

IMAGES ON PERSONAL COMPUTERS

Displaying Radiologic Images on Personal Computers: Practical Applications and Uses

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This is the fifth and final article in our series for radiologists and imaging scientists on displaying, manipulating, and analyzing radiologic images on personal computers (PCs). There are many methods of transferring radiologic images into a PC, including transfer over a network, transfer from an imaging modality storage archive, using a frame grabber in the image display console, and digitizing a radiograph or 35-mm slide. Depending on the transfer method, the image file may be an extended gray-scale contrast, 16-bit raster file or an 8-bit PC graphics file. On the PC, the image can be viewed, analyzed, enhanced, and annotated. Some specific uses and applications include making 35-mm slides, printing images for publication, making posters and handouts, facsimile (fax) transmission to referring clinicians, converting radiologic images into medical illustrations, creating a digital teaching file, and using a network to disseminate teaching material. We are distributing a 16-bit image display and analysis program for Macintosh computers, *Dr Razz*, that illustrates many of the principles discussed in this review series. The program is available for no charge by anonymous file transfer protocol (ftp).

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KEY WORDS: image display, image transfer, dye sublimation printer, facsimile transmission, World Wide Webb (WWW), Internet network.

THIS IS THE FIFTH and final article in our series for radiologists and imaging scientists on displaying, manipulating, and analyzing radiologic images on personal computers (PCs). In this article we will briefly survey some of the practical applications and uses of radiologic images with PCs.

GETTING RADIOLOGIC IMAGES INTO A PC

There are many different methods of transferring radiologic images into a PC, and each has various trade-offs in resolution, accuracy, arti-

facts, convenience, and cost.¹ Briefly, the methods can be grouped into the following categories (Fig 1A): (1) network (usually via the file transfer protocol [ftp] or American College of Radiology and National Electrical Manufacturers Association Digital Imaging and Communications in Medicine [DICOM] protocols); (2) transfer from imaging modality archive (either a 9-track ½-in tape or optical disk); (3) frame grabber from the imaging display console video image (commonly used by teleradiology systems); (4) digitizing a radiograph via laser or charge-coupled device (CCD) digitizer, flat-bed scanner, video camera/frame grabber, or other device; and (5) digitizing a 35-mm slide (obtained either from a radiograph or an image display console). Depending on the image transfer method, the image data file on the PC is usually either an extended gray-scale contrast, 16-bit raster image file, or an 8-bit PC image file such as tagged image file format (TIFF), graphic interchange format or PICT (a Macintosh [Apple Computer, Inc, Cupertino, CA] file format).

IMAGE DISPLAY, IMAGE ANALYSIS, IMAGE PROCESSING

Once the image file is transferred into the PC, the image can be viewed, analyzed, enhanced, annotated or otherwise manipulated, and incor-

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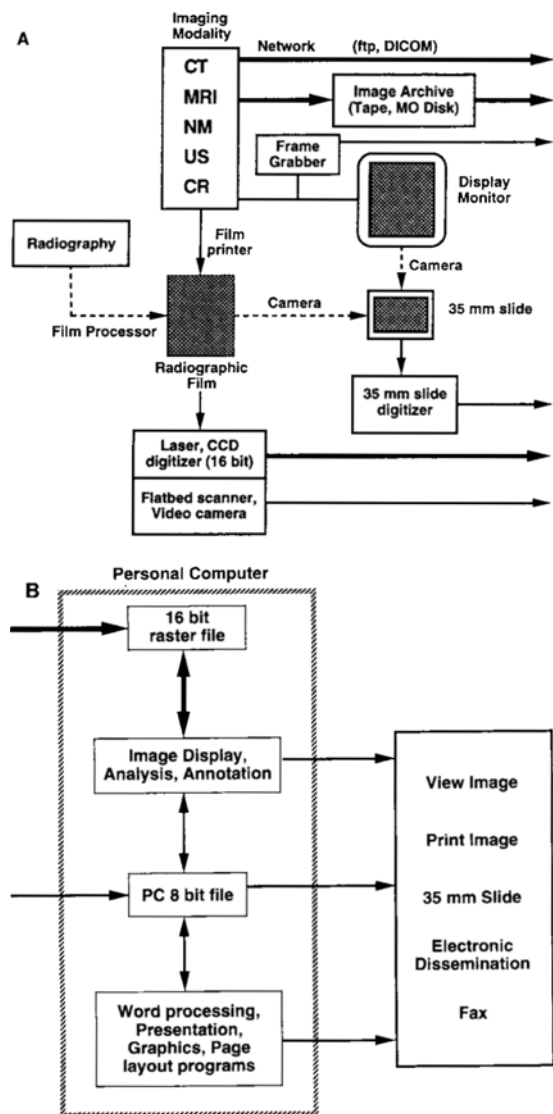


