Digital Chest Imaging Using a 57-cm Image Intensifier: A Receiver-Operating Characteristic Study of User Performance

Gerhard W. Brauer, Paul D. Fisher, Delmer B. Pengelly, and Gordon W. Ritchie

Chest radiography provides one of the great challenges to digital diagnostic imaging because of (1) the relatively large size of the chest field, (2) the contrast range required to resolve subtle pathological changes in soft tissue density, and (3) the high degree of spatial resolution required to discriminate pathological detail. The field size problem was resolved by using a 57-cm image intensifier whose video output of the chest could be digitized. The issue of contrast resolution was addressed in a recently completed receiver-operating characteristic study of the detectability of low-contrast densities in a humanoid chest phantom. The latter indicated that, despite the smaller size of the digital image, they were adequate for resolving clinically significant soft-tissue densities. The question of spatial resolution in digital diagnostic images is addressed in the study presented. A set of 41 clinical cases were selected to provide the typical range of diagnostic type experienced in routine diagnostic radiology. The images were each presented as conventional film, digital laser-printer, and digital video images. The results of an ROC analysis of five readers' performance in each of the viewing modes is presented.

THE APPLICATION of computer imaging and graphics in the clinical setting has generated many questions regarding the economic and logistical impact of the new technology.[1,2] However, it must first be determined if the fidelity of the computer image compared with the conventional one allows the clinician access to sufficient diagnostic information before the answers to these questions are of any consequence.[2,3] Although it is agreed that many ergonomic and psychophysical factors must be addressed before digital radiography can be fully implemented, the authors believe that the transition is inevitable and that clinically appropriate levels of contrast and spatial resolution can be achieved with existing technology.

The results of the clinical study reported herein follow in the wake of trials conducted using a humanoid phantom with simulated nodular pathology.[4] The results of those studies indicate that radiographic chest images digitized to 1,024 × 1,024 pixels with a 10-bit depth were of sufficient resolution to allow the detection of focal signals of diagnostically relevant size at a rate not significantly different from that achieved using conventional film images. Further, the differences could be attributed to the difference in size between the video image and the film image.[5]

The preceding studies, while adequately testing the contrast resolution of the digital imaging system, did not tax the limits of spatial resolution imposed by the computer graphics. At the level of digitization specified, the psychophysical limit of focal-signal detection is reached before the capacity of the system to capture spatial information is exhausted.[5] Important diagnostic information is also provided, however, by diffuse signal patterns in chest radiographs. Although this type of pathology can be readily detected by the radiologist, its structure is not well defined radiographically. Evidence of diffuse pathology in radiographic images is usually described as an area having a distinguishing graphic texture. However, diffuse signals are made up of discrete signals not individually distinguishable by the naked eye that may not be captured by a digital image system if the resolution is too low. Following are the results of the authors' efforts to challenge the spatial resolution limits of a diagnostic digital imaging system using a selected set of clinical cases involving a variety of both focal and diffuse pathology.

MATERIALS AND METHODS

Case Selection

Patients over 19 years of age at the Department of Medical Imaging at Victoria General Hospital, Victoria, British Columbia, for chest radiography were asked to participate in

From the School of Health Information Science, University of Victoria and the Department of Medical Imaging, Victoria General Hospital, Victoria, British Columbia, Canada.

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Address reprint requests to Gerhard W. Brauer, School of Health Information Science, University of Victoria, PO Box 1700, Victoria, BC V8W 2Y2, Canada.

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this study. They were told the purpose of the study and the risk associated with the additional exposure and that declining to participate would in no way affect their medical treatment or care. The British Columbia Ministry of Health ethics committee approved this procedure for human subject approval. Those agreeing were examined radiographically twice; once to generate a conventional film image and again to produce a digital image file. For each patient, all medical images and all related clinical information were presented to a panel of three radiologists and one respirologist for evaluation. This panel determined what, if any, diagnostic signals were present in any of the images, thereby establishing the "true" status of the images for subsequent receiver-operating characteristic (ROC) analysis of the reading data. Only those cases in which there was 75% consensus among panel members on image-signal composition were included in the study. Further, the sample was adjusted so that there were approximately equal numbers of normal and signal-bearing quadrants in the image sets. The use of a consensus panel for this purpose has been used successfully in other studies.[6] Table 1 lists, categorically, the findings of the consensus panel for the cases used in the study.

