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Superiority of MDCT with three-dimensional volume rendering over plain radiography in the assessment of spinal surgical instrumentation complications in patients with cancer

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Abstract

Objective—To compare multidetector computed tomography (MDCT) images with volume-rendered translucent display (VRTLD) series to plain radiographs for evaluating spinal surgical instrumentation following resection and reconstruction for spinal malignancies.

Methods—In 44 patients with tumor resection and spinal reconstruction, 17 with complications, three neuroradiologists evaluated plain radiographs, MDCT images alone, VRTLD images alone, and MDCT images with VRTLD images for identifying complications in three categories: subsidence/migration, construct fracture, and screw loosening. Each category was scored as 1 (complications), 2 (no complications), or 3 (not sure), and the minimum score was used for analyses. Clinical/surgical outcomes were the reference standard.

Results—Sensitivity, specificity, and accuracy (95% CI), respectively, were as follows: MDCT/VRTLD, 100%, 100%, 100% (91.96%-100.00%); MDCT alone, 88.24%, 100%, 95.45% (84.53%-99.44%); VRTLD alone, 82.35%, 96.3%, 90.91% (78.33%-97.47%); plain radiographs, 52.94%, 100%, 81.82% (67.29%-91.81%).

Conclusion—MDCT with VRTLD series seems best for evaluation of spinal instrumentation following tumor resection and reconstruction.

Keywords

Spine; Reconstruction; Complications; Multi-detector computed tomography

Introduction

The treatment of primary and metastatic spinal tumors often requires tumor resection. Following tumor resection, complex instrumentation and bone fusion may be needed for

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support, stabilization, and restoration of alignment and function. In such cases, spinal instrumentation is used to maintain or correct anatomic alignment of the spine and to provide stability in the early period after tumor resection, usually until solid biological fusion occurs. The change in spinal biomechanics after fusion increases stress on the adjacent levels above and below the surgical site, and instrumentation aids in alleviating these stresses.¹ If solid bony fusion is not achieved, instrumentation complications can occur as a result of stress on the instrumentation owing to continuous motion and pseudoarthrosis.^{2–7} Biomechanical complications include instrumentation subsidence or migration, hardware fracture, and screw loosening or pull-out.^{8–19} Subsidence is the migration greater than 3 mm of a support cage through the adjacent vertebral body endplate.¹⁸ A hardware fracture may involve the implant directly. Loosened pedicle screws appear radiographically as a rim of lucency exceeding 2 mm around the screw threads (or any hardware); or increases in size of a lucency over time.^{1,3,4,18} Early detection of construct complications is imperative to avoid neurological compromise and deficit.

While plain radiography has been the primary modality for evaluation of the spine after surgical procedures,²⁰ computed tomography (CT) has been used to evaluate surgical instrumentation and fusion^{20–23} and to detect instrumentation complications.^{1,6,20,24} Advances in multidetector CT (MDCT) allow for evaluation of the spine in multiple planes. A three-dimensional volume-rendered translucent display (VR TLD) series allows visualization of surgical instrumentation through the adjacent bony structures. The fact that VR TLD series are acquired through computer manipulation of the axial CT data without additional radiation exposure has led to an increase in demand for MDCT of the spine by surgeons at our institution, a major tertiary cancer center.

In this age of cost constraints, it is important to determine if more expensive imaging modalities are superior to less expensive modalities for diagnostic purposes. In a search of the medical literature, we could find no reports of studies comparing plain radiographs, MDCT images without and with the VR TLD series, and the VR TLD series alone in the evaluation of spinal surgical instrumentation and associated complications. Therefore, we sought to determine if MDCT images without or with the VR TLD series offer benefits over plain radiographs for evaluation of spinal surgical instrumentation and associated complications in patients after complex surgery for spinal tumor resection. We hypothesized that MDCT images with the VR TLD series would have a higher sensitivity and accuracy than plain radiographs, MDCT images alone, and the VR TLD series alone.

Materials and Methods

The Institutional Review Board at The University of Texas MD Anderson Cancer Center approved this study and waived the requirement for informed consent. Data were acquired in compliance with all applicable Health Insurance Portability and Accountability Act regulations. A retrospective review was done of MDCT examinations of the spine performed at our institution from January 2010 through April 2015 in patients who had undergone spinal tumor resection and reconstruction at our institution. MDCT examinations from 1253 patients were reviewed. From this group, 17 patients with instrumentation complications as indicated by clinical or surgical outcomes (the reference standard) were identified and

included in our study. An additional 27 consecutive patients without complications (as indicated by clinical or surgical outcomes) were also included. An attempt was made to match patients without complications with patients with complications on the basis of patient age and type of spinal instrumentation.

