Signal Detection in Digital Chest-Phantom Images Acquired With an Image Intensifier

Gerhard W. Brauer, Paul D. Fisher, James A. Hanley, and Gordon W. Ritchie

Signal detection performance was evaluated on the basis of ROC analysis using both digital and conventional images of a humanoid chest phantom. Simulated focal (coin) lesions were the target pathology. Digital images were acquired using a 57-cm image intensifier, digitized to 1024 × 1024 × 10 bits, and compared, in both video and laser-printed film formats, with conventional 14 × 17-inch chest films. Signal detection using digital video and laser printed images, of the same image polarity as conventional images, was found not to differ significantly from that achieved using conventional images, despite the smaller size of the digital images.

KEY WORDS: Digital imaging, technology assessment, humanoid chest phantom, chest radiography, image intensifier, ROC analysis, signal detection.

DUE TO advances in computer, laser, fiber-optic, and television technologies, computerized medical imaging techniques have become feasible components of the modern radiology department. Victoria General Hospital (VGH), a 500-bed community hospital, is expected to be the first non-teaching hospital to provide digital diagnostic imaging (DDI) for all imaging procedures, ie, a filmless medical imaging department. For various reasons, however, the totally digital medical imaging department is still a contentious issue.[1-4] We report here the first results of a multiphasic evaluation of DDI.

While many different digital image acquisition systems have been proposed and tried,[5] three digital imaging modes currently predominate: (1) slow scan using a vertically collimated x-ray beam and a linear array of photo-detectors[6,7]; (2) digitization of the latent image on a reusable phosphor screen[8,9]; and (3) digitization of the video output of an image intensifier. Most of the evaluative work published to date has been based, not on one of these methods, but rather on the secondary digitization of conventionally acquired film images.[3,10-14] This investigation deals with chest images (humanoid phantom) acquired by digitizing the video output from a 57-cm image intensifier.

Chest radiography was selected to be the subject of the first evaluation for three reasons: (1) chest studies comprise as much as 40% of an imaging department's case load; (2) it is an anatomical area that provides a broad spectrum of pathologic signals[15]; and (3) it is the procedure that is acknowledged to require the highest degree of spatial resolution.[16]

Conventional film chest images offer markedly higher spatial resolution than do chest images digitized to 1024 × 1024; the former being able to resolve approximately 6 line-pairs per millimeter (lp/mm) as opposed to 1.2 to 1.4 lp/mm for the latter. However, psychometric studies have shown that perceptibility falls off dramatically for lesions <5 mm in diameter.[17,18] The simulated lesions used in the investigation are large enough (majority falling in the range of 4 to 7 mm) to be captured at the resolution of digitization but are in the threshold area for perceptibility. Therefore digital chest imaging at a resolution of 1024 × 1024 should capture virtually all of the focal diagnostic signals normally used for the clinical evaluation of medical chest radiographs.

MATERIALS AND METHODS

Equipment

The digital radiography system (Siemens Electric Ltd, Mississauga, ONT) used for this investigation is shown as a block diagram in Fig 1. A Siemens Sirecon 57-cm image intensifier with a 10-cm output phosphor is used for digital chest radiography. Exposures are made using a Siemens Polydoros generator and an Opti 150/40/72c x-ray tube. Output images are captured by a Siemens Videomed H 1023 line video camera. Video output is transmitted via optic fiber to a Siemens Solitaer image acquisition and display computer and digitized to a 1024 line × 944 pixel × 10 bit image file. Digital image files are stored in a buffer within the image acquisition system and displayed as reconstructed images on

