study, achieving this balance is difficult.

The potential danger of radiation from CT imaging has been highlighted in the media. Several patients received radiation injuries from CT studies, instigating increased public scrutiny.¹⁹ Also, CT, while accounting for about one-eighth of all diagnostic imaging, delivers about six-eighths of the total radiation from these procedures.²⁰ By extrapolating atomic bomb survivor data, which demonstrates an increased cancer incidence from a single large radiation exposure of greater than 50–100 mSv, some scientists predict an increased cancer risk for lower levels of radiation.¹⁹ Diagnostic CT of the abdomen and pelvis typically generates

about 6 mSv of radiation exposure, well below the 50–100 mSv single large dose known to cause an increased cancer risk.²¹ Although the low dose radiation from CT has not been shown to cause cancer, most scientists support a linear no-threshold model, whereby an increase in radiation exposure is assumed to directly increase the risk of cancer.¹⁹ Consequently, radiation exposure from CT studies has been significantly reduced, which unfortunately also decreases image quality.

Our study has several limitations. First, our study population, which consisted of predominately an older male population, 2.1% of whom had a recent abdominal CT, may not be representative of other imaging centres. Second, intra/interobserver variation analysis was not performed in this retrospective study; prospective studies are needed for a more definitive evaluation. Finally, the CT and MRI studies in this study were separated by an average of 3.1 months, so this study's results could have been influenced by interval change. With a shorter time interval, however, the accuracy of lumbar spine evaluation using abdominal CT would be expected to improve.

CONCLUSION

Despite several limitations (e.g. spinal cord assessment, bone marrow assessment and quantum mottle) compared with evaluation of the lumbar spine using MRI, evaluation of the lumbar spine on abdominal CT studies can be accurately performed with current state-of-the-art CT scanners. Additional prospective studies are needed for a more definitive analysis.

INFORMED CONSENT

The local institutional review board approved this retrospective study and waived the informed consent requirement. This study complied with HIPAA guidelines.

ETHICAL APPROVAL

This retrospective study does not contain any procedures on human participants or animals performed by any of the authors.

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