

# An Evaluation of Ten Digital Image Review Workstations

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**A suite of performance tests are defined and performed on a total of 10 primary diagnostic image review workstations. System architectures, user interface, image manipulation tools, and data retrieval rates are discussed and analyzed. Performance timings are normalized to MB/sec to remove image file size dependencies from the data analysis. Although it is likely that some performance and capacity data may be dated as this article goes to press, it is hoped that the test definitions, methodology, and baseline data will aid those contemplating equipment purchases to make a more informed choice.**

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**KEY WORDS: PACS, teleradiology, workstations, performance evaluation, computers, radiology.**

**T**HE DECISION to purchase components of an electronic medical records system such as Hospital Information Systems (HIS), Radiology Information Systems (RIS), teleradiology workstations or Picture Archiving and Communication Systems (PACS) should be carefully considered. Fortunately, some tools are available to assist in cost and workflow simulations.<sup>1,2</sup> Once a decision has been made to purchase one or more components, careful attention must be paid to issues that will determine how well the component will fit within the existing institutional data infrastructure.<sup>3</sup> This article assumes the previous two hurdles have been cleared and goes on to an analysis of several PACS- and teleradiology-based image review workstations.

For each workstation, the user interface, modes of operation, and image analysis features will be described. Performance measurements, where appropriate, will also be provided to compare analogous functions. The performance analysis is complicated by the fact that some workstations are sold as part of an integrated PACS, whereas others are standalone products that rely on another vendor's image archival and database system. These issues will be addressed in the analysis.

## METHODS

Because some image review workstations are optimized for different tasks, it is impractical to apply the same benchmarks to all systems. Therefore, the Results section is divided into several subtopics within which workstations may be classified as part of an integrated PACS, or stand-alone systems that require external image archives and databases.

Time-related performance measurements were made on un-

loaded systems during lunch or after business hours. The total data transferred for tests such as "Image Fetch from Archive" is calculated from the product of images on screen multiplied by the nominal file size for that image type. This size in megabytes (MB) is then divided by the transfer time (averaged over at least three different study retrievals) to arrive at the stated MB/sec figures. It may be argued that such tests have more to do with the network or archive than the workstations. However, differences among vendors on the same network subnet are observed, and this may be attributable to hardware and software efficiencies of the workstation vendors. Also, further tests such as the "Screen Paint Time" (the time necessary to redraw the display after paging through a multiple page study) offer a pure look at the performance within a single workstation because the data are locally stored.

Testing methodology and nomenclature are described below. In general, if a parameter's value is not known, the space is occupied by a "?". If the feature is unavailable or not under user control, the fact is illustrated by NA (not applicable). If the feature is available, but not enabled at our site's installation, NI (not installed) is indicated.

## Archive Size

For systems with fixed, central archives, the size in MB is reported. For systems with modular long-term storage (such as an optical disk juke box), the unit is described. For systems that use neither approach, but rather transfer images among identical workstations (so called peer-to-peer systems) and those that rely on external archives, an NA is reported.

## Monitor Size and Resolution

For standard aspect ratio "landscape"-type monitors, the diagonal size of the useful viewing area is reported. Both height and width are noted for portrait-type monitors and resolution is also reported.

## Multiple Monitor

If more than one monitor may be used, the maximum number possible is reported.

## Time to Archive

Measured in MB/sec from initiating the archive transaction until completion. For systems without an archive or manual archive operation because of automatic overnight archiving, NA is indicated.

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### *Patient List Fetch*

Measured in records/sec from the list request to the completion of the operation (as defined by filling the list display with patient names). Measurement of this parameter is complicated by the fact that the list may be generated from local storage, a remote peer, a database server, or a long-term archive. Therefore, the data source will be named in parentheses.

### *Image Fetch From Local or Remote Store*

Measured in MB/sec. Timed from initiating a request for an image study from the local (or remote) fast image store, to the completion of painting all images on screen in the current display mode. Total data is computed from the product of nominal image size with the number of displayed images.

### *Image Fetch From Archive*

Measured in MB/sec and timed from initiating a request for an image study from the archive to the completion of painting all images on screen in the current display mode. For systems without an archive (or which use a third-party archive), NA is reported.

### *Screen Paint Time*

Measured in MB/sec. Timed from operation request to the completion of rendering all images to the screen in the current display mode. This test is performed on a study that is already locally memory resident to remove the network factor.

