Support Line and Tube Visibility in Chest Examinations Using Computed Radiography

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The visibility of support lines and tubes was compared in computed radiography (CR) and screen-film adult chest radiographs. Parameters investigated were radiation dose, image minification, and the use of unsharp mask enhancement. Five radiologists rated the visibility of support lines and tubes on a five-point scale ranging from 1 (entire course of line visible) to 5 (line not visible or only small portion seen). These CR results were compared with the visibility of support lines and tubes as assessed by the same readers for conventional screen-film radiographs (600 speed). Support line and tube visibility improved with image enhancement, image minification, and increasing radiation dose. At the same radiation exposure, support line and tube visibility of the screen-film combination was superior to that of standard CR images. Application of an unsharp mask enhancement algorithm to CR images, however, significantly improved support line and tube visibility in comparison to that obtained with the screen-film combination. It was concluded that unsharp mask processing is a valuable tool for improving the visibility of support lines and tubes in CR chest radiographs.

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KEY WORDS: Chest radiology; computed radiography; image enhancement; patient doses; support lines and tubes; computers; radiology

ONE MAJOR advantage of computed radiography (CR) systems is their wide linear response over four orders of magnitude, which permits films to be obtained with the required film density independent of the radiation level used to expose the CR imaging plate.¹⁻³ With CR, the amount of radiation used to perform radiographic examination affects the level of radiographic mottle in the resultant image.^{4,5} CR systems allow images to be processed to enhance the visibility of selected image features and may employ differing sizes (minification) of the displayed image.^{6,7} Image quality, and the resultant imaging performance of CR, has been shown to depend on radiation dose,⁸ unsharp mask processing,^{9,10} and image display

size.^{7,11} Increased knowledge pertaining to these factors for specific clinical applications would help to optimize the use of CR.¹²

Bedside chest radiography is an important clinical area of radiology with a continuing need to improve image quality.¹³ CR is an imaging modality which offers significant benefits when used to perform bedside examinations.^{2,3,12} An important role of bedside chest radiography in the intensive care unit setting is verifying the position of support lines and tubes and monitoring any changes in their location.^{14,15} In this study, CR chest examinations obtained from an adult medical intensive care unit (MICU) were used to assess the visibility of support lines and tubes in chest examinations as a function of radiation dose, image minification, and use of unsharp mask enhancement. In addition, the performance of CR was compared with that of a 600 speed screen-film combination normally used on this MICU.

MATERIALS AND METHODS

A Du Pont (EI Du Pont de Nemours & Co, Wilmington, DE) Linx CR 400 unit, based on the Fuji AC-1, was used to generate film radiographs. Generation ST IIIN imaging plates were employed (35 cm × 43 cm), and radiographs were printed with either one or two images in the output film. When a two-image output was selected, the left-side image was processed to have the appearance of a conventional screen-film radiograph (standard), whereas the right-side image was processed with an unsharp mask algorithm (enhanced). The CR produces a hard-copy output on a 28 cm × 35 cm film resulting in an image minification of either two thirds or one half, depending on whether one or two images were printed on the film, respectively. Table 1 lists the processing parameters used by the CR system to process chest images used in this study where the unsharp mask enhancement parameters used were the default values provided by the manufacturer. The CR system used in this study, image processing algorithms, and explanation of the role of the image processing parameters listed in Table 1 are described in detail elsewhere.^{6,16,17}

The CR system determines sensitivity (S) and latitude (L) parameters with an exposure data recognizer (EDR) system.^{6,17} The value of S selected by the EDR system ensures that the average exposure level is mapped to the correct film density. A uniform exposure of 1 mR (2.58×10^{-4} C/kg) on the imaging plate results in the EDR system generating an S value of approximately 200. For a given type of clinical examination obtained under similar conditions and processed in a consistent manner, the approximate relationship between S and radiation

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Table 1. Image Processing Parameters Used by The CR System

CR Format	GA	GT	GC	GS	RN	RT	RE
2/3 (Standard)	1.1	E	1.6	-0.10	4	R	0.5
1/2 (Standard)	1.1	E	1.6	-0.10	4	R	0.5
1/2 (Enhanced)	0.9	A	1.5	-0.20	4	R	5.0

exposure (X) given^{6,18} is:

$$S \approx \frac{200}{X(\text{mR})}$$

(1)

The L parameter is the exposure latitude where values of 1 and 2 correspond to dynamic ranges of 10:1 and 100:1, respectively. With the Linx CR system, the value of L is selected by the CR system based on an analysis of the image data and for chest examinations is between 1.6 and 2.6. To minimize the influence of the L parameter on the resultant film densities,¹⁹ only CR films with a value of L equal to 1.6 were included in the study evaluating line visibility.

