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This information is current as of May 9, 2025.

AJNR Am J Neuroradiol 2008, 29 (8) 1446-1449

doi: <https://doi.org/10.3174/ajnr.A1152>

<http://www.ajnr.org/content/29/8/1446>

**ORIGINAL
RESEARCH**

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Fracture Detection in the Cervical Spine with Multidetector CT: 1-mm versus 3-mm Axial Images

BACKGROUND AND PURPOSE: Multidetector CT imaging of the cervical spine performed with submillimeter collimation allows for the production of excellent quality multiplanar reformations and reconstructed axial images at any chosen section thickness. Currently there is no consensus on what images need to be reviewed for accurate diagnosis of cervical spine fractures. Our study assesses whether 1-mm axial images provide any diagnostic advantage over 3-mm images in detection of cervical spine fractures when read in conjunction with multiplanar reformations.

MATERIALS AND METHODS: The dataset consisted 50 cases of CT of the cervical spine and included 25 consecutive cases of cervical spine fractures and 25 matched normal CTs. Axial images were reconstructed at 1- and 3-mm thicknesses, and the sagittal and coronal reformations between 2- and 3-mm thicknesses. Four radiologists reviewed all 50 of the cases twice, once at 1 mm and once at 3 mm. Reads were separated by 3 months.

RESULTS: There were 39 fractures in total, consisting of 29 clinically significant and 10 insignificant fractures. Thirty-three fractures were missed in 400 reads. Twenty-one misses were at 3 mm (sensitivity, 86%), and 12 misses at 1 mm (sensitivity, 92%; $P = .228$). Ten of 33 misses were of clinically significant fractures, 6 misses at 1 mm and 4 at 3 mm ($P = .52$). Twenty-three of 33 misses were of clinically insignificant fractures, 6 at 1 mm and 17 at 3 mm ($P = .006$).

CONCLUSION: For detection of clinically important fractures, there is no significant difference between 1- and 3-mm axial images when read in conjunction with multiplanar reformations.

Multidetector CT imaging of the cervical spine performed with submillimeter collimation allows for the production of excellent quality multiplanar reformations and reconstructed axial images at any chosen section thickness. The large image dataset and the ability to reconstruct a vast number of images leads to issues with data storage and time needed to review the examination. Currently there is no consensus on what images need to be reviewed for accurate diagnosis of cervical spine fractures. The standard in our institution is to read 1-mm axial images with sagittal and coronal reformations. The purpose of our study was to assess whether 1-mm axial images provide any diagnostic advantage over 3-mm images in the detection of cervical spine fractures when read in conjunction with multiplanar reformations, thereby providing objective data in the formulation of guidelines for the assessment of cervical spine CTs.

Materials and Methods

Institutional review board permission was granted for this study. The study dataset consisted of 50 cases of CT of the cervical spine. Twenty five were consecutive cases of cervical spine fractures that presented to Oregon Health & Science University (OHSU) between April and June 2005. These were matched with 25 "normal" CTs based on the initial

read scanned at OHSU during the same period. All of the patients had history of trauma necessitating CT of the cervical spine and were scanned on a 16-section multidetector CT scanner (Philips Healthcare, Eindhoven, the Netherlands). The technical factors were 350 mAs, 140 kV, pitch 0.663, and an acquisition thickness of 0.75 mm. Axial images were created at 1-mm and 3-mm thicknesses from the same source data for each patient. The sagittal and coronal images were reformatted between 2 and 3 mm, and the same set of sagittal and coronal reconstructions was used for the 1-mm and 3-mm axial read on each patient.

Four radiologists reviewed each of the 50 cases twice, once at 1 mm and once at 3 mm. Images were reviewed on a PACS workstation (Agfa, Ridgefield Park, NJ). At the first read, each individual case was read 4 times, by 2 radiologists at 1 mm and 2 other radiologists at 3 mm. Each radiologist read 25 cases at 1 mm and 25 cases at 3 mm. The order of the cases was random with respect to fracture distribution. At this first read, radiologists were asked to review the coronal and sagittal reformations first and to document the presence of fractures and then to review the single specified set of axial images before making a final analysis.

