Digital Processing of Radiographic Images From PACS to Publishing

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Several studies have addressed the implications of filmless radiologic imaging on telemedicine, diagnostic ability, and electronic teaching files. However, many publishers still require authors to submit hardcopy images for publication of articles and textbooks. This study compares the quality digital images directly exported from picture archive and communications systems (PACS) to images digitized from radiographic film. The authors evaluated the quality of publication-grade glossy photographs produced from digital radiographic images using 3 different methods: (1) film images digitized using a desktop scanner and then printed, (2) digital images obtained directly from PACS then printed, and (3) digital images obtained from PACS and processed to improve sharpness prior to printing. Twenty images were printed using each of the 3 different methods and rated for quality by 7 radiologists. The results were analyzed for statistically significant differences among the image sets. Subjective evaluations of the filmless images found them to be of equal or better quality than the digitized images. Direct electronic transfer of PACS images reduces the number of steps involved in creating publication-quality images as well as providing the means to produce high-quality radiographic images in a digital environment.

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KEY WORDS: filmless imaging, picture archive and communications systems, digital imaging, digital radiology, scanner, publishing.

ADVANCES IN FILMLESS imaging facilitate the radiologist's ability to make diagnoses,¹ review radiologic studies over the Internet,² produce digital teaching files,³ and maintain images in picture archive and communications systems (PACS).⁴ Another challenge in the filmless radiology department is the management and preparation

of high-resolution images for publication or other paper-based production. Although PACS management has mostly affected the radiologist's clinical aspect of practice, producing publication quality images for use in traditional print media has not been addressed fully. Some studies have been conducted to assess the feasibility of producing high-resolution images from the PACS.² Moreover, little has been done to compare the image print quality of filmless images versus digitized radiologic images for publication. By nature, digital images have low spatial resolution, but print and future electronic display require higher resolution. This study attempts to narrow the gap in what may be the last link in the filmless radiology department, from PACS to publishing.

MATERIALS AND METHODS

We selected 20 digital images, including images from routine head and neck neuroradiologic examinations and 1 standard test pattern image. We then made 3 different versions of glossy photographic prints of each image: (1) hardcopy film image redigitized using a desktop CCD scanner and then printed, (2) digital filmless image obtained directly from PACS then printed without additional filtering, and (3) digital filmless image obtained from PACS and processed with sharpening filter before printing. All images were obtained from digital computed tomography (CT) and magnetic resonance (MR) modalities. Hardcopy images were printed as secondary output from the respective digital modalities and then redigitized using a commercial flatbed scanner with backlighting connected to a personal computer (PC). The flatbed scanner was set to scan at 300 dots per inch (dpi) using default settings for sharp black and white photograph. The modalities and body regions of these images are enumerated in Table 1.

All images were resized to a pixel dimension of 1,000 × 1,000 pixels using bicubic interpolation, with a print resolution of 300 pixels per inch. The unfiltered filmless images were exported as TIFF files directly from PACS to a network drive accessible by PC. The raw digital files were interpolated and cropped to dimensions of 1,000 × 1,000 pixels. The filtered filmless images were obtained from PACS and resized in the same manner, followed by application of an unsharp mask sharpening filter (170%, pixel radius 1.5). Interpolation and filtering were performed in Photoshop version 4.0 (Adobe Systems Inc, Mountain View, CA). No adjustments were made to brightness or contrast. Figure 1 shows the steps involved to create the 3 prints for each image.

Each set of 3 images, consisting of a digitized image, an unfiltered filmless image, and a sharpened filmless image, then was placed in random order and printed on glossy photographic

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Table 1. Image Set Body Regions, Modalities, and Techniques

Modality	Body Region	Techniques
CT	Suprahyoid neck	Axial, contrast enhanced, soft tissue algorithm
	Cervical spine	Axial, contrast enhanced, soft tissue algorithm
		Axial, bone algorithm
	Orbit	Axial, contrast enhanced, soft tissue algorithm
	Temporal bone	Axial thin section, bone algorithm (standard and magnified field of view)
MR		Coronal thin section, bone algorithm (standard and magnified field of view)
	Suprahyoid neck	Axial T ₂ -weighted, fat suppression
		Coronal inversion recovery
		Axial T ₁ -weighted, contrast enhanced, fat suppression (at two distinct locations)
		Coronal T ₁ -weighted, contrast enhanced (at two distinct locations)
	Cervical spine	Sagittal T ₂ -weighted
		Sagittal inversion recovery
Test		Sagittal T ₁ -weighted image
	Temporal bone	Axial thin section, T ₂ fast spin echo
	Carotid arteries	Dynamic bolus contrast enhanced MR angiogram
	Test pattern	SMPTE grayscale test image

Abbreviation: SMPTE, Society of Motion Picture and Television Engineers.

paper using a Kodak 8650 PS dye sublimation printer (Eastman Kodak Company, Rochester, NY). The 20 image sets were then reviewed by 7 board certified radiologists who were asked to rank the images from best (1) to worst (3) in overall quality, which was defined as sharpness, clarity, and absence of artifact. No diagnosis was given but radiologists were expected to focus on areas of diagnostic importance as they compared the images.

