Comparison of Radiographic Image Quality From Four Digitization Devices as Viewed on Computer Monitors

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The objective of this study was to compare the quality of radiographic images digitized from commercial-grade and consumer-grade digital cameras and scanners as viewed on computer monitor. Radiographic images were digitized from hardcopy film using a commercial-grade laser scanner, a consumer-grade desktop flatbed scanner, a commercial-grade digital camera, and a consumer-grade digital camera. The quality of images without and with grayscale histogram adjustment was evaluated subjectively by 10 board-certified radiologists. Optical density response was evaluated objectively using a grayscale test pattern. There was no significant difference in subjective quality among images digitized with the commercial scanner, consumer scanner, and commercial camera. The quality of images digitized with the consumer camera was lower than the other 3. Objective tests showed the commercial scanner to have the most linear optical density response. For the purpose of viewing images on a computer monitor, a consumer-grade desktop scanner can produce images of similar quality to those produced by more expensive laser commercial-grade scanners and digital cameras and provides cost-efficient means to digitize radiographic plain films. A consumer-grade camera may not be optimal for use in this setting.

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KEY WORDS: digital imaging, digital radiology, scanner, digital camera, teleradiology

THE DIGITIZATION of radiographic films has become a necessity in today's practice of radiology. The widespread use of computers in radiology has made image digitization vital for publications, reference books, educational projects, and multimedia presentations.^{1,2} Teaching files are beginning to emerge on the Internet,³ and these contain large numbers of digital images.⁴⁻⁶ Furthermore, many radiologic and medical journals are becoming accessible via the Worldwide Web.^{7,8}

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Submission of manuscripts with accompanying radiographic images to some journals can be accomplished electronically, which promises to greatly simplify the peer review and editing process.⁹

With the continued development of digital medical imaging technology, more radiology departments will begin to move toward a "filmless" environment, thus avoiding the traditional problems of file rooms and the costs involved with maintaining large inventories of film. A sheet of duplication film may cost several dollars to produce and store, whereas that same image could be stored digitally for a fraction of the cost. Film-based teaching files are expensive to produce and must be stored at a central location. A digital version of such a teaching file could be placed on CD-ROM or Internet server, and thus be more available and affordable to a wide range of users.⁵

The digitization of film in a radiology department is an issue relating to picture archiving and communication systems (PACS). Electronic copies of these images are created directly at the time of the scan. However, many departments have huge volumes of teaching files or interesting cases that are stored historically as film. Cost efficient methods are needed to convert these films into quality digital images for use in Internet teaching files, presentations, and textbooks.

A variety of digitization methods exists, and generally can be classified as either film scanners or digital cameras. Current scanner technology includes laser scanners, which offer maximum resolution at a premium price, typically used for high-volume commercial digitization; and charge-coupling device (CCD) scanners that are more widespread and less expensive, and include most common desktop scanners. Digital camera technology captures an image on a CCD array through the optics of a hand-held photographic camera; the quality of the optics and the digital array varies widely among models.

Although expensive digitization options do exist, it is reasonable to question how the image quality of the less costly devices would compare. Do the expensive scanners and cameras really provide a substantial increase in the quality of images? A recent study of lower-cost digital cam-

eras showed that such devices were able to produce quality digital images for use in various media.¹⁰ However, we know of no studies that compare the quality of images produced by high-end commercial scanners and cameras against less-expensive consumer models. This report describes the results of comparison tests between a commercial-grade laser scanner, a consumer-grade desktop CCD flat-bed scanner, a commercial-grade digital camera, and a consumer-grade digital camera.

MATERIALS AND METHODS

Two digital scanners and 2 digital cameras were used in this study. The scanners used were the Lumisys Lumiscan 75 (Part #0068-770; Lumisys Inc, Sunnyvale, CA), a commercial-grade laser scanner costing approximately \$50,000, and the Hewlett-Packard (HP) ScanJet 6100C/T with transparency adapter (Product #HPC6260; Hewlett-Packard, Palo Alto, CA), a desktop CCD scanner with backlit adapter costing approximately \$1,500. The cameras used were the Kodak Digital Science DSC420m camera (Eastman Kodak, Rochester, NY) with Nikon front, a commercial-grade digital camera costing approximately \$8,000, and the Olympus Digital Camera D-500L (Model #D-500L; Olympus, Melville, NY), a consumer-grade digital camera costing approximately \$1,000.