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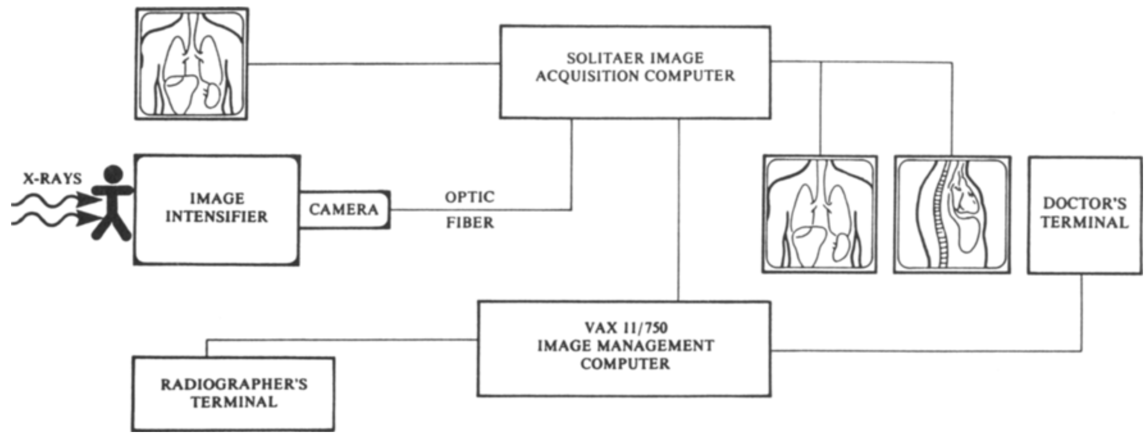

Fig 1. Block diagram of the digital imaging system at Victoria General Hospital.

the system image monitors. The image acquisition and display systems are controlled by a VAX 11/750 computer (Digital Equipment Corp, Toronto, ONT), which also controls archiving procedures and image processing.

Image Processing

While the image file is resident in the image display system, the reconstructed video image can be windowed interactively. Image data are retrieved from the image acquisition system buffer, transferred to disc, and can be replaced into that buffer without any loss of the original information. Alternatively, the image may be mathematically processed on the VAX computer to enhance particular structures and the enhanced image transferred to the image display system buffer without altering the original data. Images are transferred from either the display buffer or the disc to magnetic tape for long term archiving. Archiving will ultimately be done on optical media as the technology becomes available.

Simulated Lesions

All images were acquired from a humanoid chest phantom (Humanoid Systems, Inc, Carson, CA) in which simulated lesions were implanted (Fig 2). Twenty lesions were constructed from the phantom's muscle-equivalent material. They ranged from 4 to 20 mm in diameter and from 0.5 to 4 mm in thickness, well within the resolvable frequency range of both the digital and conventional imaging systems, and were roughly circular in shape and tapered at the edges. This size range was chosen to include the reported threshold for lesion detectability in conventional images. Kelsey et al[17] reported virtually no difference in the detectability of 1.5 cm compared with 1.0-cm lesions but a fivefold decrease in the detectability of 0.5-cm lesions. Further, Gray and Taylor[18] reported a fivefold increase in detectability of 0.48-cm lesions compared with 0.64-cm lesions. Both of these studies were conducted using conventional film-based imaging.

The phantom was considered to be divided into quadrants delineated (in the image) horizontally by the inferior edge of the sixth rib and vertically by the spinal axis. The decisions as to whether or not to place a lesion in a given quadrant and where a lesion (if any) was to be placed, were made according to a strict randomization procedure.

Image Acquisition

Each of the 20 phantom cases was imaged twice, once digitally and once conventionally. The kV settings were determined by standard practice (for conventional images) and best image quality (for digital images); the object of the study being the comparison of two imaging techniques rather than the comparison of imaging equipment. Accordingly, the exposure technique used for the conventional image was

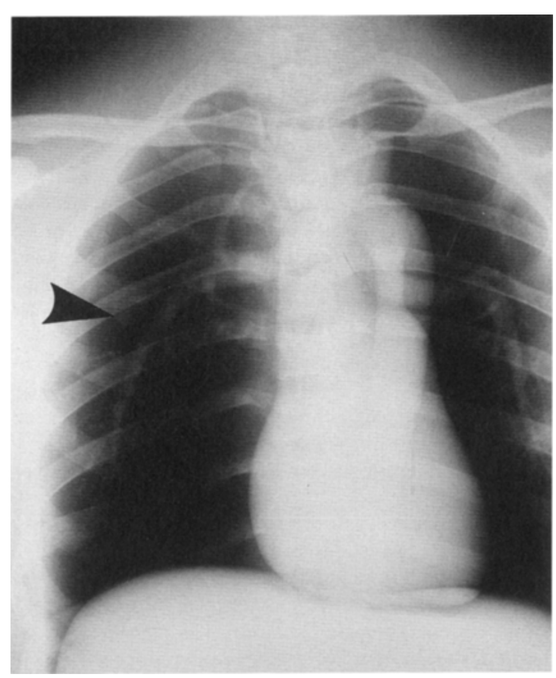

Fig 2. Typical hard copy of a phantom chest image reconstructed from a digital image data file and printed by laser recorder.