Beside chest examinations were performed with GE AMX IV (General Electric Corp, Milwaukee, WI) portable radiograph units, no antiscatter grids and a Focus-Film Distance (FFD) of 100 cm. The CR system accounted for only 25% of the chest radiograph examinations performed on this MICU and was compared with a 600 speed screen-film combination (Kodak Lanex Fast screen and Kodak T-Mat L [TML] film combination) normally used in this MICU. Average techniques for CR imaging plates (kVp and mAs) were, therefore, identical to those employed with the screen-film system. Most bedside chest radiographs on this MICU are taken at 75 kVp and between 1 and 2 mAs.

Only those CR images with a constant L value at the mode of 1.6 were selected for inclusion in the line visibility study (Fig 1).

Fig 1. S and L histogram distribution for the first 137 CR radiographs taken in the MICU.

Table 2. Ranking Scheme for Line Visibility in Chest Radiographs

Visibility of Lines and Tubes		Comments
1	Excellent	Lines visualized along entire length
2	Good	Confident about line positions but some areas minimally obscured
3	Average	Portions of line obscured but can infer position
4	Inferior	Major portions of line obscured & exact position is in question
5	Not visible	Line not seen or only small portion seen

From these CR images, 9 two-thirds size films with a single standard image and 12 one-half size films, each containing a standard and enhanced image, were selected for assessment of line visibility. For comparison purposes, seven conventional screen-film radiographs were also evaluated. Films with poor positioning that hindered support line and tube visibility were excluded.

Five board-certified radiologists who routinely read bedside chest radiographs ranked the visibility of support lines and tubes using the five-point scheme summarized in Table 2. The radiologists were allowed to preview all cases to gauge the variability in image quality before the formal evaluation. Conventional and CR films were randomly presented on a light box in a darkened room in a single reading. A rank was allocated to each line by the radiologist and recorded by the investigator.

Support lines and tubes present on an image that were not explicitly mentioned by the radiologist were assumed to have been missed and allocated a rank of five. A statistical *t*-test analysis for each type of line was performed by comparing the ranks assigned to screen-film radiographs with each CR image category. Categories 1 and 2 listed in Table 2 may be classified as being desirable for clinical diagnosis. An analysis was made of the percentage of images within each category and imaging mode that fell into this desirable classification.

RESULTS

Figure 1 shows the S and L histogram distributions for the first 137 CR studies performed in the MICU. The average value of the S parameter was 680, corresponding to a screen-film exposure of about 0.3 mR. Variations in the S parameter reflect different radiation exposures, and it is this feature that permits the influence of dose differences to be empirically investigated. About 50% of the CR examinations generated an L value of 1.6, which is the minimum value this CR unit employs to process chest examinations.

The total number of feeding tubes, endotracheal tubes, and vascular catheters in the radiographs employed in this study are summarized in Table 3. Also given is the percentage for each type of line missed by readers and assigned a rank score of five (ie, not visible). Feeding tubes were twice as likely

Table 3. Number of Tubes and Catheters in Each Category of Radiograph. Given in Brackets Is The Percentage (%) of Lines Missed by The Five Radiologists

Film or CR Category	Images	Feeding Tubes	Endotracheal Tubes	Vascular Catheters
Screen-film	7	8 (7.5%)	4 (10.0%)	10 (2.0%)
CR 2/3 (standard)	9	5 (8.0%)	5 (0.0%)	10 (10.0%)
CR 1/2 (standard)	12	7 (11.4%)	7 (2.9%)	9 (0.0%)
CR 1/2 (enhanced)	12	7 (2.9%)	7 (2.9%)	9 (0.0%)

to be missed (7.4%) than either endotracheal tubes (3.5%) or vascular catheters (3.2%). The enhanced CR images showed fewer misses (1.7%) than screen-film (5.4%), two-thirds standard CR (7.0%), or one-half standard CR (4.3%).

Table 4 summarizes the average rank scores for support line and tube visibility for the three types of CR image investigated, as well as the scores for the screen-film system. The results of the statistical significance tests are summarized in Table 5, demonstrating that standard CR images were inferior to screen-film for visualizing lines. CR images enhanced by an unsharp mask algorithm, however, resulted in a line visibility which was always superior to that achieved using screen-film.