### *Time to Print Images*

Measured in seconds on an unloaded networked laser camera (to eliminate queuing dependencies). Timed from the operation request to the ejection of a  $4 \times 3$  formatted film from the laser camera. At our institution, many of the workstations are not connected to a laser camera. In these instances, NI is used in place of NA to avoid confusing a local installation restriction with the lack of a workstation feature.

### *Video Controls*

Listing of available tools for brightness, contrast, window, level, and inverting the gray scale Look Up Table (LUT).

### *Orientation Tools*

Listing of image tools present to rotate (in screen plane), flip (out of screen plane), and pan (translational movement within the image).

### *Magnify, cine*

Listed if present.

### *Region of Interest*

Description of allowed region of interest (ROI) shapes (round, rectangular, or free-form), and the image quantification tools supported (pixel mean, standard deviation, pixel value).

### *Digital Image Communication in Medicine Input and Output (DICOM I/O)*

“Yes” if both input and output are DICOM compliant; “No” if neither input or output are DICOM compliant. If only one direction is DICOM compliant, it is listed and the protocol for the other direction is given in parentheses.

### *Remote Maintenance*

“Yes” if service can be done by vendor remotely over phone or network connection.

For some systems, additional entries are also listed. For instance, ultrasound PACS systems are subject to the following.

### *Frame Grab Time*

At the time of this evaluation, the ultrasound PACS workstations reviewed did not have the capability to perform direct digital image acquisition (in DICOM or other formats). Hence images were acquired by digitizing (frame grabbing) live video. This time was measured in seconds required from frame grab initiation to software report of completion. Because a rapid sequence of frame grabs can cause the time interval per digitization to increase, times are reported for single images and over a series of six.

### *Camtronics Input*

Indicates whether or not the unit can accept images from Camtronics 20 MB floptical disks.

## RESULTS

The Results section is divided into four main topics: Teleradiology Workstation Review, CT and MRI Standalone Workstation Review, Ultrasound miniPACS Workstation Review, and Ultrasound miniPACS Workstation Review. Each section is self-contained and can be understood without reference to the others. For each section, the systems evaluated within are listed, followed by the specific workstation reviews. Each review consists of an overview of the workstation's architecture (and relationship to the associated PACS components) followed by a detailed account of the workstation user interface. The review concludes with some remarks on the overall strengths and possible weaknesses of the system. At the end of each topic, a table summarizes the feature sets and performance measurements of the systems reviewed. The Results section concludes with several plots, which summarize those performance features that have the greatest applicability to all diagnostic workstations.

### *Teleradiology Workstation Review*

Within this section, the following offerings are evaluated: Physician's Display System V2.5.6 (Ko-

dak, Rochester NY), Telexmax V2.0 (ICON Medical Systems, Campbell, CA), and StatView/DX V1.1A (EMED, San Antonio, TX).

In general, teleradiology workstations acquire images from digitized film (or video) rather than directly in digital form from a networked imaging system. A dedicated workstation may be used to control the film digitizer or frame grabber, whereas other workstations are specialized for image review. Alternatively, the same workstation may be capable of performing both tasks. Once acquired, the image may be centrally archived, but more often (on current teleradiology systems) the image is passed from workstation to workstation (the peer-to-peer approach) over telephone lines or network links.

Teleradiology vendors also have different approaches to the basic architecture of their systems. Some use a peer-to-peer approach with high bandwidth T1 lines in order to avoid using image compression schemes. Others use peer-to-peer over standard phone lines and implement some minimally (as defined by vendors) lossy compression scheme. Finally, some products make use of a central server approach that can accept images over telephone lines or network links. Users then contact the central server to view studies. All three approaches are described in this section.

*Kodak Physician's Display System (PDS).* The PDS approach to teleradiology is somewhat different from many vendors in that they do not support image transfers from remote sites via standard telephone lines.<sup>4</sup> Rather, the PDS philosophy is to send full-resolution, uncompressed images from workstation to workstation using wide area network (WAN) or local area network (LAN) methods. At our institution, remote image access is provided by dedicated T1 lines. Local access is provided over an ethernet LAN. For image acquisition, the PDS system is accompanied by a Lumisys Laser Film Digitizer. The digitizer is connected to a SUN workstation running an X/Motif application for digitizer control. After acquisition, the SUN stores the image on its own network accessible disk, but may also pass images on to selected Macintosh-based PDS workstations.