typically 81 kV and 3.5 mAs; while for digital imaging, a falling load technique at 117 kV, typically phototimed to 0.78 mAs, was used. A 10-cm air gap was used instead of a grid because in the digital technique the air gap provided slightly better spatial resolution than did the grid.

The conventional image was recorded on 14 × 17 inch Dupont Chronex 7 film (Dupont Co, Wilmington, DE) using a Dupont daylight cassette at an x-ray tube to film plane distance of 175 cm. The 100-mm film images of the output phosphor of the image intensifier were recorded at the time of exposure using a Siemens Sircam 100L camera and Kodak X-omat GR film (Kodak Canada Ltd, Toronto, ONT). Laser film prints (4000 × 5000 pixels, 8 bits deep) of the digital images were produced, before scheduled readings, on 14 × 17-inch infrared-sensitive film using a laser image recorder (Matrix Instruments, Inc, Orangeburg, NY). Digital video images (8 bits deep) were generated from the image data file at the time of scheduled readings, and shown on a Siemens 7 × 7.67-inch blue phosphor VDT with an interlaced display and a refresh rate of 60 fields per second.

Relative to conventional 14 × 17-inch films (size = 1), the sizes (linear scale) of digital images are 0.73 (laser print) and 0.49 (video); 100-mm films are 0.27, the size of the large films.

Image Reading

Each of nine readers (five radiologists and four radiographers) examined and rated 20 sets of paired images. The use of radiographers as image readers was justified because the study was a non-clinical exercise in signal detection. The images were read in four presentation formats: (1) as conventional 14 × 17-inch films, (2) as digital laser print films, (3) as conventional 100-mm films, and (4) as digital video images. The image reading schedule was randomized for each reader; the image sequence being constrained so that no paired images were presented to a reader during the same reading session. Each reader was presented with four to five "cases" per day five days per week for 5 weeks. Each reading session lasted between 15 and 30 minutes.

The readers were told that each image quadrant could contain one lesion or no lesions independent of the lesion content of the other three image quadrants, ie, the lesions were distributed randomly. Thus, the sample size is effectively 80 (20 images times four quadrants) for each reader per modality and 720 for the whole group per modality. Readers were instructed to rate each image quadrant separately for signal (lesion) content according to the following: (1) No lesion present; (2) Not sure but lesion probably not present; (3) Not sure, 50/50 chance of lesion being present; (4) Not sure, but lesion probably present; and (5) Lesion present.

Each quadrant was further divided into quarters. In order for observations to qualify as true positives, readers had to locate them within the correct quarter. However, as there was only one incident of incorrect localization, subsequent analyses did not take account of localization. A random sample of readings were repeated to measure both the replicability of readings and the extent (if any exists) of a learning effect.

ROC Analysis

Receiver operating characteristic (ROC) analysis[19,20] has been reported as the preferred technique for evaluating diagnostic imaging procedures.[21] The area under the ROC curve (an indicator of reader performance) was calculated for each modality for each reader using the non-parametric method of Hanley and McNeil.[22-24] This method was also used to determine the difference between the two ROC areas as an indicator of the difference in perceivable information content between each pair of modalities. The standard error of this difference[23] was used to form a critical ratio, which was then referred to the Z-distribution to assess the significance of the difference.

The true positive (TP) rate at a fixed false positive (FP) rate of 0.2 was selected as an additional index for the assessment of reader performance within the specific limits of clinical applicability.[24] Choosing the reference point for such an index is somewhat arbitrary, but since a FP rate of 0.2 is commonly used as a limit of decision tolerance, this was chosen as the cutoff. Critical values of the difference in TP rates compared with that for conventional film radiography were calculated using the method of Hanley and McNeil[23] for unpaired data. The data presented are paired; however, because the covariance calculated for the area data (typically 0.0001) was negligible compared with individual variances (typically 0.004), the simpler calculation for unpaired samples was applied.