Fig 1. Radiologic images and PCs. (A) Transferring images into the PC. The thick, solid lines depict 16-bit digital images. The thin, solid lines depict 8-bit digital images and the thin, dashed lines indicate analog photography or radiographic film processing. Abbreviations: CT, computed tomography; MR, magnetic resonance imaging; NM, nuclear medicine; US, ultrasound; CR, computed radiography; MO, magneto-optical; ftp, file transfer protocol; DICOM, Digital Imaging and Communications standard. (B) Overview of practical applications is shown.

porated into standard PC documents using word-processing, graphics, illustration, page-layout, or presentation programs (Fig 1B). The ability to customize the appearance of the image is perhaps the biggest advantage of transferring it into the PC. Selecting the appropriate software for these functions is strongly depen-

dent on whether the image file is 16 or 8 bit (see the first article in this series for a discussion of the "bit depth" of an image¹). As a general guideline, scientific image display and image-processing programs usually can accommodate 16-bit radiologic images, whereas standard PC software require a PC-standard 8-bit graphics file. Typically, the programs capable of displaying 16-bit images can save a radiologic image as a standard 8-bit gray-scale file after appropriate window and level adjustments have been made. Then the 8-bit file can be incorporated or pasted into a document using standard PC software.

The problems of displaying 16-bit radiologic images on PCs with standard red-green-blue (RGB) graphics hardware have been discussed previously in this series and elsewhere in this journal.^{2,3} Common image-processing operations that can be performed to enhance image appearance have also been discussed in this series.⁴

Although PCs are being increasingly used as low-cost image display workstations, the remainder of this article will survey the practical uses and applications of radiologic images for an individual with a PC on the desktop. Unless stated otherwise, the remaining uses assume the radiologic image has already been converted into an 8-bit gray-scale PC graphics file.

MAKING 35-MM SLIDES

Currently, many text and graphic 35-mm slides used for lectures and other presentations are produced by presentation programs such as Persuasion (Aldus Corp, Seattle, WA) and PowerPoint (Microsoft Corp, Redmond, WA). These programs typically integrate an outline and template system that greatly facilitates slide creation. Text can be entered via the outliner or imported from other word-processing software. This text can be formatted on the screen with many choices of font, type size, and text color. Bullets and other special characters can be added automatically. Special background colors, designs, and special effects can be saved in templates, for further use in other presentations. Built-in spelling checkers can scan the text in the presentation for misspelled words. Graphic elements can be easily added to the slides from within the program, or imported

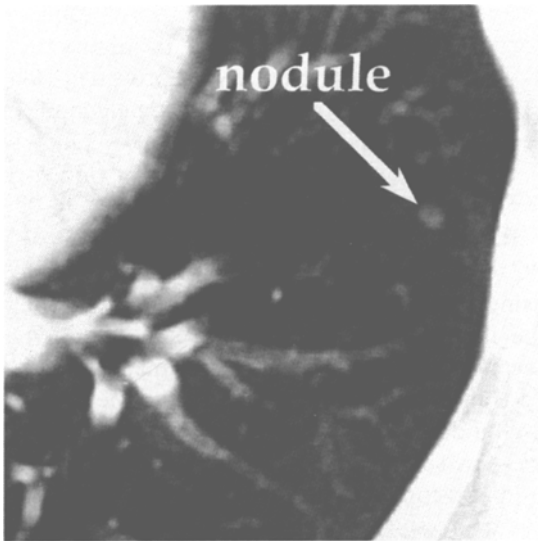


Fig 2. Altering a digital image on a PC. CT scan of the chest showing a pulmonary nodule (arrow). Using PC software, the original 16-bit digital image has been cropped, enlarged, enhanced, and labeled. The original full-sized figure is from Fig 1A in the fourth article in this series.⁴ This figure was submitted to the publisher in the form of a dye sublimation print, but the same file could have also been used to make a 35-mm slide.

from many sources. Copyright-free artwork can be scanned in from illustrations in the public domain,⁵ or can be copied from commercially available medical clip-art collections such as the MediClip software available from *The Alpha Media Catalog*.⁶

However, slides of radiographic images are still commonly produced by photographing the images and having the developed film mounted in 35-mm slide mounts. Limitations of this method include inability to adjust image quality or annotate the image after it has been radiographed. Digital radiographic images on a PC, on the other hand, can be cropped, enlarged, enhanced, and annotated (Fig 2).

