Impact of Image Size on Effectiveness of Digital Imaging Systems

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Radiologists detect small diagnostic signals in radiographic film images by altering the distance between the eye and the image, effectively zooming in on a particular detail. Details thus enlarged are more perceptible to the viewer. Considering that conventional film images are nearly life-size, the potential for increasing the detection of small signals in this manner is high. Digital images, however, presented in video format are usually smaller than life-size, sometimes more than 50% smaller. While local enlargements using computer-based imaging systems are extremely useful, the radiologist cannot examine a whole, life-size image. The importance of the latter in the diagnostic process is revealed in detection studies using the same images of a chest phantom with small nodular inclusions, in different size formats. A clear positive correlation exists between overall image size and the detection of signals that are of a diagnostically-relevant size. While it is widely accepted that image fidelity is an important determinant in the clinical acceptability of digital radiography, digital image displays should also be large enough to display life-size images.

KEY WORDS: Image size, digital imaging signal detection, chest radiography, technology assessment.

THE CLINICAL potential of digital diagnostic imaging (DDI) is usually judged by the spatial and contrast resolution capabilities of that particular DDI system. It is the contention of the authors, who are currently evaluating the clinical performance of the first community hospital DDI department, that the actual size of the image is of equal importance as the clinical effectiveness of the system. In this report, the authors deal first with the issues of spatial and contrast resolution, and then present some findings regarding the role that image size plays in signal detection.

While absolute image quality in terms of radiographic information content increases with increasing spatial and contrast resolution, the psychophysics of visual perception limits the detection of that information by the human eye. Even within the bounds of readily perceivable spatial frequencies, the radiologist identifies only those that they have been trained to identify as clinically significant. Other signals of equal size may go unnoticed, filtered out by the immediate need for a diagnosis. The physiological and psychophysical factors that limit signal detection in medical images are outlined in a review on the subject by Carl Jaffe.[1] While one can argue that a diagnostic system should be capable of resolving the finest of signals, arbitrarily exceeding the above limits may compromise the cost effectiveness of the diagnostic system.

The cost of achieving a level of resolution that cannot be used is best explained by examining the components of a digital image installation. These can be split up into acquisition devices, a communication network, a storage/archiving device, and display devices. The nature of digital imaging information dictates that an incremental step in spatial resolution is double the previous level, ie, from 2n to 2(n + 1). For example, the incremental step from an image consisting of 1024 × 1024 picture elements (pixels) is to an image with 2048 × 2048 pixels, effectively quadrupling the size of the digital image file. Acquisition and display devices for such high resolution images are considerably more expensive, and the archive space needed to store the larger image files quadruples with each step in resolution. Thus, a typical ten-room radiology department might produce 1 Gigabyte (Gb) of image data per day when using 1024^2 pixel images, and require four 500 Megabyte (Mb) hard drives of on-line storage at a total cost of $250,000. The step to 2048^2 pixel images would require 4 Gb of on-line storage for a total cost of $1,000,000. The effect of a move to higher spatial resolution also has a profound effect on image networks. The effect on image traffic would be analogous to the rush-hour traffic problems created by quadrupling the length of vehicles. Clearly, increasing

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the spatial resolution of imaging systems has serious implications for the image communication aspects of picture archiving and communication systems (PACS). The processing of such larger images will require more powerful and expensive processors to accomplish the manipulation without incurring a clinically unacceptable delay.

None of the aforementioned problems is insurmountable. If higher resolution images ($>1024^2$ pixels) are indeed clinically required, the developers of computer and communications technology can be relied upon to provide technological solutions. Even as some manufacturers of medical imaging equipment promise to provide ever increasing amounts of spatial resolution, the issue of how much spatial resolution is required clinically has not yet been resolved.[2-5]

At some time in the near future, the amount of spatial resolution required for each modality will be determined. The diagnostic utility of images with adequate spatial resolution may, however, still be jeopardized by inattention to such contributing psychophysical factors as image size. It is generally agreed that object perception is best when the signal frequency is 3 to 6 cycles per degree of visual arc.[1] This corresponds to a spatial resolution of 0.34 to 0.68 line pairs per millimeter (lp/mm) at 50-cm viewing distance. Smaller detail must be magnified to permit optimum perception. This is the reason that the use of magnifiers has become a part of film-based diagnosis. On the other hand, soft tissue features in x-ray films are best viewed from farther away so that they subtend a smaller arc of retinal surface. In both cases, film image size is manipulated by altering the viewing distance. There are, however, practical limitations. To bring the smallest resolvable detail of chest images, conventionally recorded on 14-inch × 17-inch x-ray film (with a typical spatial resolution of 6 lp/mm), to an optimum viewing scale at 50-cm viewing distance, a radiologist would have to scan that image enlarged in size to 2.0 m × 2.5 m. The matter is further complicated by the fact that (gray-scale) contrast affects spatial perception optima; the frequency optimum for perception is compromised by decreasing contrast resolution. However, the dynamic windowing of digital video images will compensate for this and allow the resolution of small scale, subtle contrast features.[6] It has been said that the increase in contrast resolution may compensate for the lower spatial resolution in digital imaging. It will not, however, compensate for inadequate image size.