The second read was performed to decrease the effect of interobserver variability. This was conducted 2 to 4 months (average, 3 months) after the first read, and the order of cases was reversed so as to decrease the reader familiarity with the cases. Each radiologist reviewed the opposite set of axial images that they reviewed on the first read. The instructions for the read were also changed such that the axial images were reviewed first to document the presence of fractures, and the multiplanar reformations were reviewed second to document any additionally detected fractures.

A consensus panel of 2 radiologists reviewed all of the available imaging for findings and image quality, as well as the clinical notes for all 50 of the patients. The age range of the patients was 3 to 93 years (mean age, 45.6 years). There were 40 male patients and 10 female

Received January 2, 2008; accepted after revision March 25.

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Previously presented in part at: Annual Meeting of the American Society of Neuroradiology, May 2, 2006; San Diego, Calif.

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DOI 10.3174/ajnr.A1152

Table 1: Missed significant fractures

Fracture Description	No. of Times Missed	No. of Misses at 1 mm	No. of Misses at 3 mm
Left occipital condyle fracture	3	1	2
Nondisplaced fracture through the base of dens	2	1	1
C7 anterior superior endplate fracture	2	2	0
C1 anterior/posterior arch fractures (Jefferson)	1	0	1
Left occipital condyle fracture	1	1	0
C6 anterior superior endplate fracture	1	1	0

Table 2: Missed nonsignificant fractures

Fracture Description	No. of Times Missed	No. of Misses at 1 mm	No. of Misses at 3 mm
Mildly displaced fracture of the right transverse process of C6	4	1	3
Minimally displaced fracture of the right transverse process of C7	4	1	3
Fracture through inferolateral C6 vertebral body, at uncovertebral joint	4	1	3
Comminuted fracture of the right transverse process of C3	3	1	2
Right C7 transverse process fracture	2	0	2
Right C7 transverse process fracture	2	1	1
Left C1 transverse process fracture	2	0	2
C5 spinous process fracture	1	1	0
Nondisplaced right C7 transverse process fracture	1	0	1

Table 3: Sensitivity of fracture detection for all fractures

Detection	1-mm Images	3-mm Images
Fracture detected	144	135
Fracture not detected	12	21
Sensitivity of fracture detection	92.3	86.5

Note: $-P = 0.2280$.

patients. The final dataset consisted of 39 fractures in 26 patients. For fracture categorization, a fracture involving 1 geographic region but 2 contiguous levels was considered to be 1 fracture. Compared with the initial clinical interpretations, 2 additional fractures were identified. The 39 fractures were further subclassified by clinical significance according to the definition in the NEXUS Study,¹ where a clinically nonsignificant fracture was defined as one that was not expected to cause harm to the patient if not identified and would ordinarily not receive any specific treatment. Twenty-nine fractures were deemed clinically significant and 10 clinically insignificant.

Statistical analysis was performed by creating a binary variable to represent correct fracture detection, and a logistic regression model was fitted to assess whether 1-mm axial images provide any diagnostic advantage over 3-mm images. The model took into account the reader differences, and all of the reads were used in this analysis. McNemar test of symmetry was used to assess the intraobserver variability of the results between months 0 and 3. The χ^2 and Fisher exact tests were used to assess the differences between 1-mm and 3-mm images for each reader. The 63 data points used in the analysis consisted of 39 fractures and 24 “no fractures.”

Results

Missed significant and nonsignificant fractures are shown in Tables 1 and 2, respectively. Tables 3–5 compare sensitivities of fracture detection between 1 mm and 3 mm in 3 groups: all fractures, clinically significant fractures, and nonclinically significant fractures. The P values obtained from the logistic regression model comparing the difference in fracture detection at 1 mm and 3 mm are also shown.

Table 4: Sensitivity of fracture detection for clinically significant fractures

Detection	1-mm Images	3-mm Images
Fracture detected	110	112
Fracture not detected	6	4
Sensitivity of fracture detection	94.8	96.6

Note: $-P = 0.5164$.

Table 5: Sensitivity of fracture detection for clinically insignificant fractures

Detection	1-mm Images	3-mm Images
Fracture detected	34	23
Fracture not detected	6	17
Sensitivity of fracture detection	85	57.5

Note: $-P = 0.0064$.