MDCT examinations were performed on a multidetector CT scanner (GE Medical Systems) in the axial plane, with two-dimensional images in the sagittal and coronal planes reformatted at the CT scanner by the technologist. Post-processing to provide the three-dimensional VR TLD series was performed by trained technologists on an Advantage AW4.2 workstation (GE Medical Systems) using Volume View software (GE Medical Systems).

When available, two-view plain radiographs in the posterior-anterior and lateral planes were reviewed.

For each patient, three neuroradiologists with a minimum of 15 years' experience interpreting spine CT images (NGT, TLC, and LK) independently reviewed the plain radiographs, MDCT images alone, VR TLD images alone, and MDCT images with the VR TLD series to determine whether complications were present. The four different imaging types were evaluated separately and in random order with at least 1 week between evaluations, and the reviewers were blinded to the results of the studies. The readers looked for complications in the following three categories: instrumentation subsidence or migration (Figures 1 and 2), instrumentation/construct fracture (Figure 3), and screw loosening (Figure 4). Each category was scored as 1 (complications), 2 (no complications), or 3 (not sure). If any of the categories had evidence of complications, the hardware construct was considered to have complications.

Summary statistics of rating was calculated in frequency tables and percentages by category, modality, reader, and failure status. Overall rating of each reviewer was obtained by taking the minimum score of all categories. A consensus overall score was obtained using majority voting and diagnostic performance metrics (accuracy, sensitivity, specificity, PPV, and NPV) were estimated by modality. Fisher's exact test was used to test associations between patient symptoms and the presence or absence of surgical complications. All tests were two-sided and p-values of 0.05 or less were considered statistically significant. Statistical analysis was carried out using SAS version 9.4 (SAS Institute, Cary, NC). Kappa testing was used to determine inter-observer variability.

Results

The types of instrumentation in the 27 patients without complications are listed in Table 1. The demographics, primary tumor type and location, and instrumentation in the 17 patients with instrumentation complications are included in Table 2. The complications were instrumentation subsidence/migration in 12 patients, instrumentation/construct fracture in two patients, and screw loosening in 3 patients (Table 2). Forty-three patients had plain radiographs for review, and 44 patients had MDCT and VR TLD studies available for review.

Summary of accuracy status by modality, reader, and indication are provided in Table 3. When a failure was detected, the PPV of plain film, CT, VR TLD, and MDCT with VR TLD were about 75%, 85%, 80%, and 90%, respectively. The performance of the different imaging categories in identifying instrumentation complications is summarized in Table 4. MDCT images with the VR TLD series had the highest sensitivity (100%), specificity (100%), and accuracy (100%; 95% CI, 91.96%-100.00%). Kappa statistics demonstrated at least substantial agreement between the neuroradiologists for all modalities (Table 5). Complications associated with false-positive and false-negative findings by imaging category are listed in Tables 6 and 7, respectively.

Fifteen of the 17 patients (88%) with complications had back pain or weakness, compared to six of the 27 patients (22%) without complications ($p < 0.0001$ by Fisher's exact test).

Discussion

Our results demonstrate that MDCT images with the VR TLD series were the most sensitive, specific, and accurate of the imaging types that we studied in the detection of spinal surgical instrumentation complications. The addition of the VR TLD series to MDCT images alone increased sensitivity from 88.2% to 100% and accuracy from 95.5% to 100%. The VR TLD series alone had lower sensitivity, specificity, and accuracy than MDCT images alone. This indicates that care should be taken in interpretation of the VR TLD series alone, especially when the focus of the evaluation is for screw loosening. The kappa statistics for VR TLD were substantial.

To detect instrumentation complications, radiologists should assess each vertebral level individually. When evaluating for cage subsidence, we find that the sagittal and coronal planes on MDCT images and the VR TLD series are the most helpful. By scrolling through the images and comparing the superior and inferior aspect of the cage in relation to the endplate, one can detect cage subsidence into the adjacent vertebral body (Fig 1). This is true especially when an anterior or lateral fusion plate is used because the plate obscures the operative field on plain radiographs (Fig 1C and 1D). To detect subsidence, the distance between the instrument/endplate interface and the anterior and posterior margins of the vertebral body (sagittal plane) or the lateral margins of the vertebral body (coronal plane) should also be measured on the initial postoperative study and subsequent scans and compared between scans (Fig 2).