Figure 2 shows ranks for support line and tube visibility as a function of radiation dose. In each CR category, there was a trend showing a reduction in support line and tube visibility as the S parameter increased. The correlation coefficient between rank score and the S parameter was 0.28 (two-thirds minification images), 0.46 (one-half minification [standard]), and 0.34 (one-half minification [enhanced]). Because the S parameter is inversely proportional to the radiation exposure used, these data show that the visibility of support lines and tubes increased with increasing radiation dose.

Table 6 summarizes the percentage of images deemed to be desirable in terms of the visualization of support lines and tubes. Figure 3 shows the combined data for all support lines and tubes

Table 4. Mean Scores (±SD) for Line Visibility

Film Type	Feeding Tubes	Endotracheal Tubes	Vascular Catheters
Screen-film	2.55 ± 1.12	2.25 ± 1.22	1.78 ± 0.88
CR 2/3 (standard)	3.04 ± 0.96	2.36 ± 0.93	2.88 ± 1.26
CR 1/2 (standard)	3.31 ± 0.95	2.09 ± 0.97	1.73 ± 0.80
CR 1/2 (enhanced)	1.83 ± 0.94	1.86 ± 1.02	1.29 ± 0.54

Table 5. Statistical Significance of The Line Visibility in CR Images Compared to Screen-Film

Film Type	Feeding Tubes	Endotracheal Tubes	Vascular Catheters
CR 2/3 (standard)	S-F (<i>P</i> < .05)	NSD	S-F (<i>P</i> < .001)
CR 1/2 (standard)	S-F (<i>P</i> < .001)	NSD	NSD
CR 1/2 (enhanced)	CR (<i>P</i> < .005)	NSD	CR (<i>P</i> < .005)

Note: Each box gives the modality with the superior rank score (Screen-film [S-F] or computed radiography [CR]) along with the *P* value. No significant difference [NSD] corresponds to *P* > .05.

indicating that standard CR is generally inferior to conventional screen-film systems when exposed to the same (average) radiation dose. Image minification and use of unsharp mask image enhancement improved the visibility of support lines and tubes in bedside chest radiographs.

DISCUSSION

This study focused on detecting support lines and tubes and the results therefore only pertain to this specific task. Although identification of lines is an important clinical task in bedside radiographs,^{14,20} lines are not manufactured to maximize their visibility in radiographic images.¹⁵ The suboptimal quality of many bedside chest radiographs¹³ warrants an investigation into factors that have the potential to improve the visibility of lines. In digital images acquired with CR, these factors are radiation dose, image minification, and unsharp mask enhancement.

The use of unsharp mask enhancement for improving clinical detection has been investigated for interstitial lung disease,²¹ fine pulmonary lines,⁹ and cortical bone defects.¹⁰ In general, these studies have not shown that image enhancement resulted in markedly improved lesion detection. The most likely explanation for this finding is that unsharp mask enhancement reduces the overall signal-to-noise ratio²² and introduces artifacts that reduce detection specificity.²¹ Unsharp mask emphasizes discontinuities such as edges and is therefore expected to improve the visibility of support lines and tubes.

Data presented in Tables 4 and 6 and Figure 3 clearly show that use of unsharp mask enhancement results in CR being consistently superior to that of the screen-film combination. Similar find-

Fig 2. Rankings for CR chest radiographs investigated versus S parameter: (A) CR two-thirds (standard); (B) CR one-half (standard); and (C) CR one-half (enhanced).

ings of improved visibility of lines have been reported by other research groups.^{23,24} Although use of unsharp mask enhancement may be problematical for detection of clinical lesions, it is clearly useful for visualizing lines in chest radiographs.