In the first read, the fracture detection rate from review of the multiplanar reformatted images before the review of the axial images was 83%. In the second read, the multiplanar reformatted images assisted in the diagnosis of fractures not seen on the initial read 19 times (19 of 116 total fracture reads, 16.4%). The fracture detection rate in the actual clinical reads was 95% (37 of 39).

McNemar test for correct detection of fracture between 0 and 3 months gave P values of .4386 for 1-mm images and 0.1967 for 3-mm images. Because the McNemar test P values for 1-mm and 3-mm axial images are not significant at the 0.05 level (ie, $P > 0.05$), the difference between the reads at the start of the study and after the third month is not significant.

The χ^2 or Fisher exact test (when the number of incorrect detection was too small) was used to assess the difference between 1-mm and 3-mm images for each reader. Three readers had a higher percentage of correct detection with 1-mm images. Reader 1 correctly detected all of the fractures by using the 1-mm images but only detected 90.48% of the fractures by using the 3-mm images. The Fisher exact test P value of .0276

indicates that there is a significant association between (correct) detection and the image type. Reader 3 had more correct reads at 3 mm; however, for readers 2, 3, and 4, the nonsignificant P values ($P > .05$) indicate that there is no significant association between correct fracture detection and image type.

Discussion

CT of the cervical spine has an established role in the imaging of the trauma patient, because it is more sensitive than plain radiographs in the detection of fractures²⁻⁸ and is also more cost-effective in the moderate- and high-risk patient.⁴ Multi-detector CT allows the rapid acquisition of volume data.⁹ However, this “data explosion”¹⁰ leads to problems with data storage and raises issues of how to best use the data, because images can be reconstructed at any section thickness and in multiple planes. Consideration must also be given to the time needed to read the study. There is little in the literature about how the data from a CT of the cervical spine are optimally reviewed. The notion exists that thinner sections are better.¹¹ In the craniofacial bones, reformatted images reconstructed from thinner collimation have been shown to be advantageous with respect to subtle fracture detection.¹² It has also been shown that 1-mm axial images are superior to 3-mm images with respect to detection of nondisplaced dens fractures,¹³ though this study did not demonstrate the same benefit of the coronal and sagittal reformatted images, as was seen in our study. The standard in our institution is to read 1-mm axial images with sagittal and coronal reformations. The purpose of our study was to compare 1-mm and 3-mm axial CT images with respect to fracture detection in the cervical spine, thereby providing objective data in the formulation of guidelines for the assessment of cervical spine CTs. Our results suggest that there is no significant diagnostic advantage of 1-mm over 3-mm axial images when read in conjunction with multiplanar reformations.

Comparing all of the results for 1 mm and 3 mm, fracture detection was slightly greater with 1-mm axial images compared with 3-mm images (92% compared with 86.5%), but the difference was not statistically significant ($P = .22$). In the diagnosis of clinically significant fractures, the 3-mm axial images actually performed slightly better than the 1-mm images (sensitivity: 3 mm, 96.5; 1 mm, 94.8), but this difference was not statistically significant ($P = .52$). However, in the non-clinically significant fractures, the 1-mm axial images performed considerably better than the 3-mm images (sensitivity, 85 compared with 58; $P = .0064$). The medicolegal implication¹⁴ of missing such fractures is uncertain, and it is beyond the scope of this article to speculate on such matters.

McNemar test demonstrated no significant intraobserver difference between 1-mm and 3-mm images over the 2 reads separated by 3 months. However, there was some variability in the individual reader's performance at 1 mm and 3 mm. Of the 3 readers who detected more fractures at 1 mm, only 1 of the 3 had a statistically better performance at 1 mm. This reader also had the second highest overall detection rate and correctly detected all of the fractures at 1 mm. One reader performed better with 3-mm images, but this was not a statistically significant result.