Image Acquisition

Posterior/anterior and lateral exposures for both conventional and digital techniques were made using a Siemens Polydoros generator (Siemens Electric Ltd, Mississauga, Ontario, Canada) and an Opti 150/40/72c x-ray tube. The 117-kV phototimed exposure technique used for both images resulted in a skin dose of 0.150 mSv for the conventional image and 0.030 mSv for the digital image (see Ewen et al[7] for a discussion of radiation doses using different chest radiography techniques). The conventional image was recorded on 14-in ×17-in Dupont Cronex 7 film (Dupont Co, Wilmington, DE) using a Dupont daylight cassette and focused grid (12:1) at a distance of 175 cm from the source. Digital images were acquired by digitizing the video output from a Siemens Sirecon 57-cm image intensifier[8] with a 10-cm airgap. The Siemens digital radiography system used is shown in block form in Fig 1; detailed information may be found in Nosil et al.[9] The image on the 10-cm output phosphor of the image intensifier was recorded using a Siemens Videomed H 1,023-line video camera. The video output is transmitted via optic fiber to a Siemens DR1000 image acquisition and display computer and digitized to a 1,023-line ×944 pixel ×10-bit image file. Image acquisition is controlled by a VAX 11/750 computer (Digital Equipment Corp, Toronto, Ontario, Canada), which is also used for image archiving and processing. The image files are then transferred from the VAX 11/750 to a MicroVAX II, which serves as host to the Siemens prototype three-screen reporting station, where the images may be viewed and windowed. Prints of the digital images were made using a Matrix Instruments Laser film printer (Matrix Instruments, Inc, Orangeburg, NY) connected to the VAX 11/750. Both the printer and viewing screens were capable of only 256 levels of grey (8 bits). The remaining 2 bits acquired during digitization could be accessed by windowing during viewing or before printing. Banding errors were occasionally encountered during printing; only images with no apparent banding errors were used for the study.

Table 1. Distribution of Pathologies by Category as Identified by Consensus Panel

Symptoms	No. of Cases
Pleural effusion	8
Chronic obstructive pulmonary disease	1
Pneumonia	12
Pneumothorax	3
Masses or focal lesions	5
Vascular disease	2
Normal	11
Total cases	42

Image Reading

Of over 200 cases recorded both conventionally and digitally, 41 were selected for reading using the aforementioned consensus procedure. Consequently, there were 123 sets of images (41 digital film, 41 digital video, and 41 conventional), which were numbered so that radiologist would not view the different types of images for the same patient during the same week of reading sessions, and which appeared random to the readers. Each of five radiologists examined eight sets of images (mixture of digital and conventional images) per daily session until all images had been read by each radiologist.

For each image set, the radiologists were asked to consider each quadrant of the chest (Fig 2) and assign a number from the following scale to each quadrant for the presence of diffuse and focal pathology: 1—almost definitely not present; 2—probably not present; 3—50/50 chance of being present; 4—probably present; and 5—almost definitely present. The distribution of signal types in the images as determined by the consensus panel are shown in Table 2.

A typical, completed reading form is shown in Fig 3. The readers were not restricted for time or from viewing aids (magnifiers and "bright lights" for film, windowing and zooming on video) during the reading sessions.

Receiver-Operating Characteristic

ROC analysis was conducted as previously described.[4] The data from all five readers were grouped to provide a more homogeneous distribution of detection certainty for each case. (Pooling data was justified because of very low inter-reader variation.) Further, all image quadrants containing a signal, in the opinion of the consensus panel, but which all five radiologists called normal in all three image formats, were removed from the data pool. These data skewed the distribution of certainties, thereby increasing the error in the ROC statistics, yet contributed nothing to the comparison of signal detection in conventional images compared with digital ones. That this was necessary confirms the already well-known fact that associated clinical information is critical in those diagnostic processes that use medical images.