Digitization Procedures

Lumisys Lumiscan 75. The plain films were scanned in Photoshop, version 4.0 (Adobe Systems Incorporated, Mountain View, CA) using the Twain plug-in for Lumisys (Scanx for DOS). Automatic brightness/contrast and resolution settings were used. The Lumisys scanner digitizes at 2,048 pixels from side to side. With a radiographic film 14 inches across, the scan resolution is 2,048 dots/14 inches or 146.5 dots per inch (DPI). Using Photoshop, the images were increased to a resolution of 300 DPI, resized to make the images 800 pixels on the shortest side, and saved as tagged image format (TIF) files.

Hewlett Packard ScanJet 6100C. The plain films were placed by hand on the flatbed scanner at center of the field. Using the HP DeskScan software, images were scanned in grayscale at 300 DPI using settings of brightness, 146 and contrast, 150 and imported into Photoshop using standard TWAIN plug-in. Images were then resized to make the image 800 pixels on the shortest side, and saved as TIF files.

Kodak Digital Science DSC420m camera. The plain films were placed on a back-lit glass transparency bed, and the subject area was cropped with opaque strips at the margins. The Kodak camera was attached to a tripod overhead. Pictures were taken with settings of f4, 1/800, ISO 400 and were imported into Photoshop using standard TWAIN plug-in. Images were then resized to make the image 800 pixels on the shortest side, and saved as TIF files.

Olympus Digital Camera D-500L. The plain films were placed on a back-lit glass transparency bed in the same fashion as with the other camera. The Olympus camera was set to telephoto mode, highest quality (least compression) mode, and standard auto exposure setting. The subject area was adjusted by raising or lowering the camera on the stand. Because the

Olympus camera takes pictures in color and saves them in the JPEG image format, the images were imported into Photoshop using standard TWAIN plug-in, and converted to grayscale. Images were then resized to make the images 800 pixels on the shortest side, and then saved as TIF files.

Subjective Testing

Ten normal diagnostic radiologic images were digitized from film using each of the 4 devices. These images were selected as a representative cross section of the type of images encountered in routine radiologic imaging and included abdominal computed tomography (CT), head CT, chest CT, spine magnetic resonance imaging (MRI), pelvis MRI, head MRI, chest x-ray, c-spine x-ray, aortic arch angiogram, and fetal ultrasound scan. Two versions of each of the 4 scanned images were generated: a first unprocessed image and a second image that was optimized using manual histogram post-processing in Photoshop. The histogram postprocessing consisted of adjusting the lower and upper margins of the output of the linear intensity transfer function to the corresponding lower and upper limits of the grayscale range input, with proportional adjustment of the center point.

The result of this digitization and processing was 8 versions of each of the 10 images (4 processed and 4 unprocessed). The 8 versions of each image were arranged in random order on 2 digital slides of 4 images each, yielding 10 slide pairs for dual-monitor display (8 images per pair). Images were resized as necessary within each slide. Three different slide shows were created with the 10 pairs of slides presented in a different random order.

Ten board-certified radiologists were recruited to evaluate the quality of the images. Each radiologist viewed 1 of the 3 slide shows on a desktop computer with dual Viewsonic P810 Professional Series 21-inch color monitors (Viewsonic Corp, Walnut, CA). Monitor specifications included a dot pitch of 0.25 mm (diagonal) and luminance of 108 candela-m². Evaluators were asked to grade each image on a scale from 0 to 10 (10 = best), based on the overall quality of the image. They were instructed to score each image independently of the others on the slide, and images on the same slide could be given the same score. Evaluators viewed the images in ambient light and were allowed to alter viewing distance. Evaluators were not given the ability to change grayscale window/level or to zoom the images.

Statistical analysis of the results was performed using analysis of variance ANOVA. Contrast statistical analysis was performed post-hoc using Least-Squares.