Because the end point in our study was fracture detection, a radiologic finding, the results were stratified according to

clinical significance in an effort to increase the clinical relevance. As mentioned previously, the definition used in our study was the same as that in the NEXUS Study.¹ Of the 39 fractures in our study, 10 were deemed not to be significant. These clinically nonsignificant fractures consisted of 8 fractures involving the transverse process, a single fracture of the spinous process, and a minimally displaced fracture of the inferolateral vertebral body. Historically, the relevance of diagnosing clinically insignificant fractures is unclear. In 1971, Abel¹⁵ showed that, by performing an 11-view cervical spine series, it was possible to diagnose more fractures than with a conventional 5 view series. However, because the additional detected injuries were not associated with neurologic impairment or disability, it was decided that a 5-view series was sufficient. Conversely, Woodring et al¹⁶ stressed the importance of diagnosing transverse process fractures due to the association with vertebral artery dissection and brachial plexus injury. We acknowledge the limitation of the definition of clinical significance used in this study but stress that, of the 8 transverse process fractures in the study, only 3 fractures abutted the foramen (or vertebral artery), and none had fragments displaced into the foramen. Two of these 3 fractures were at C7 and are, therefore, of uncertain significance given that the vertebral artery does not enter the C7 foramen in most patients. One was at C1, immediately adjacent to vertebral artery. CT angiography was not clinically necessary in any of these patients.

In the assessment of imaging technology, an important feature to consider is whether the results are generalizable to everyday practice.¹⁷ Our study used imaging from a 16-detector CT scanner, and, therefore, our results may not be applicable to the assessment of images from other CT scanners, particularly those with less detectors and lower image quality.

In addition, there are a number of phenomena that may hinder the generalizability of results. One of these is the “study knowledge effect,” which predicts that participants in a study will behave differently due to the knowledge that their results will have no clinical consequence.^{18,19} This may be a potential limitation in our study. The overall fracture detection rate was 89.4% in 400 reads. The actual detection rate in clinical practice is probably closer to 95% (37 of 39), based on the 2 fractures missed on the original reads that were subsequently detected by the consensus panel.

The prevalence effect has also been described as a factor that may hinder the generalizability of study results to clinical practice.²⁰ It states that the results of a study may be affected by the case mix, particularly when study and clinical populations have different proportions of negative cases.²¹ In our study, the prevalence rate of cervical spine fracture was 52%, considerably greater than in clinical practice. However, a recent study showed that prevalence had no effect on the detection of abnormalities in the laboratory setting.¹⁸ Therefore, the effect of translating these results to the clinical setting remains uncertain.

In our study, 12 of the 26 patients had more than 1 fracture. There was a total of 33 times that fractures were missed by 4 reviewers, of which 26 (79%) were in patients who had fractures elsewhere in the cervical spine that were identified by the reader. This is likely to illustrate the “satisfaction of search” phenomenon, described as a situation where the diagnosis of

one radiographic abnormality interferes with the diagnosis of others.^{22,23} The most commonly missed fractures in our study were minimally displaced transverse process fractures at C6 and C7 in a patient with an occipital condyle fracture (both C6 and C7 fractures were missed in 50% of the reads) and a minimally displaced fracture of the inferolateral C6 vertebral body in a patient with complex fractures elsewhere (also missed in 50% of the reads). Seventy percent of the clinically significant misses were between C0 and C2. The upper cervical spine has also had a higher rate of misdiagnosed fractures in other studies.²⁴

There are a number of interesting observations in our study regarding the use of multiplanar reformatted (MPR) images. Consensus panel review demonstrated that all of the fractures were visible on 1-mm and 3-mm images, as well as multiplanar reformations, but were not as frequently detected on the 3-mm data or MPR images, though they were often at least as conspicuous as on the 1-mm axial images. Given that the study design requested readers to review the MPR images on all of the reads, there theoretically should not have been a difference in the sensitivities of the 1-mm and 3-mm images. This finding, along with the relatively low (83%) fracture detection rate on the MPR images on the first read, suggests that there remains a reliance on the axial images. On the second set of reads, the MPR images enabled our readers to diagnose an additional 16% of fractures, further highlighting their importance. This knowledge of the usefulness of the MPR images has the potential to change clinical practice and concurs with findings in a study by Begemann et al.²⁵ For example, it would seem reasonable to assess these images first and expect to diagnose most fractures. Three-mm axial images could be subsequently used to confirm the findings. The use of MPR images in the assessment of cervical spine fractures is an area that warrants further evaluation.

Conclusion

For detection of clinically significant fractures, there is no significant difference between 1- and 3-mm axial images when read in conjunction with multiplanar reformations.

Acknowledgments

Biostatistics support was provided by the Biostatistics and Bioinformatics Shared Resource of the Center for Biostatistics, Computing, and Informatics in Biology and Medicine at Oregon Health & Science University.

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