Data in Tables 4 and 6 and Figure 3 show a trend for improved line visibility as the minification of standard images changed from two thirds to one half. Perception of radiographic noise is reduced as

Table 6. Percentage of Images Ranked in The Desirable Category (ie, 1 or 2 in Table 2) for The Visualization of Support Lines and Tubes

Film Type	Feeding Tubes (%)	Endotracheal Tubes (%)	Vascular Catheters (%)
Screen-film	52.5	60.0	88.0
CR 2/3 (standard)	28.0	64.0	40.0
CR 1/2 (standard)	22.9	80.0	82.2
CR 1/2 (enhanced)	82.9	85.7	95.6

Fig 3. Percentage of images ranked in the desirable category (ie, 1 or 2 in Table 2) for the visualization of support lines and tubes.

images are made smaller,¹¹ and this may account for the improvements in line visibility with image minification. An investigation of the detectability of simulated nodules, fine pulmonary lines, and micronodular opacities as a function of image minification has been performed using receiver operating characteristic (ROC) analysis.⁷ This study showed that detection of lines and micronodular opacities was reduced with declining image size, but there was little difference for detection of nodules. Effects of minification on feature detection are therefore task specific, and general conclusions are unwarranted. Radiologists may benefit, however, by stepping back from chest images when inspecting line placements that are not readily visualized.

Studies have quantified image noise in CR and compared these data with image noise in screen-film radiographs.^{4,5,11} These studies have generally shown that the image noise associated with CR is higher than that found in optimally exposed medium speed screen-film combinations. At low radiation exposures below about 1 mR, the dominant source of image noise is quantum mottle.⁵ At radiation doses above about 1 mR, it is the imaging plate granularity, luminescence noise, and electronic noise that are the most important noise components.⁴ In this study the radiation exposures used for the CR and screen-film combination were the same. The lower performance of the standard CR images (two thirds and one half) as compared to

screen-film is most likely a result of increased noise in the CR images.¹⁸

The conclusion that increased image noise reduces line visibility has the corollary that an increased dose should improve line visibility. The data in Figure 2 do show a trend for improved line visibility with increasing dose. These findings are similar to those of other workers who investigated the effect of changing radiation dose on feature detection. Dobbins et al²⁵ showed that CR required between 75% and 100% more radiation to match the performance of screen-film for detection of objects between 0.05 and 2 cm in diameter. Other studies have shown that higher radiation doses are required in CR radiography to achieve the same detection of catheters as achieved with screen-film⁸ and that reducing CR doses has a deleterious effect on the detection of nodules.²⁶

Unsharp mask image processing appears to be more important than increasing the dose or minifying the image to improve line visibility. Furthermore, it was only the use of image enhancement that improved the visibility of lines in CR chest radiographs when compared to that of screen-film. We are planning to introduce a filmless picture archiving and communications system (PACS) to perform all bedside examinations in our hospital²⁷ and would like to take advantage of the benefits that image enhancement offers for visualizing lines in bedside chest radiographs. Current workstations, however, significantly slow down the diagnostic reading of chest radiographs.²⁸ Any additional use of on-line (real time) image processing would likely be prohibitively time-consuming. As a result, a strategy is required that incorporates the benefits of image enhancement without paying any significant time penalty.

Our diagnostic workstations have rapid data transfer times (disk to display) of about 1 second and no image processing capabilities beyond simple window and level adjustments.²⁹ Chest radiographs will also be preprocessed off-line with unsharp mask algorithms similar to those described in this study. The radiologist will thus have the option of using a "hot button" to retrieve a preprocessed image in about 1 second to help locate poorly visualized lines in the original image. The preprocessed image will be displayed on a second monitor and permit a direct comparison with the original image. Although this strategy increases data stor-

age requirements, the additional cost of disk storage is favored to improve radiologist's reading times with on-line image processing. In this way, the benefits of unsharp mask enhancement for visualizing lines will be available without incurring significant time penalties that any strategy using on-line image processing would require.