The user interacts with one of two PDS workstation types: a quality assurance workstation situated near the film digitizer, or the radiologist's review workstation. The quality-assurance system uses a small (12 × 15-in) portrait monitor while the radi-

ologist workstation monitors are large enough to approximate a life-sized AP chest image. The PDS workstation software is layered on "At Ease" which in turn is laid on Finder (the Macintosh operating system). At Ease is a security program to limit user access to only those functions necessary to run the PDS software. The user interface should be fairly easy to navigate for anyone who is already familiar with a personal computer-based windowing system. Having said that, however, software developed for the Macintosh, Windows, or UNIX/X markets should conform to the accepted style on that platform, and this goal has not always been met.

The PDS system is based on a peer-to-peer network with no central archive or database. Hence, measurements such as archival capacity are not applicable. User interaction is via the Viewing and Communication windows. The Viewing tool provides menu bars along the bottom of each monitor (if two monitors are used) to control image layout, brightness, and contrast. Images can appear tiled or separately stacked, each within its own window. The image windows have barely recognizable Macintosh qualities and do not have a visible drag bar or sizing gadget. However, these features are present and the images can be moved and sized if needed. If one needs to see an image that is not present on the local PDS, one launches the Communication Control window. This window has Source and Destination menus. Only other PDS workstations that have been registered with the system are visible from these menus. This means that for one PDS to see another, it must run a server advertising its presence on the network. Furthermore, each PDS must be manually configured to recognize and communicate with every other PDS.

Assuming that the desired PDS station is available, one selects it and chooses List in order to view a patient list (listing does not occur automatically). To actually view the image, it must be manually pulled onto one's local PDS. This implies that a telephone call may be required to inform a radiologist of a study on a remote workstation. Failing that, one must manually search each workstation to find the study unless someone pushes it to them unbidden. Furthermore, perhaps as a security feature, after pushing an image from one workstation to another, the image on the remote station cannot be deleted.

The quality-assurance workstation monitor is a

small portrait type, and the communication window is actually too large to fit completely on screen. Because there is no sizing gadget on the communication window, it simply covers over displays and must be dismissed for one to view patient images. The patient list window also completely covers the screen and there is no sizing gadget. On the radiologist's review workstation (which has two very large monitors), the windows fit on the display, but the curvature of the monitors induces significant warping of the image borders. This may be somewhat confusing when viewing long, linear structures.

The most critical limitation is the requirement of manually configuring each PDS to recognize every other PDS on the network. This will ultimately result in unacceptable system administration overhead as the PDS network grows beyond a few units (in fact only six workstations are supported at our site). It would seem preferable to use the Macintosh's native networking tool (the Chooser) to allow unlimited image sharing across the network, rather than incurring the additional overhead of a proprietary network protocol. Finally, it would be useful for the software to offer the user information about image file resolution verses the displayed resolution.

*The ICON System.* The ICON teleradiology software runs on a Macintosh and consists of several clients: the ICON ImageComm window, ICON File Conversion window, the ICON Image Quality Assurance window and the ICON TeleMax Viewing tool.<sup>5</sup> ICON may accept images from remote sites via a modem or network link. Remote clients can initiate image transfers, and the ICON will automatically log the files, and transfer them to long-term storage on a Macintosh file server. Obviously, image transfer performance is highly dependent on modem speed. The system as tested consisted of a dual monitor Macintosh Quadra 700 with a 14.4 KB Hayes compatible modem. After the software is loaded (including At Ease, a previously discussed security program), there is about 55 MB of memory free for image acquisition and display.

All incoming images are initially acquired by a modem equipped ICON workstation. Afterward, images may be viewed locally or passed to other networked ICON workstations. Because all drives are networked via the Chooser, the image viewing

tool can access studies at any workstation. However, there is no central database or archive.

By default the ICON workstation loads the communication window on the left of its dual portrait monitors. This window consists mainly of a large viewing area with a column on the right containing five buttons. One is a pull-down menu for selecting the input source. This can be set to various modem types. Below this area are Send, Receive, Quit, and Cancel buttons. Choosing Send or Receive brings up a list of defined modem accessible locations that are available for sharing images with. Below these buttons to the bottom of the screen is an area that reports on the status of incoming studies; the number of images contained within, the transmission start time, transmission end time, and any errors. (For example, one MR study was logged as being transmitted in 26 minutes. The study consisted of 44 images, compressed at 5:1, with 256 gray shades.)