RESULTS AND DISCUSSION

The results of the ROC analysis are somewhat equivocal in terms of the readers' ability to discriminate focal and diffuse signals in digital

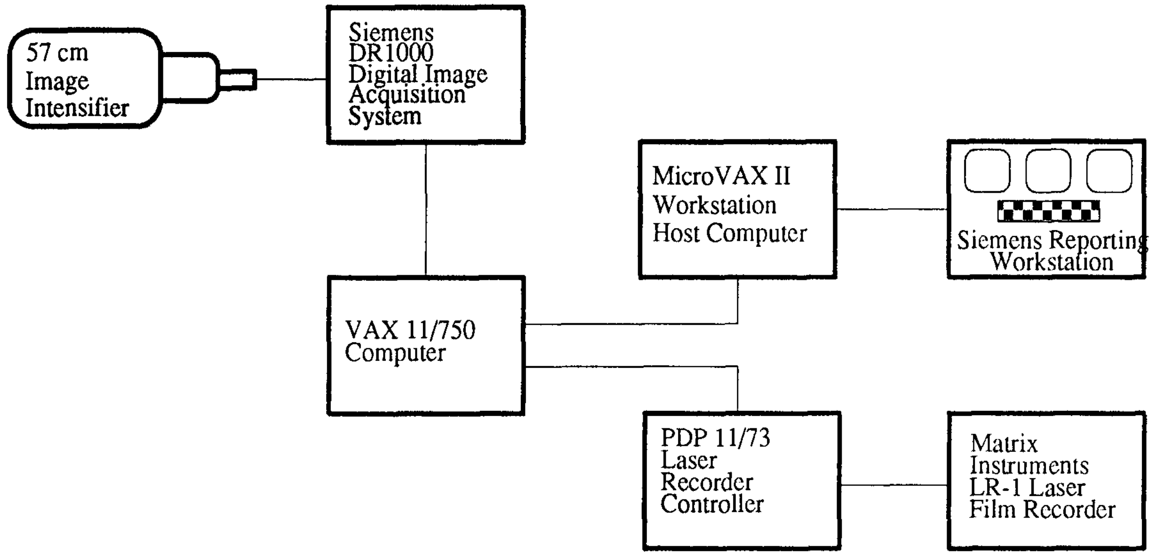

Fig 1. Block diagram of the Siemens digital image acquisition system.

images compared with conventional ones. Detection performance for focal or diffuse signals is distinctly lower with digital images than with conventional ones, when the two are considered separately. However, when the distinction between focal and diffuse signals is ignored, signal detection using digital images is as good as or better than that using conventional images (Fig 4). It can only be assumed from these data that the individual readers were not consistent in their definition of focal and diffuse signal types.

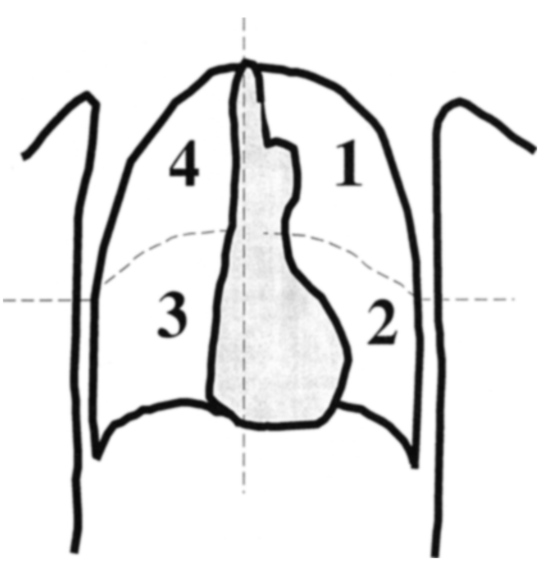

Fig 2. Chest-quadrant designation for location of detected signals. Shaded area indicates mediastinum in each quadrant.