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REFERENCES

1. Sonoda M, Takano M, Miyahara J, et al: Computed radiography utilizing scanning laser stimulated luminescence. *Radiology* 148:833-838, 1983
2. Schaeffer CM, Greene RE, Oestmann JW, et al: Improved control of image optical density with low-dose digital and conventional radiography in bedside imaging. *Radiology* 173:713-716, 1989
3. Niklason LT, Chan H-P, Cascade PN, et al: Portable chest imaging: Comparison of storage phosphor digital, asymmetric screen-film, and conventional screen-film systems. *Radiology* 186:387-393, 1993
4. Hillen W, Schiebel U, Zaengel T: Imaging performance of a digital storage phosphor system. *Med Phys* 14:744-751, 1987
5. Fujita H, Ueda K, Morishita J, et al: Basic imaging properties of a computed radiographic system with photostimulable phosphors. *Med Phys* 16:52-59, 1989
6. Seibert JA: Photostimulable phosphor system acceptance testing. American Association of Physicists in Medicine, AFIP, Washington DC, 1991 (Medical Physics Monograph No. 20, pp 771-800)
7. Schaefer CM, Prokop M, Oestmann JW, et al: Impact of hard-copy size on observer performance in digital chest radiography. *Radiology* 184:77-81, 1992
8. Galanski M, Prokop M, Thorns E, et al: The visibility of a central venous catheter using digital luminescence radiography in intensive care radiology. *Rofo Fortscher Geb Rontgenstra Neuen Bidgeb Verfahr* (in German) 156:68-72, 1992
9. Oestmann JW, Greene R, Rubens JR, et al: High frequency edge enhancement in the detection of fine pulmonary lines. Parity between storage phosphor digital images and conventional chest radiography. *Invest Radiol* 24:643-646, 1989
10. Prokop M, Galanski M, Oestmann JW, et al: Storage phosphor versus screen-film radiography: Effect of varying exposure parameters and unsharp mask filtering on the detectability of cortical bone defects. *Radiology* 177:109-113, 1990
11. Sanada S, Doi K, Xu X-W, et al: Comparison of imaging properties of a computed radiography system and screen-film systems. *Med Phys* 18:414-420, 1991
12. Schaefer CM, Prokop M: Storage phosphor radiography of the chest. *Radiology* 186:314-315, 1993
13. Wandtke JC: Bedside chest radiography. *Radiology* 190:1-10, 1994
14. Silverstein DS, Livingston DH, Elcavage J, et al: The utility of routine daily chest radiography in the surgical intensive care unit. *J Trauma* 35:643-646, 1993
15. Hunter TB: Tubes, lines, catheters, and other interesting devices. *Curr Probl Diagn Radiol* 24:53-108, 1995
16. Kato H: Photostimulable phosphor radiography—Design considerations. American Association of Physicists in Medicine, AFIP, Washington DC, 1991 (Medical Physics Monograph No. 20, pp 731-770)
17. Cowen AR, Workman A, Price JS: Physical aspects of photostimulable phosphor computed radiography. *Br J Radiol* 66:332-345, 1993
18. Huda W, Slone RM, Belden CJ, et al: Radiographic mottle in pediatric chest examinations using computed radiography. *Radiology* 199:249-252, 1996
19. Chotas HG, Ravin CE: Digital radiography with photostimulable storage phosphors: Control of detector latitude. *Invest Radiol* 27:822-828, 1992
20. Thompson MJ, Kubicka RA, Smith C: Evaluation of cardiopulmonary devices on chest radiographs: Digital vs analog radiographs. *AJR* 153:1165-1168, 1989
21. Kehler M, Albrechtsson U, Andresdottir A, et al: Digital luminescence radiography in interstitial lung disease. A receiver operating characteristic (ROC) analysis. *Acta Radiol* 32:18-23, 1991
22. Miettinen RH, Korhola OA: The effect of digital unsharp-mask filtering on the signal-to-noise ratio in computed radiography. *Eur J Radiol* 13:225-228, 1991
23. Jennings P, Padley SPG, Hansell DM: Portable chest radiography in intensive care: A comparison of computed and conventional radiography. *Br J Radiol* 65:852-856, 1992
24. Hoffmann KR, Doi K, MacMahon H, et al: Development of a digital duplication system for portable chest radiographs. *J Digit Imaging* 7:146-153, 1994
25. Dobbins JT, Rice JJ, Beam CA, et al: Threshold perception performance with computed and screen-film radiography: Implications for chest radiography. *Radiology* 183:179-187, 1992
26. Kimme-Smith C, Aberle DR, Sayre JW, et al: Effects of reduced exposure on computed radiography: Comparison of nodule detection accuracy with conventional and asymmetric screen-film radiographs of a chest phantom. *AJR* 165:269-273, 1995
27. Huda W, Honeyman JC, Frost MM, et al: A cost-analysis of computed radiography and picture archiving and communications system in portable radiography. *J Digital Imag* 9:1-6, 1996
28. Krupinski EA, Maloney K, Bessen SC, et al: Receiver operating characteristic evaluation of computer display of adult portable chest radiographs. *Invest Radiol* 29:141-146, 1994
29. Honeyman JC, Huda W, Palmer CK, et al: Preliminary evaluation of a high resolution workstation for diagnostic interpretation of portable radiographs. *SPIE* 2431:530-537, 1995