The ICON image viewing tool supports a variable dimension tiled display as well as a stacked window display with Next and Previous buttons available to step through the images. At the bottom of the screen the total number of images in the study, the range of images currently displayed, several image manipulation tools, and image brightness and contrast adjustments are displayed.

The following concerns arise with the ICON software. A single threaded communication tool with a single modem may fail if several remote sites simultaneously compete for attention of the central dial in server. This concern would presumably be met with multiple dial-in ICON servers. The user interface would be simplified if there were one umbrella application with menu choices to launch the viewing tool, Quality Assurance tool, and communication tool. Given the limited multitasking of the Macintosh, putting the communication tool in the background (by bringing the viewing application to the foreground) may cause the Communication tool to fail. This could happen if a user was examining an "arrived" study while another study was in transmission.

*StatView/DX.* Emed's StatView/DX teleradiology offering consists of a dual portrait monitor equipped Intel based PC running MS-Windows 3.11.<sup>6</sup> The application uses Windows' start-up facility to launch two Structured Query Language (SQL) servers and one Digital Image Communication in Medicine (DICOM) server with an associ-

ated SQL-DICOM bridge. Incoming images are sent automatically to the DICOM area on the disk drive while the associated patient textual data is logged into one of the SQL servers. The other SQL server may be used to log studies that are on other EMED (or other DICOM based) image archives. Because image sources are configured to automatically push studies to the EMED SQL-DICOM server, StatView/DX does not permit ad hoc queries of remote computers, only study requests from hosts for which a SQL entry exists in its database. However, the centralized nature of the design allows remote users to use a DICOM compatible image client (such as StatView/DX) to dial in from a remote site to view patient studies at the central server.

StatView's application window consists of a large image viewing area, which may be configured into a custom dimensioned tiled display, or alternatively a stacked image display with each image in its own sizable window. The Open menu produces a listing of the patient studies on the local machine, while a search option allows a query by patient name, ID number, or other demographics on any DICOM image archive that the system is configured for. In addition to standard display tools (orientation, zoom, etc), StatView/DX supports a "hot light" feature and a user customized tool bar that allows placement of often used pull-down menu functions on a single click button.

Because most of the administration tools (defining allowed image sources, other databases to query, etc) are controlled by applications outside of StatView/DX, the StatView/DX interface is very clean, supporting only what is need for radiology image review. This may make the EMED system very comfortable to end users. Likewise the ability to configure the system as a central query point for image studies, whether originating from telephone links at remote clinics or on the departmental PACS, is a powerful feature that should appeal to mobile radiologists with modem based workstations at numerous locations. The use of SQL for building the local image database (and communicating with remote archives) may become problematic if one must interface to HL7 or DICOM image databases. However, it seems likely that software gateways can be provided to cope with this eventuality. Table 1 summarizes the features of systems evaluated in this section.

#### *CT and MRI Standalone Workstation Review*

Within this section, the following offerings are evaluated: GE's Advantage Windows (GE Medical Systems, Milwaukee WI), and CEMAX, VIP Release 1.41 (CEMAX, Fremont CA). The systems described in this section are essentially operated as standalone systems at our site without integral PACS support. They acquire their images via network links directly to scanners or external image

**Table 1. Teleradiology Workstation Summary**

Test	ICON*	EMED†	Kodak PDS‡
Archive size	NA	NA	NA
Monitor size, res.	12 × 15 in, 1600 × 1200	12 × 15 in, 1600 × 1200	14 × 20 in, 2500 × 2000
Multimonitor	Max 2	Max 2	Max 2
Send to archive (MB/sec)	NA	NA	0.13 (LAN peer transfer, 1/61.5 s)
Patient list fetch (records/sec)	2 (1/5 local) .25 (9/36 remote dial)	1.5 (2/1.3 local) NA (remote)	9.4 (18/1.9 local) 4.3 (35/10.9 remote LAN peer)
Image fetch from local or remote store (MB/sec)	0.09 (local, 12/8.7 s) 0.002 (remote dial, 44/26 min)	0.6 (local, 12/10.4 s) NA (remote LAN)	1.6 (local, 1/4.9 s) 0.13 (remote LAN, 1/61.5 s)
Image fetch from archive (MB/sec)	NA	NA	NA
Screen paint (MB/sec)	1.1 (12/0.71 s)	6.2 (12/1 s)	0.96 (1/8.3 s)
Time to print images (sec)	NI	NI	450 (12 on 1 for all)
Video controls	Brightness, contrast, invert LUT	Window, level	Brightness, contrast, invert LUT
Orientation tools	Rotate, flip, pan	Flip, rotate, pan	Rotate, flip, pan
Magnify, cine	Mag	Mag, rulers, hot light, cine	Mag
ROI	NA	NA	Rect, circ (mean, std dev, pixel value)
DICOM I/O	No	Yes	No
Remote maintenance	No	?	No