Irrespective of signal type, signal detection performance using the laser-printed film was significantly better than with conventional film and not significantly different from that using the video images (Fig 4). This difference in quality was primarily a result of the lower incidence of false-positive (FP) calls using the digital images. The effect of this on the ROC statistics is shown in Fig 5. Whereas the areas under each curve in Fig 5 are not significantly different, the curve for signal detection in video images has a greater slope at the low-FP end than does that for conventional images. In fact, the data at the low-FP end of the curves are of greater clinical significance than those in the rest of the curve because high FP rates in a diagnostic test are usually unacceptable in a clinical setting despite a favorable true-positive (TP) rate. The TP rate at an FP rate of 0.2 is often considered a

Table 2. Distribution of Signal Types as Determined by Consensus Panel

	Quadrant				
	1	2	3	4	Total
Mediastinal signal	2	2	3	1	8*
Diffuse signal	10	17	15	11	53
Focal signal	7	14	14	11	46
Total signal	19	33	32	23	107
Normals	26	9	13	21	69

*Gross mediastinal signals such as aortic unfolding or cardiomegaly, while present in many cases, were ignored for the purpose of this study, being considered too gross in nature to contribute to the results.

ident. code	quadrant	focal	diffuse
46 laser	1	5	1
	2	1	1
	3	3	4
	4	1	2

Fig 3. Typical scoring sheet completed for each set of images.

clinically valid ROC statistic; ie, 0.2 is a maximum clinically acceptable FP rate. In Fig 4, the TP rate at an FP rate of 0.2 is about 20% higher for video images than for conventional ones. Contrast this with areas under the ROC curves (Fig 4), which are less than 5% different. This change in the shape of the ROC curve for digital images can also be seen in the data of Seeley et al.[6] They attribute the result to the facility of being able to window the digital images; when images were not windowed, the two curves, while not identical, did not cross and were of the same shape.

Windowing may also account for the unexpected difference in reader signal-detection performance between conventional and laser-printed digital images. Digital images were windowed before printing to provide a compromise between the amount of detail visible in the lungs and behind the mediastinum. This procedure was performed with the operator blind to patient identity and pathology. This manipulation may

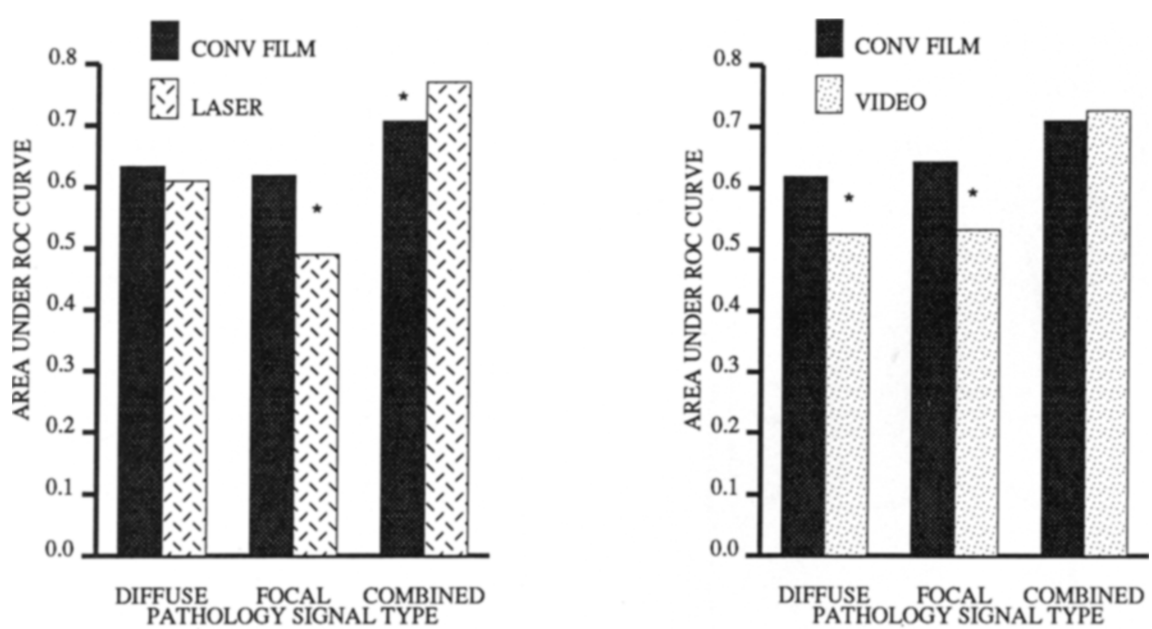

Fig 4. Signal-detection performance indicated by the area under the ROC curve for each of two signal categories and for both categories combined. (*) Significant differences at the P <.05 level. SE ranged between 0.023 and 0.036.