It is particularly important to detect loose screws early because the loose screws may retract over time and can be expelled from bone, resulting in further complications. Screw loosening is characterized by lucency around the screw. When aseptic screw loosening is detected associated fusion failure or infection may occur.^{1,3,4,6}

Both plain radiographs and CT images have been described in the literature as providing relevant diagnostic information about surgical grafts, implants, and hardware.^{3,4,25} The primary imaging modality for postoperative evaluation of spinal fusion has been plain radiography because of its universal availability and cost-effectiveness. However, CT has been reported to be more accurate for imaging of the spine,^{3,26,27} especially for imaging

bone detail; the position of instrumentation, including pedicular screws; alignment; degree of bone fusion; and postoperative complications.^{28,29} Our results confirm these findings and further show that MDCT with addition of the VR TLD series has higher sensitivity and accuracy than MDCT alone.

MDCT allows acquisition of high-resolution isotropic data from which two-dimensional reformatted images can be obtained in sagittal, coronal, and axial planes even with varying angulation; such images are considered standard of care for imaging of spinal trauma in many emergency departments.^{23,30,31} Shah et al³² described the benefit of CT with sagittal and coronal reformatted images compared to plain radiographs in assessment of surgical fusion cages and the bony trabeculation that subsequently forms. In their study, two observers identified bridging trabeculation surrounding the fusion cages on CT scans in 90% of cases but on radiographs in only 8% of cases. In addition, a radiolucent interface around the metallic cages suggesting non-fusion of the cage was recognized in six patients on CT scans and in only two patients on plain radiographs. Multiple other authors have characterized CT images as being preferred for monitoring interbody spinal fusion.^{33–38} Similarly, we have found that sagittal reformatted images are especially useful to monitor an anterior or lateral spinal fusion migration.

In addition to the sagittal and coronal reformatted images, VR TLD images can be reformatted from the source axial MDCT images. These VR TLD images can be rotated and provide a 360-degree view of the spine construct. Zinreich et al³⁹ evaluated patients with postsurgical “failed back” syndrome and found that the three-dimensional images provided information beyond that provided by the direct axial and multiplanar two-dimensional reconstructed images in 76 of 100 patients with fusions. Ohashi et al²¹ retrospectively reviewed MDCT studies, which included multiplanar reformatted images and three-dimensional images, in 109 patients, 23 with complications, for possible orthopedic instrumentation complications of the spine. These authors found a sensitivity of 74% and specificity of 95%, and they concluded that MDCT is an effective tool for detecting orthopedic hardware complications. Similarly, our results demonstrated that MDCT images with the VR TLD series were the most sensitive and accurate in evaluation of spinal instrumentation.

The cases in our study were collected by review of postoperative MDCT examinations; thus, the results may be biased towards MDCT as hardware complications in other patients may have been successfully visualized with plain radiographs only. However, we have illustrated the advantages of MDCT with the VR TLD series over plain radiography in the evaluation of surgical hardware complications. Again, we are not proposing that MDCT will replace plain radiography of the spine following tumor resection. Rather, our findings indicate that in certain, if not all, patients with hardware complications, MDCT images with the VR TLD series are more sensitive and accurate than plain radiographs.

Patel et al⁴⁰ evaluated the frequency of CT after spine surgery. They found that the prevalence of postoperative CT was lower for simple compared to complex procedures at all studied time intervals. By 5 years 40% of patients with a complex surgery had a CT scan whereas in patients who underwent a simple procedure the frequency did not exceed 30%.

Further study could evaluate the necessity of MRCT with VR TLD for detection of hardware complications in simple versus complex reconstructions. It could also be of interest to study the necessity of CT for detection of hardware complications in symptomatic versus asymptomatic patients as 15 of 17 patients (88%) in our study with hardware complications exhibited pain or weakness.

MDCT requires radiation for image acquisition, and the amount of radiation required can range from 5 mSv to 8 mSv.⁴¹ Because of concerns about radiation exposure,^{42,43} the spine surgeon and radiologist should determine if the benefits of MDCT outweigh the risks associated with the radiation dose.

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Figure 1.

Subsidence (patient 2). A,B, Frontal and lateral radiographs following vertebrectomy with placement of an expandable titanium cage and lateral fusion with a metallic plate [Note position of the cage resting on the adjacent inferior and superior endplates (arrows in A)]. C,D, Follow-up radiographs. Subsidence of the cage into - the superior endplate (arrow in C) is difficult to detect. The fusion plate in B and D obscures the view of the titanium cage. E,F, Coronal and sagittal MDCT images of the operative site show the cage resting on the superior endplate (arrows). G,H, Follow-up MDCT images demonstrate subsidence of the cage into the adjacent vertebral bodies. Note the position of the cage (large arrows) relative to the adjacent inferior and superior endplates (small arrows).

Figure 2.