RESULTS

Preliminary readings, by five radiologists, of 23 sets of images (N = 415) were repeated after a 10 week interval. There was no difference between reader performance during the second readings and that during the first in any of the four viewing formats tested, indicating the absence of a significant learning effect (Fig 3). It

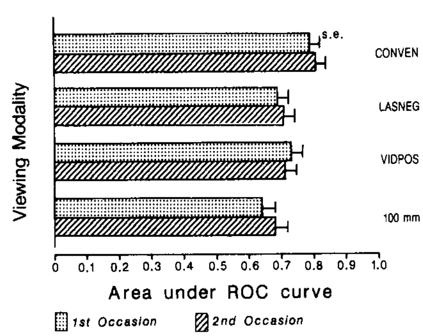

Fig 3. The effect of learning on the detection of radiographic signals using digital imaging techniques compared to conventional ones. The 30 image sets were read on two occasions (1 and 2) separated by 10 weeks during which the readers did not use digital viewing modes. There is no consistent change in performance from one reading to the next, nor are any of the individual changes significant. CONVEN, positive conventional image on 14 × 17 inch film; VIDPOS, positive digital image on 1,024 line video; VIDNEG, negative digital image on 1,024 line video; LASPOS, positive digital image on 14 × 17 inch laser film; LASNEG, negative digital image on 14 × 17 inch laser film; 100MM, positive conventional (on 100-mm film) image of output phosphor of the image intensifier.

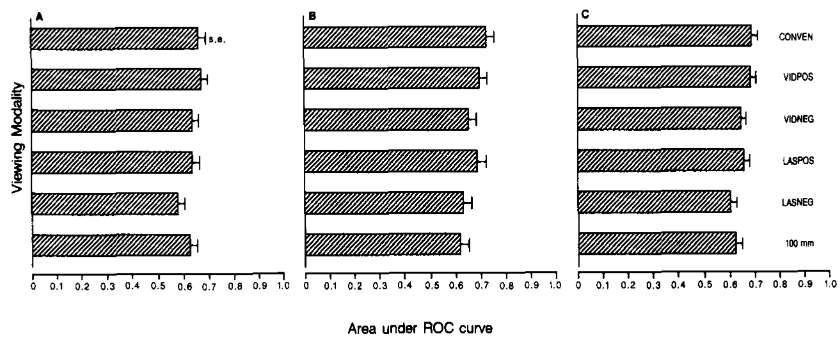

Fig 4. Signal detection performance in each of the six viewing modes is presented as the area under the ROC curve as calculated from the grouped reading results. Graph A is for the grouped radiologist readings; graph B for the grouped radiographer readings; and graph C for all of the readings grouped. CONVEN, positive conventional image on 14 × 17 inch film; VIDPOS, positive digital image on 1,024 line video; VIDNEG, negative digital image on 1,024 line video; LASPOS, positive digital image on 14 × 17 inch laser film; LASNEG, negative digital image on 14 × 17 inch laser film; 100MM, positive conventional (on 100-mm film) image of output phosphor of the image intensifier.

is assumed therefore that learning effects did not significantly influence signal detection in phantom images in any of the subsequent trials.

Average areas under the ROC curve for each viewing mode are shown in Fig 4. The difference in average area (under the ROC curve) between conventional image ROC curves and those of each of the nonconventional viewing modes was taken to represent a relative index of signal detection utility in each viewing mode (Fig 5).

In positive digital images signal detection, using both laser print and video, image detection was not significantly less than that in conventional film images, despite the differences in image size. Signal detection by radiologists actually improved (over the larger conventional images) with positive video images (Fig 5). That positive images appear to yield better results than their negative counterparts probably reflects reader preference for the image appearance they are accustomed to.

The calculated TP rates at an FP rate of 0.2 reflect the same trends observed using the area under the whole ROC curve as an index of reader performance (Fig 6). The differences in the TP rates between digital and conventional modes are not significantly greater than the differences observed in the area index.