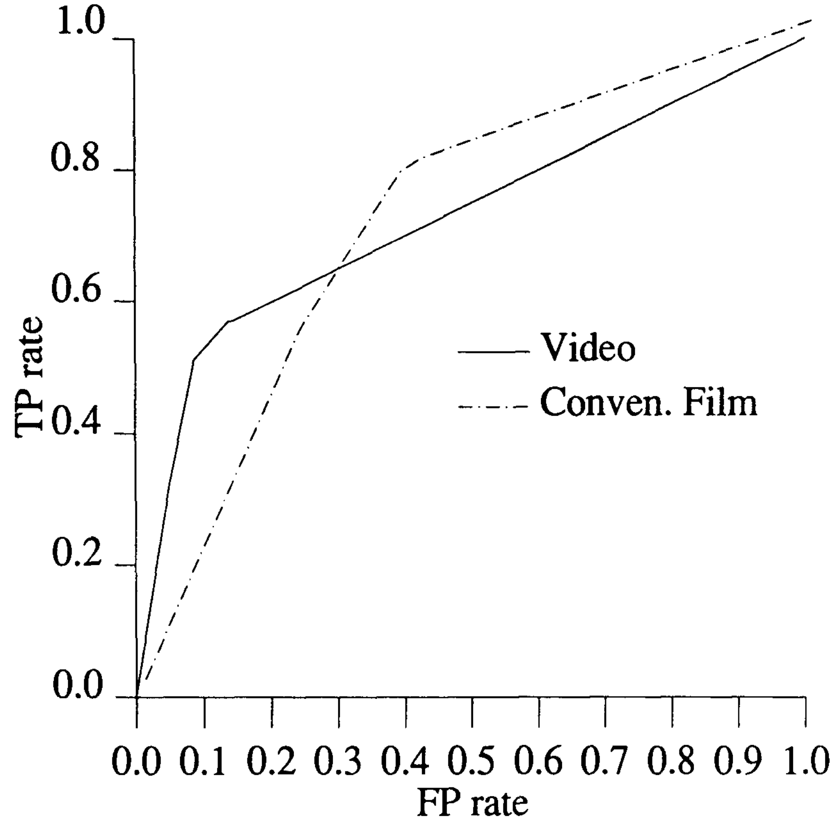

Fig 5. ROC curves for video and conventional film display formats calculated using the combined data, ie, irrespective of signal type.

mitigate the effects of variables such as patient girth or position, on the original image, a compensation that cannot be interactively achieved with conventional film images.

It is somewhat surprising that signal-detection performance with laser-printed films was significantly better than that with conventional films, whereas performance with video images was not, because the readers usually preferred the video images to the laser prints (in contrast to the experience of MacMahon et al[10]). However, consistent with the findings of MacMahon et al,[10] the readers in the present study performed better with hard copy than with video images. This difference in performance may be a result of the video images being about half the size of the conventional chest images and 65% the size of the laser-printed ones. Signal detection is strongly correlated to image size.[5]

These data do not conclusively resolve the issue of how much resolution is required from digital imaging systems to provide clinical radiographic information in all cases. However, it may be said that the level provided, 1,023-line × 944-pixel × 10-bit, was sufficient for most of the variety of cases used in this study, which was a representative cross section of the routine chest imaging caseload of that department. This result may affect the configuration and cost of clinical viewing stations and/or the distribution of different resolution viewing stations within a digital radiology department. For example, a work station comprising one 2,048 × 2,048 monitor and three 1,024 × 1,024 monitors may be sufficient for the radiologist. Alternatively, a department might have only one or two high-resolution work stations, most of the department using the more economical 1,024 × 1,024 variety.

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