Migration (patient 10). A, Lateral radiograph following multilevel vertebrectomy with placement of a methylmethacrylate graft and Steinmann pin (arrow). B, Follow-up lateral radiograph. Posterior migration of the graft and pin are difficult to detect (arrow). C,D, Preoperative and postoperative MDCT show interval posterolateral migration of the Steinmann pin. Note the position of the inferior portion of the pin relative to the posterior aspect of the vertebral body (arrows). E,F, Preoperative and postoperative VR TLD images demonstrate posterior migration of the pin (arrows). This sequence can be viewed from 360°.

Figure 3.

Instrumentation fracture (patient 11). A,B, Frontal and lateral radiographs following lumboiliac stabilization. Fracture of the right iliac screw is quite apparent (large arrows) but the fracture of proximal left iliac screw is less conspicuous (small arrows). C, Sagittal MDCT image demonstrates a displaced fracture of the proximal left iliac rod (arrow). D, VR TLD image with bone that is removed easily to demonstrate displaced fractures of the iliac rods (arrows).

Figure 4.

Screw loosening (patient 5). A,B, Frontal and lateral radiographs following L4 laminectomy and posterior metallic stabilization with subtle lucency and adjacent sclerosis related to loosening of the right L3 pedicle screw (arrow). C,D, Axial and sagittal MDCT images. Lucency and adjacent sclerosis are more easily visualized (arrows).

Table 1

Surgical procedure and instrumentation type in the 27 patients without complications

Surgical procedure(s) and instrumentation	No. of Patients
Vertebrectomy, expandable titanium cage placement, and anterior fusion	10
Vertebrectomy, expandable titanium cage placement, and anterior and posterior fusion	3
Vertebrectomy with laminectomy with posterior stabilization	3
Posterior stabilization	2
Corpectomy with anterior stabilization	2
Partial vertebrectomy with posterior stabilization	2
Vertebrectomy, expandable titanium cage placement, and posterior fusion	1
Corpectomy with anterior and posterior stabilization	1
Partial vertebrectomy with anterior stabilization	1
Decompression with posterior stabilization	1
Partial sacrectomy with lumbopelvic stabilization	1

Table 2

Demographics, primary tumor type and location, and instrumentation complications in the 17 patients with complications

Patient	Age, years/Sex	Tumor type	Tumor location	Prior surgery	Instrumentation complication
1	55/F	Chordoma	Sacrum	Resection Total sacrectomy Iliolumbar fusion	Collapse of anterior fusion (migration)
2	62/F	Melanoma	L3	L3 vertebrectomy Expandable titanium cage placement Anterior plate placement, L2-4	Subsidence of cage into L2 and L4 vertebral bodies
3	63/M	RCC	T5-6	T5 and T6 vertebrectomy Methylmethacrylate reconstruction Posterior stabilization, T3-9	Tilted graft (migration)
4	52/F	RCC	T12	T12 vertebrectomy Expandable titanium cage placement Anterior plate placement, T11-L1	Vertebral body collapse (migration)
5	65/M	RCC	L4	L4 laminectomy Posterior stabilization, L3-5	L3 screw loosening
6	65/M	RCC	L3	L3 vertebrectomy Expandable titanium cage placement Anterior plate placement, L2-4	Posterior migration of cage
7	57/M	Renal sarcomatoid carcinoma	C2	C1-2 laminectomy Posterior stabilization, occiput-C5	Collapse of C1-2 construct with retropulsion (migration) <i>Tumor progression</i>
8	57/F	Ependymoma	Sacrum	Tumor resection Anterior fusion, T4-S1 T10-sacral fusion	Loosening of iliac fixation screws
9	33/M	Melanotic schwannoma	C5,6	Resection Posterior stabilization, C4-7	C6 screw loosening <i>Tumor progression</i>
10	39/M	RCC	T2-4	Vertebrectomy, T2-4 Steinmann pin placement Methylmethacrylate reconstruction Posterior stabilization, C5-T7	Posterior migration of methylmethacrylate
11	57/F	Multiple myeloma	S1-2	Fixation, L3-sacrum	Fracture of fixation rods
12	51/M	Colon cancer	C3	C3 vertebrectomy Expandable titanium cage placement Anterior stabilization, C2-4	Cage tilting (migration)
13	70/M	RCC	C5	C5 corpectomy Anterior stabilization, C4-6 Methylmethacrylate reconstruction	Fracture of inferior pedicular screw <i>Tumor progression</i>
14	33/F	Giant cell tumor	T8-10	Vertebrectomy, T8-10 Methylmethacrylate reconstruction Posterior stabilization, T5-L1	Migration of methylmethacrylate graft
15	49/M	Thyroid cancer	T7	T7 vertebrectomy	Migration of Steinmann pin

Patient	Age, years/Sex	Tumor type	Tumor location	Prior surgery	Instrumentation complication
16	67/F	Breast cancer	C5	Steinmann pin placement Methylmethacrylate reconstruction Posterior stabilization, T5-9 C5 vertebrectomy Expandable titanium cage placement Anterior stabilization, C4-6	Cage subsidence
17	53/M	Colon cancer	C3	C3 vertebrectomy Expandable titanium cage placement Anterior stabilization, C2-4	Cage migration

F, female; M, male; RCC, renal cell carcinoma.