The 35-mm slides of both text and radiologic images can then be produced on a dedicated

35-mm film recorder directly from the computer data file. Typically, the user submits the data file of a presentation or graphics program to a service bureau on a 3.5-in floppy disk or sends the file over a network to a file server. The file type required depends on the program that produced the slide, the computer platform (Macintosh, IBM compatible, UNIX, etc), and the type of slide. The service bureau uses this data file to produce the slide.

PRINTING RADIOLOGIC IMAGES

Many educational and scientific uses of radiologic images require that the images be printed for further distribution. Most PC-based printing technologies that can print reasonable-quality gray-scale images use clusters of small dots—known as dithering—to mimic different gray shades. Color images are printed by clustering dots of three or four different colors, which simulate many different colors. Printing technologies that use dithering to produce gray-scale or color images include laser, color laser, ink jet, thermal wax, and facsimile (fax) transmission (Table 1).⁷⁻⁹ Much better gray-scale and continuous-tone color images are produced by dye sublimation printers, which print individual pixels of color instead of printing small dots. Selecting the appropriate printing device hinges on the resolution requirements, cost, and whether line art or text is included with the image (Table). The images can either be printed directly from the PC, or an image file can be sent to a service bureau for final output.

Prints for Journals and Other Publications

Journals and other publications that accept manuscripts for publication typically request that radiologic images and line art be submitted as 3-in × 5-in or 5-in × 7-in photographs printed on glossy paper. However, the decreas-

Table 1. PC Printing Technologies Suitable for Printing Radiologic Images

Printing Technology	Cost/Image	Printing Speed	Gray-Scale Image Quality	Text, Line-Art Quality	Color Availability
Laser	Very low	Very fast	Fair-good*	Excellent	No
Color laser	Low-moderate	Fast	Fair-good	Excellent	Yes
Ink jet	Moderate	Slow	Good	Good	Yes
Thermal wax	Moderate	Slow	Good	Good	Yes
Dye sublimation	High	Slow	Excellent	Good	Yes
Fax	Low	Fair	Fair	Fair	No

*Laser printers with Photograde or similar gray-scale printing technology were used.

ing cost of high-quality color printers is making it increasingly feasible to submit computer-printed images and art work. Dye sublimation printers are widely considered to be superior at producing continuous-tone images such as radiologic images. Most of the gray-scale images in this series were submitted to the publisher as dye sublimation color prints printed on 8.5-in \times 11-in or 8.5-in \times 13-in glossy paper (Fig 2). The gray-scale images were printed from PICT files (for example, see Fig 1 in the third article in this series¹⁰), whereas the mixed gray-scale/line-drawing images were printed from PostScript files (see Figs 1 and 4 in the second article²). We have found that PICT or TIFF files sometimes showed pixelation artifacts if text or line drawings were included in the image, whereas the PostScript files did not produce this artifact. On the Macintosh, PostScript files are easily generated by selecting an option from the print dialog box, and a similar function is available in the Microsoft Windows (Microsoft) operating system.

In the future, journals will accept digital images on a disk or transferred over a network. Then the publisher can directly print the image in the journal from the digital image file. This should improve the quality of the printed images in the journal because any intermediate digitizing steps will be avoided.

Making Posters and Other Display Materials

PCs are being increasingly used to generate the text and graphics for posters and other display materials at a fraction of the cost compared with conventional methods. The printed output is typically mounted on poster board. As described above, radiologic images can also be printed from the PC for inclusion into the poster.

Handouts

Handouts are commonly used to supplement medical lectures and other types of teaching conferences. Many laser printers are capable of printing gray-scale images with acceptable image quality for educational and informational uses. Laser printers sold by Apple Computers that have the Photograde capability are suitable for printing gray-scale images. Other vendors distribute laser printers with similar technology.

The images can be directly incorporated into a document with word-processor programs such as Microsoft Word, page layout programs such as Aldus PageMaker (Aldus), or presentation programs such as Aldus Persuasion.