Objective Testing

A standard Society of Motion Picture and Television Engineers (SMPTE) test pattern was used to test each device (Fig 1). The test pattern includes grayscale steps from black to white, labeled from 0% to 100% in 10% increments. The optical density (OD) of each grayscale step was measured from a film hardcopy of the pattern using a film densitometer. The hardcopy test pattern was then digitized by each of the 4 devices. The 8-bit grayscale value of each scanned or photographed test pattern was plotted as a semilogarithmic function of optical density (Fig 2). Digitization was first done using the default settings on each device. Contrast and brightness were adjusted on the desktop scanner, and exposure was adjusted on the

Fig 1. Society of Motion Picture and Television Engineers (SMPTE) test pattern used for grayscale level and optical density comparisons.

cameras, to achieve a response that was as close to linear as possible for each device. The commercial scanner only allowed automatic contrast and brightness adjustment. The best response settings for each device were used for the objective assessment as well as in the digitization of radiographic films used in the subjective portion of the study.

RESULTS

The overall subjective performance of the devices is described in Table 1. Comparing the mean scores for all devices, the commercial scanner scored highest with a mean of 6.99. The consumer scanner was second, with a mean score of 6.75, followed by the commercial camera with a score of 6.64. The mean score of the consumer camera was below the other 3 by a much larger margin with a score of 5.82. ANOVA confirmed these differences as statistically significant ($P < .001$, $DF = 3$; $F\text{-value} = 22.90$). Contrast analysis of the differences between the commercial scanner, the consumer scanner, and the commercial camera was not statistically significant ($P = .10$ to $.49$, $DF = 1$; $F\text{-value} = 2.64$ to 0.49). When the 2 scanners are grouped together and the 2 cameras grouped together, contrast analysis showed the scanners to

have a higher mean score than the cameras ($P < .001$, $DF = 1$; $F\text{-value} = 36.07$).

The effect of postdigitization processing with histogram optimization of image brightness and contrast is shown in Table 2. Across all devices, the image quality was increased in the postprocessed images ($P < .001$, $DF = 1$; $F\text{-value} = 66.66$). Contrast analysis showed that no one device was affected more or less than another device by adjusting image grayscale.

The Kendall coefficient of concordance (W) test for these results is $W = 0.469$. This yields a χ^2 value of 371 with 79 degrees of freedom, which is significant at $P < .001$, meaning that there was, in general, a high degree of agreement among the radiologists who evaluated these images.

The grayscale responses of the 4 devices deviated from the idealized linear semilogarithmic response by differing amounts (Fig 2). The commercial scanner most closely paralleled the ideal optical density curve, except that it tended to yield slightly higher (brighter) values for regions of greater density. The consumer camera deviated most from the idealized response curve. All 4 of the devices were

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Fig 2. Graph comparing the grayscale value and optical density of images processed using the different devices. Scan, scanner; Cam, digital camera; Comm, commercial grade device; Cons, consumer grade device.

relatively close to the ideal curve near the extremes of optical density.

DISCUSSION

The results showed that there was little difference in the subjective quality of the top 3 devices: the commercial scanner, consumer scanner, and commercial camera. However, the consumer scanner is much less expensive than the other 2 devices. For viewing these images on a computer monitor, such as in educational projects and Internet publishing, the consumer scanner is a cost-efficient

choice. Although the commercial scanner had a more linear grayscale response curve than consumer scanner, the differences were not apparent in the subjective tests. The fact that scanners did better overall than the cameras was in part because of the poorer overall performance of the consumer camera.

The consumer camera was not able to match the quality of the other 3 devices. One reason for this is that these cameras are designed for consumers to take color pictures, and this type of digital light photography tends to exaggerate the amount of contrast, which distorts the grayscale of a radiograph. When photographing a plain film radio-

Table 1. Results of Subjective Image Quality Comparison

Device	No.	Mean	SD
Commercial scanner	200	6.99	1.523
Consumer scanner	200	6.75	1.902
Commercial camera	200	6.64	1.730
Consumer camera	200	5.82	2.012

NOTE. $P < .0001$.