In a recent study, the authors showed a significant correlation (radius (r) = 0.97) between image size and the detection of lesion-like signals on hard-copy chest phantom images (Fig 1). Images of different sizes for the same signal configuration were read by radiologists in a double-blind procedure to obtain the receiver operating characteristic data used to establish this relationship. The images did not provide the same spatial resolution. The smallest (100-mm spot films from a 57-cm image intensifier) and largest (14 inch × 17 inch Chronex 7 film [E.I. Dupont & Co, Wilmington, DE] exposed with a 1:12 grid) resolved about 6 lp/pm while the mid-size images (laser film prints of the digital images) were of lower spatial resolution, 1.2 lp/pm. Spatial resolution did not make a differ-

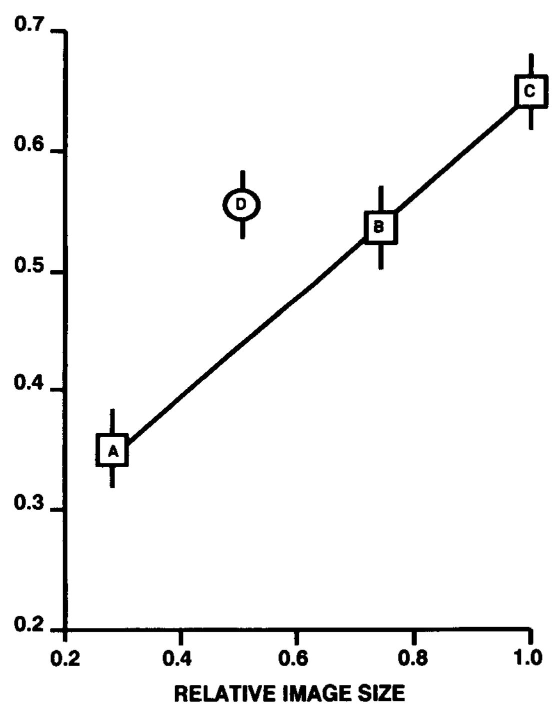

Fig 1. The influence of image size on reader performance as indicated by the true positive ratio (TP) at a false positive ratio (FP) of 0.2. Points A, B and C are the values for 100 mm, laser print, and conventional film images respectively. Point D is the value for digital video images. The results are grouped for 5 radiologists reading 30 images each, in each viewing format.

ence because the signal-producing lesions imaged were from 3 to 10 mm in diameter, well within the resolvable range of both systems, but at the limit of what is considered perceivable in diagnostic chest x-rays.[7,8] In this case, actual image size rather than spatial resolution is felt to be the key factor determining signal detection, ie, the perception of the lesions.

In spite of image size, however, signal detection in the smaller digital video images was as good as that in the full-size, high resolution images (Fig 1), probably because of better contrast resolution. In the digital imaging system being investigated by the authors, the video chest images are 50% smaller than the almost-life-size 14 inch $\times$ 17 inch film images. Detail present at a spatial resolution of 1 lp/mm in film, while still present on video, is much less perceptible; not because of the difference in viewing format, but simply as a result of the reduction in size. With the continuous zoom feature available with most digital image systems, it is possible to increase the size of a portion of the image. Viewing conditions would thereby be optimized for signal detection at the system's spatial resolution limit (1.2 lp/mm for 1024 $\times$ 1024 pixel digital images). Using the zoom, the more spatial resolution that can be provided in the original image, the greater the amount of diagnostic information that can be obtained. The problem, however, is that using the zoom is somewhat comparable with making 2 $\times$ 2.5 m enlargements of film images. Short of routinely scanning all images at a scale that provides optimum viewing of the smallest resolvable detail, one would have to know what to look for and precisely where to look. Given the size of the video image, each one-sixteenth of a digital chest image would have to be magnified and examined in succession, to the size of the viewing screen to bring the smallest resolvable detail to optimum viewing scale. This is obviously not a feasible or routine procedure.

The focus of development in digital imaging systems has been to enhance image fidelity or the information content of the images. However, image size and the size of the diagnostic detail clearly dictates how much of that information can be quickly and accurately gleaned by a viewer. Consequently, image size should be recognized as an important factor in the diagnostic process.

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