Fax Image Transfer

Radiologic images can be transferred from a PC to a remote location over telephone lines by using a modem with fax capability. Typically, the image is transmitted to a standalone fax-receiving station, although the image can also be transmitted to another PC equipped with a fax modem. Software on the PC first converts the gray-scale image into a form suitable for fax transmission using the dithering technique discussed above. Image quality is surprisingly good as long as the image is transmitted from the PC instead of being scanned in a conventional fax-transmission station.⁹ In one study, clinicians strongly preferred radiologic reports that included an annotated image, and many of them indicated they would review films in the film library less often if such reports were routinely available.¹¹

CONVERTING RADIOLOGIC IMAGES INTO MEDICAL ILLUSTRATIONS

One of us (M.L.R.) has described a method for converting digital radiologic images into medical illustrations.¹² First, a gray-scale image is converted into line art using a graphics program such as Adobe Streamline (Adobe, Mountain View, CA) (Fig 3). Adobe Streamline uses sophisticated image-analysis algorithms to create outlines of the various anatomic features in the image. Then a graphics program such as Illustrator (Adobe) is used to edit the line art image to remove artifacts and anatomic inaccuracies. Finally, the various anatomic features can be colored (or shaded) and labeled. The result is an computer graphic that rivals the quality produced by a professional illustrator.

THE DIGITAL TEACHING FILE

We have previously estimated that a film-based teaching file of 1,000 cases would cost \$9,000 to \$15,000 for the cost of copy film alone.¹³ On the other hand, this number of cases could be stored on three 3.5-in magneto-optical (MO) disks for a current cost of about