DISCUSSION

There should, up to a point, be a correlation between image size and signal perception, if for no other reason than that details in the larger image will subtend a larger arc of the retina resulting in greater probability of detection.[25] Kelsey et al[17] and Gray and Taylor[18] have demonstrated this in a radiographic setting using simulated lesions of various sizes. This effect on

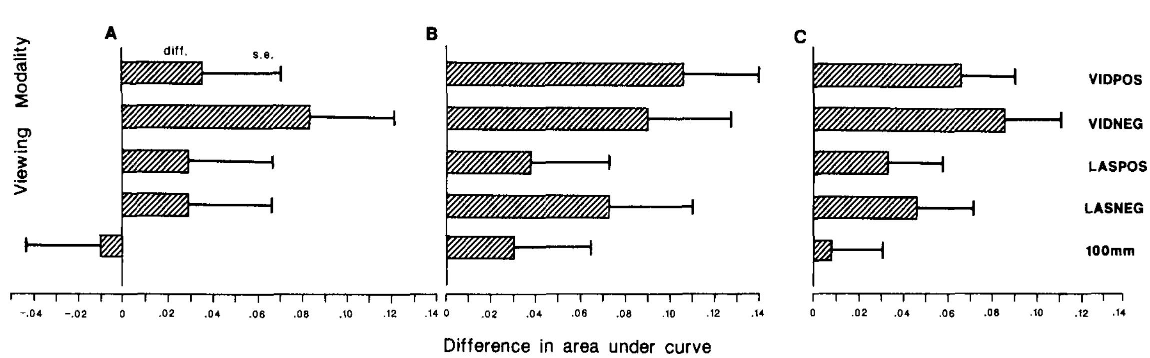

Fig 5. The difference in signal detection performance between each of the five unconventional viewing modes. The conventional one is presented as the difference in area under the ROC curves. Graph A is for the grouped radiologist readings; graph B for the grouped radiographer readings; and graph C for all of the readings grouped. CONVEN, positive conventional image on 14 × 17 inch film; VIDPOS, positive digital image on 1,024 line video; VIDNEG, negative digital image on 1,024 line video; LASPOS, positive digital image on 14 × 17 inch laser film; LASNEG, negative digital image on 14 × 17 inch laser film; 100MM, positive conventional (on 100-mm film) image of output phosphor of the image intensifier.

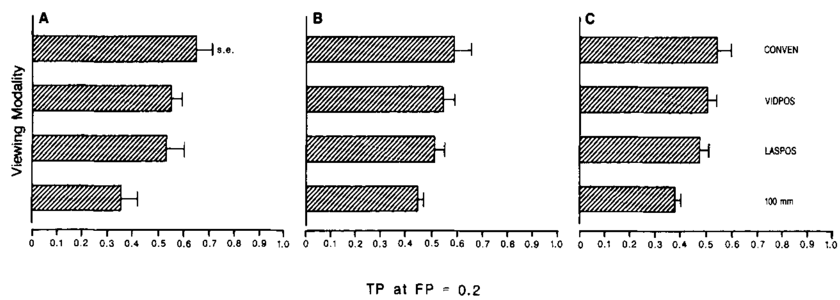

Fig 6. Signal detection performance in each of the six viewing modes is presented as the TP ratio at an FP ratio of 0.2, an index of reader performance in the region of clinical interest, as calculated from the grouped reading results. Graph A is for the grouped radiologist readings; graph B for the grouped radiographer readings; and graph C for all of the readings grouped. CONVEN, positive conventional image on 14 × 17 inch film; VIDPOS, positive digital image on 1,024 line video; VIDNEG, negative digital image on 1,024 line video; LASPOS, positive digital image on 14 × 17 inch laser film; LASNEG, negative digital image on 14 × 17 inch laser film; 100MM, positive conventional (on 100-mm film) image of output phosphor of the image intensifier.

signal detection accuracy would be the same if images were scaled. While the larger conventional images could have been reduced to the scale of the digital images, the comparison could not have been related to a clinical setting since chest examinations are routinely done using the 14 inch × 17 inch format. The results presented here were not adjusted for scale, and digital images were presented in the largest format possible.