Table 2. Results of Subjective Image Quality Comparison After Histogram Postprocessing

Method	No.	Mean	SD
Processed	400	6.98	1.621
Unprocessed	400	6.11	1.964

NOTE. $P < .0001$.

graph, the color picture output can create areas of high contrast and dark shades on the final image.

The output of all 4 devices was improved with the simple histogram optimization, and the relative quality of images produced by each device was the same after processing. Another result suggested by the subjective testing was that the quality of the digitization was affected by the type of radiographic image. The digitization process may capture images with intrinsic high contrast and signal more effectively, but this assertion cannot be proven because only 1 of each image type was used in this study.

The objective performance of the devices on the optical density versus grayscale response curve correlated roughly with the subjective tests in that the commercial scanner followed the ideal curve in the most linear fashion and also had the highest subjective scores. The commercial camera showed the next least amount of deviation from the ideal curve, followed by the consumer scanner. It is worth noting that all curves were closest to the control curve at the 2 ends of the grayscale spectrum. This shows that even devices of lesser quality can compete in grayscale image reproduction at the extremes of the grayscale. What separates the devices is how well they follow the control in the middle of the grayscale curve. These distinguishing shades of gray in the middle of the spectrum often are the important shades necessary for tissue contrast.

These results imply that the type of digitization equipment may affect the diagnostic quality of digital images that are imported into clinical digital systems such as PACS. However, this study did not address the issue of how these different digitization methods affect diagnostic quality. A study that does address this issue would be extremely useful in determining whether the use of devices other than commercial scanners is justifiable in a clinical setting. For purposes of this discussion, these results suggest that a variety of digitization methods may be useful in educational and other nonclinical applications.

Two types of modality-specific artifacts were noted during image processing, although not directly reflected in the objective or subjective tests. The consumer scanner left a faint crosshatch artifact that is presumed to be related to the motorized CCD mechanism, particularly when the image being scanned was small and required digital magni-

fication. A more expensive lens-driven desktop scanner would be expected to minimize this type of artifact. Also, both digital cameras left a halo or glow artifact next to bright white objects (such as bone on CT), probably caused by a combination of the back-lit glass transparency bed and the optics of the photographic cameras.

An interesting question to ask is how the quality of the next generation of inexpensive "starter" scanners would compare with the scanners evaluated here? Digital scanners costing less than \$200 are now available on the consumer market. Additionally, newer consumer-grade digital cameras are now available with up to 3-megabyte pixel resolution or more, which would be expected to improve digitized image quality. A consumer-grade digital camera that takes pictures in grayscale mode or that gives the user more control over brightness and contrast before taking a picture also may perform better.

Possible limitations in the design of the subjective evaluation in this study include the number of images used and the method of presentation. The number of different images was limited to 10 to prevent evaluator fatigue, because each image was presented in 8 versions for a total of 80 different versions. A greater number of images potentially could demonstrate additional significant distinctions between the various digitization methods and image types. Another potential limitation is the possible bias introduced by the presentation paradigm. Because all the versions of an image were viewed together, judgment of each image may not have been independent. However, simultaneous viewing of all versions of an image would be expected to improve the reliability of relative comparisons. Also, the presentation paradigm and lack of zooming limited the size of images on the monitor. For many digital modalities such as CT and MR, the monitor resolution allowed images to be presented at a resolution similar to the original digital data. However, for computed radiography images, the full spatial resolution was not possible in the 4-on-1 presentation, and this represents a potential limitation in the generalization of these results. It also is important to recognize that this study only looked at the quality of these 4 devices for display on a computer monitor. It did not address the issue of which scanner or camera would produce the best output on printed paper or photographic slides.

CONCLUSION

The commercial scanner, consumer scanner, and commercial digital camera produce digitized radiographic images of similar quality when viewed on a computer monitor. However, the consumer-grade desktop scanner is less expensive than the other 2 devices and presents an attractive cost-effective choice for use in the electronic publication of teaching files and other educational materials on the Internet. Such a device can provide a relatively inexpensive means for academic and community-

based radiologists to digitize their own collections of hardcopy images. The consumer-grade digital camera did not perform as well as the other devices tested in this study, and this type of device may not be as well suited for radiographic film digitization.

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