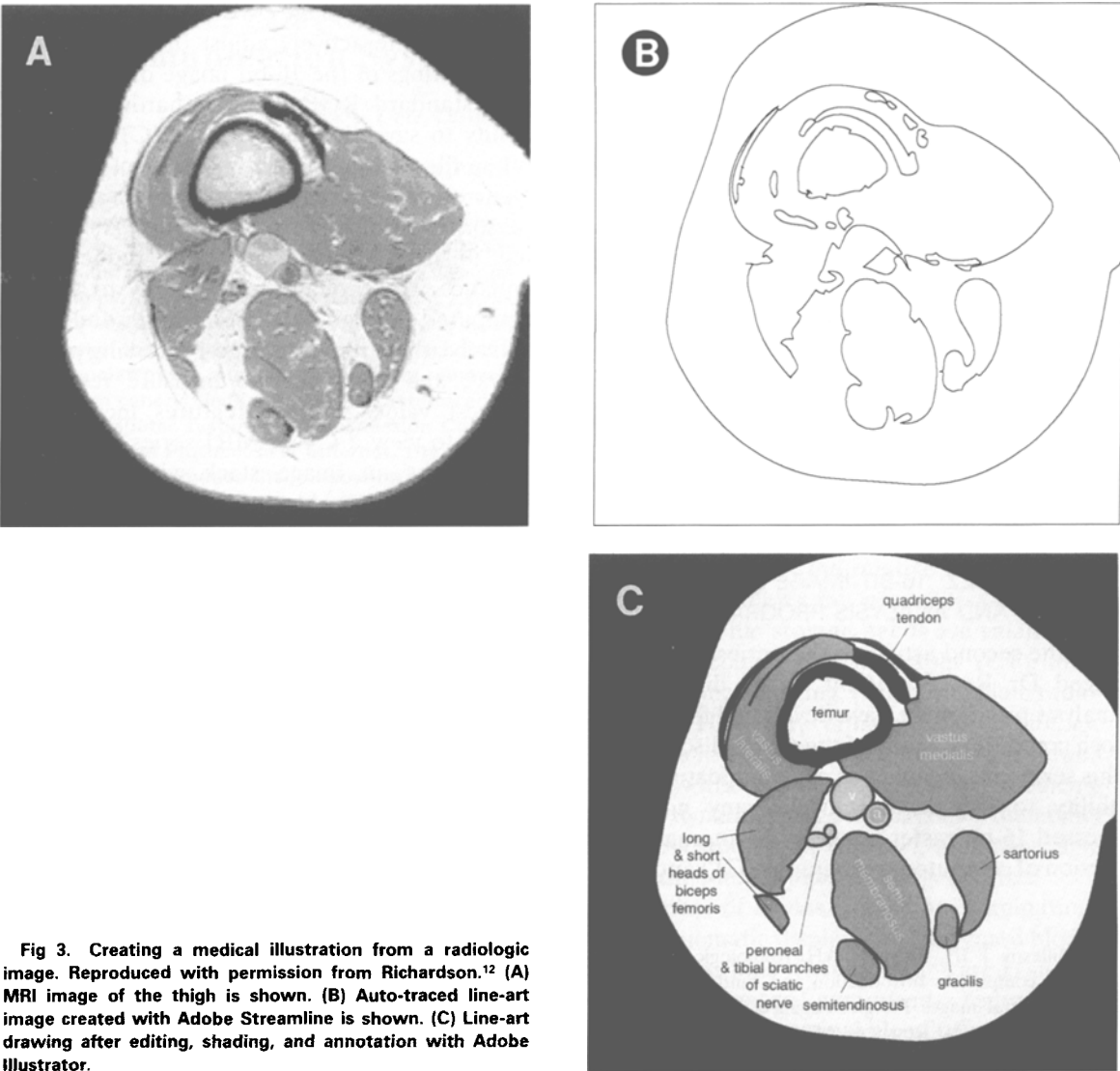


Fig 3. Creating a medical illustration from a radiologic image. Reproduced with permission from Richardson.¹² (A) MRI image of the thigh is shown. (B) Auto-traced line-art image created with Adobe Streamline is shown. (C) Line-art drawing after editing, shading, and annotation with Adobe Illustrator.

\$100 to \$150. The same film-based teaching file would occupy about 1.6 m of shelf space, compared with about 3 cm of shelf space for the MO disks. This markedly decreased cost means that one could disseminate about 100 copies of a digital teaching file in the form of such cartridges for the cost of one film-based set. Moreover, duplicating the film-based teaching file would take many days, whereas an MO disk can be copied in 10 minutes or less.

ELECTRONIC IMAGE DISSEMINATION

Digital images often need to be disseminated or made available to other users for educational, research, and other purposes. Images

can be disseminated by 9-track ½-in magnetic tape (increasingly uncommon), computer disk (see article three in the series for a review of different computer storage methods¹⁰), or over a computer network. We have studied distributing a digital teaching library over the Internet network using a software file format available on many different computer systems.¹⁴

However, recently we have studied using the World-Wide Web (WWW) as a method of disseminating digital teaching materials. The WWW is a client-server database architecture that greatly facilitates access to various digital resources on the Internet. WWW clients allow users to download files, view text or images,

listen to sounds, and watch movies on a WWW server with a simple hypertext interface. The hypertext interface is much easier to use than traditional methods of file transfer such as ftp. The National Center for Supercomputing Applications (NCSA) has distributed an excellent WWW client called Mosaic, which allows easy access to the WWW.¹⁵ Versions of Mosaic are available for the Macintosh and Microsoft Windows computer operating systems, and for the X-Windows system display server. A particular WWW document looks nearly the same on any of these computing platforms when viewed with Mosaic. Server software is also available for each of these platforms. Therefore, one can easily create a WWW server and digital archive on one's own PC or workstation and publish the archive on the Internet.

DR RAZZ: 16-BIT IMAGE DISPLAY AND ANALYSIS PROGRAM

In the second article in this series,² we introduced Dr Razz, a 16-bit image display and analysis program we have developed for Macintosh computers. Many of the topics discussed in this series are included as program features: (1) ability to import and display any noncompressed 16-bit raster image with automatic detection of computed tomography (CT) and mag-

netic resonance image (MRI) image types¹; (2) ability to interactively adjust the window and level settings of the 16-bit image data on a PC with standard RGB graphics hardware^{2,3}; (3) ability to save the image as a PICT, TIFF or other file format,¹ including several different types of image compression^{10,16}; (4) ability to perform basic image processing such as sharpening, unsharp masking, and noise reduction to enhance image quality⁴; (5) ability to display computed radiographic (CR) images and interactively adjust the CR image-processing parameters⁴; and (6) ability to measure region of interest values.⁴ Other features include the ability to view a CT or MRI series in a single window as an image stack with interactive scrolling of the stack.

Dr Razz is available for no charge by anonymous ftp at the following Internet address: [ftp.u.washington.edu](ftp://u.washington.edu). The files are located in the directory /public/razz. Sample images and documentation are available at the same location. The program and several sample images are also available on computer disk from Dr Gillespy. Please send a double-sided, high-density 3.5-in floppy disk (Macintosh format) and a self-addressed envelope suitable for return mailing. Please include sufficient US postage for the return mailing.

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