Reader performance, as measured by the TP ratio, seems to be positively correlated with film image size, regardless of the image acquisition technique (Fig 7). Reader performance with video images, however, appears to be superior to that predicted for film images of the same scale. Extrapolating these findings suggests that, if digital images were presented on video at the same scale as that of conventional film radiographs, signal detection using digital techniques could prove to be superior to that achieved with conventional films.

An earlier pilot study showed the inferiority of 100-mm (non-digital) film images in signal detection. This finding is consistent with the 100-mm film results presented here, especially using the TP rate as an index of reader performance. Reader performance using 100-mm films is significantly worse than that using 14 × 17 inch films. Consequently, this format appears to be an unsuitable alternative to the larger conventional films in a clinical setting. This must, however, be attributed to scale only, since the spatial resolution provided by these images is in fact considerably higher than that provided by any of the digital formats investigated.

The spatial resolution in digital images, 1.2 to 1.4 lp/mm in any viewing format is markedly less than that provided in conventional radiography, 6 to 7 lp/mm. However, the detection of

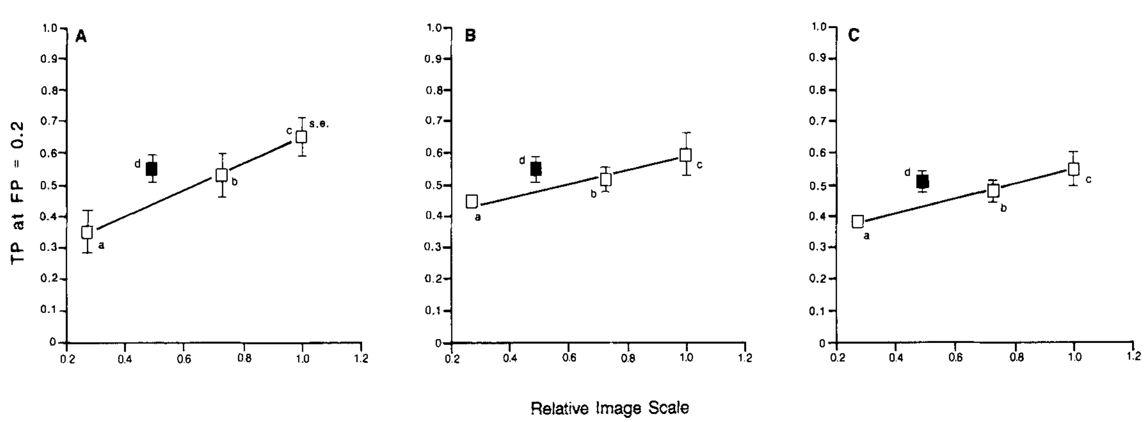

Fig 7. The influence of film image size on reader performance as indicated by the TP ratio at an FP ratio of 0.2. Points a, b, and c are the values for 100mm, laser, and conventional film images respectively. Point d is the value for video images included for reference. Graph A is for the grouped radiologist readings; graph B for the grouped radiographer readings; and graph C for all of the readings grouped.

diagnostically-relevant signals in digital images does not appear to be limited by the spatial resolution provided. Seeley[3] came to a similar conclusion using clinical images: detection of diagnostic signals was not impaired in digital images resolved to 1,024 × 1,024 pixels, the spatial resolution used in the present study. It should be noted that, to accommodate a margin for error, the clinical staff participating in that study suggested 2,048 × 2,048 pixels as a spatial resolution standard. However, the fourfold increase in computer archive space needed to store such images (to name just one implication of this difference) will likely present serious economic and logistical problems. In any case, there is as yet some doubt as to whether or not there is a clinical requirement for the additional spatial resolution.

The investigators concur with the conclusions reached by Seeley[3] that, to encompass a margin for error, images should be digitized to 2,048 × 2,048. Seeley et al[14] have recently published promising work in the detection of interstitial lung disease using film digitized to 2,048 × 2,048 but viewed on a 1,024 × 1,536 monitor. However, the results presented here suggest that in most cases detection of clinically-significant nodular signals would be achieved by viewing a 1,024 × 1,024 image. In these cases it would be reasonable, and certainly more economical, to store them as such.

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