The differences in assigned rank were analyzed using analysis of variance (ANOVA). Rank was modeled as being dependent on type of image, observing radiologist, and image set. Differences between modalities were compared using the Tukey grouping.

RESULTS

The scores for each radiologist as a function of the 3 modalities and 3 print techniques is given in Table 2. Image quality was found to differ significantly dependent on image type but did not differ dependent on radiologist or image set. The filmless sharpened images (mean, 1.44) were found to differ significantly from unfiltered filmless images (mean, 2.26) and the film digitized images (mean, 2.30), with overall $P < .0001$. The unfiltered filmless images and the digitized images did not differ significantly from each other. In other words, the filmless images from PACS that had been sharpened had the best overall quality. The film digitized images and filmless unfiltered images were of similar quality (Fig 2).

Fig 1. Flow chart of the steps taken to create a high-resolution image in a filmless versus film based environment.

Table 2. Mean Scores for Each Radiologist as a Function of the 3 Methods

Radiologist	Method 1: Filmless Unmodified Image	Method 2: Filmless Sharpened Image	Method 3: Digitized Image
1	2.5	1.1	2.4
2	1.9	1.5	2.6
3	1.9	1.4	2.7
4	2.5	1.4	2.2
5	2.2	2.0	1.8
6	2.4	1.2	2.4
7	2.5	1.3	2.2

Note: 1, best quality; 3, worst quality.

Fig 2. Comparison of images using three different methods. (A) Redigitized image scanned from film. This image has lost some grayscale resolution and shows too much contrast. (B) Digital image taken directly from PACS and then modified with sharpening filter. This image retains full grayscale range. (C) Digital image taken directly from PACS without additional filtering. The image appears less sharp than Fig 2B.

DISCUSSION

To understand the differences between digital and traditional printed media, it is important to first understand the components of radiographic images from a digital graphics standpoint. The digital radiographic images used in workstations, telemedicine, and digital teaching files often are of inherently low resolution. Such small files are easy to store and their resolution is well suited for display on typical computer monitors, which generally have a screen resolution of 72 dpi. However, when it comes time to transfer radiographic images

to print media, this becomes a problem. The image print resolution that is best suited to paper and the minimum required by many publishers is 300 dpi or higher. For example, a raw MR image with a size of 256×256 pixels would be less than 1-inch square when printed at 300 dpi and would be unsuitable for publication.

In general, there are several ways in which digital grayscale images can be manipulated. These include interpolation, filtering, intensity modification, output resolution, and other functions that can affect the perceived quality of a digital grayscale

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image. Interpolation is used to increase the number of pixels in an image by decreasing pixel size and estimating the values of the new smaller pixels based on the intensities of neighboring pixels. For example, an MR image with an original size of 256×256 pixels may be increased to $1,000 \times 1,000$ pixels, providing a less coarse-appearing image. Print dpi is calculated by dividing the number of pixels by the desired print dimensions. In our study, all images were resized and interpolated to 1,000 pixels yielding a print resolution of 300 dpi at 3.3 inches, which is a hardcopy format that is acceptable to most commercial publishers.

In the case of radiographic film produced by clinical imaging systems (such as MR or CT scanners), images are interpolated routinely and processed automatically by the film printer. Interpolation at the level of both PACS and film printers has been developed extensively but because of the proprietary techniques the exact details of the image enhancing used by these systems often is unknown. In any case, the end result is a transparency film-based image that has a high spatial resolution and is visually pleasing to the eyes of the healthcare workers who must then use the image to make patient care decisions. Taking this optimized image and putting it back in a form that is amenable to the traditional methods of submission and printing for paper publication can be difficult.

Currently, in most medical imaging departments, the process of digitization involves scanning existing films that already came from digital images using commercial laser or charge-coupled device (CCD) scanner. However, both processes of printing films and digitizing films are redundant steps because original images can be made directly from PACS and exported directly for graphic modification. Filmless image transfer from the PACS directly to graphic software reduces the need for a film hard copy and at the same time decreases

degradation steps. Because these enhancements can be applied digitally, the analog intermediate steps are superfluous and result in unnecessary degradation. Because some uses, such as scholarly publication, require printed media, the high-resolution digital form can be printed when necessary.

CONCLUSION

Computer technology now has advanced to the point at which filmless digital imaging is not only possible but is equal to or superior over traditional film-based imaging. Many aspects of diagnosis, telemedicine, and teaching files all can be performed without the use of hard-copy radiographic films. In this study, we have shown that images taken directly from a digital source and optimized digitally before printing are of superior quality compared to the method often used in preparing publications that requires digitization. Eventually, radiographic film will become obsolete as medical imaging departments make the transition to a filmless environment; obtaining high-resolution images without the use of film completes the last step in the digital evolution. This will allow academic radiology departments to close the gap from PACS to publishing.

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