Table 3

Summary of accuracy statistics by reader and modality

Category	Modality	Reader	Failure	No.	%	No.	%
Overall	CT	A	No	12	44.44	15	55.56
			Yes	3	17.65	14	82.35
		B	No	12	44.44	15	55.56
			Yes	1	5.88	16	94.12
		C	No	12	44.44	15	55.56
			Yes	3	17.65	14	82.35
		All	Failure				
			No	36	44.44	45	55.56
			Yes	7	13.73	44	86.27
	CT/VR	Reader	Failure				
		A	No	13	48.15	14	51.85
			Yes	3	17.65	14	82.35
		B	No	14	51.85	13	48.15
			Yes	1	5.88	16	94.12
		C	No	15	55.56	12	44.44
			Yes	1	5.88	16	94.12
		All	Failure				
			No	42	51.85	39	48.15
			Yes	5	9.80	46	90.20
	VR	Reader	Failure				
		A	No	16	59.26	11	40.74
			Yes	4	23.53	13	76.47
		B	No	14	51.85	13	5
			Yes	3	17.65	14	82.35
		C	No	14	51.85	13	48.15
			Yes	2	11.76	15	88.24
		All	Failure				

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Category	Modality	Reader	Failure	No.		%	
				No.		%	
Plain Radiograph		Reader	No	44	37	54.32	45.68
			Yes	9	42	17.65	82.35
			Failure				
		A	No	13	14	48.15	51.85
			Yes	3	13	18.75	81.25
		B	No	12	15	44.44	55.56
			Yes	5	11	31.25	68.75
		C	No	12	15	44.44	55.56
			Yes	4	12	25.00	75.00
		All	Failure				
			No	37	44	45.68	54.32
			Yes	12	36	25.00	75.00

Table 4

Performance of imaging studies in identification of spinal instrumentation complications after resection and reconstruction for spinal malignancies.
Consensus overall score was used for each modality.

Imaging study/studies	Hardware Complication Status						
	No Complication (N = 27)		Complication (N = 17)		All (N = 44)		
	No Complications by Imaging, no.	NPV, %	Specificity, %	Complications by Imaging, no.	PPV, %	Sensitivity, %	Accuracy, % 95% CI for Accuracy
MDCT images alone	27	93.1	100	15	100	88.24	95.45 84.53-99.44
MDCT and VRTLD images	27	100	100	17	100	100	100 91.96-100.00
VR TLD images alone	26	89.66	96.3	14	93.33	82.35	90.91 78.33-97.47
Plain radiographs	27	77.14	100	9	100	52.94	81.82 67.29-91.81

Table 5

Summary of Kappa statistics by modality using overall ratings.

Modality	Kappa	95% LCL	95% UCL
CT	0.68	0.51	0.85
CTVR	0.71	0.54	0.88
VR	0.73	0.56	0.90
Plain Radiographs	0.81	0.64	0.98

Kappa	Interpretation
< 0	Poor agreement
0.01 – 0.20	Slight agreement
0.21 – 0.40	Fair agreement
0.41 – 0.60	Moderate agreement
0.61 – 0.80	Substantial agreement
0.81 – 1.00	Almost perfect agreement

Table 6

Complications associated with false-positive findings by at least one radiologist by type of image

<u>Plain radiographs</u>
Construct collapse (1 case)
Screw loosening (4 cases)
<u>MDCT images only</u>
Construct collapse (1 case)
Screw fracture (1 case)
Screw loosening (1 case)
<u>VL TLD images only</u>
Construct collapse (1 case)
Screw loosening (4 cases)

Table 7

Complications missed by two or more radiologists by type of image

Plain radiographs

Cage subsidence (1 case)

Fractured transpedicular screw (1 case)

Tilted methylmethacrylate graft (1 case)

Migrated Steinmann pin (1 case)

Screw loosening (2 case)

Tilted cage (1 case)

MDCT images only

Tilted methylmethacrylate graft (1 case)

VR TLD images only

Tilted methylmethacrylate graft (1 case)

Fractured transpedicular screw (1 case)