\*256 × 256 × 1 MR images, with 5:1 compression.

†Measurements based on CT images (512 × 512 × 2).

‡CR Lateral chest (assumed 8 MB) at normal priority.

archives and rely on the institutional Ethernet network. Hence, archival figures of merit will not be reported here.

*GE Advantage Windows.* The *Advantage Windows* workstation is a SUN SPARC 20, attached to a single large monitor, running the UNIX operating system and X/Motif.<sup>7</sup> *Advantage Windows* was developed by GE as a unified image review workstation to work with GE's CT and MRI imaging systems. At our institution, studies may be manually pulled or automatically pushed from the independent console (IC) attached to the CT or MR scanner, or manually pushed from an image archive.

The primary application window (referred to as the Browser) has a main menu which includes: Selection, Remove, Sort, Network, Queue, Services, and Messages. The remainder of the window is occupied by three scrolled lists: the examination window, series window, and image window. The examination window is in the upper left and lists patients by name, but also includes date, examination, and the location of the examination. The series window to the upper right displays all image studies on record for the patient selected in the examination window. Finally, the bottom image window explicitly lists every image in the series selected in the series window. Image operations are initiated by a column of buttons down the right side of the display: 3D, Add/Subtract, Film Composer, mini Viewer, Reformat, Viewer, Shutdown. A smaller window along the bottom of the monitor acts as a container for iconified tools. By default it contains icons for the local Browser, a remote session Browser, and the Film Composer.

Choosing Selection allows one to show all examinations, series, images, or only subsets of each category based on relevant parameters. Similarly Remove allows deleting individual images, series, or entire examinations. Sort allows sorting the examination window by date, name, ID number, or examination location. The Network menu allows connecting to remote study sources (and if activated produces another Browser window, which has a subset of the main Browser's functions), and permits pushing or pulling either single images or examinations to those hosts. Queue displays what, if any, network operations are pending. The Services menu facilitates adding or deleting image tools (3D, Film Composer, Viewer and the other packages that are listed in the right hand button

column). Finally, the Messages menu shows a log of network activity and film printing jobs.

To actually view patient images, the user must select the patient, examination series, and the range of images of interest. That done, either the mini-Viewer, Viewer, Add/Sub, or 3D constructor can be brought to bear to view the image set. The mini Viewer presents an image area to the right of the screen, while a column to the left has several display options. Layout buttons control whether the display is a single, 2, or  $2 \times 2$  tiled layout. It is not possible to display images in their own movable and sizable windows. Below this are preset window and level buttons for various anatomical structures. Text and drawing tools are available for annotation and magnification and panning tools are present. The cine' tool consists of two slide bars that define the range of images to include in the cine' loop and the speed (frames per second) at which to loop through them. Playback may also be done manually. Once satisfied with the image presentation, the current screen may be saved to a file, or the Film Composer tool activated to print the current display in any of the tiled formats available on the laser camera.

The main Viewer is basically a recapitulation of the mini Viewer, except the entire screen is used for image display and a column to the right of the monitor displays postage-stamp-sized images of the examination series to aid the user in reaching images of interest more quickly. Both the main image area and the postage stamp area, have independent Prior and Next buttons, which move through the image series in intervals that equal the number displayed in the respective area. The main Viewer is also capable of a Compare mode, whereby the current viewing area, is halved vertically to make room for a second Viewer, which may contain analogous images from a prior exam. The Add/Sub tool performs the expected operations on images, and outputs the result to the Viewer.

Selecting the 3D tool triggers the construction of a surface rendered image based on the images selected in the image window. A dialog box is presented that requests what kind of reconstruction filters to use (CT Bone, CT Angio, etc). A new display (the VoxTool) then appears, which has the 3D image, encompassed by a "box" that can be grabbed and manipulated in any way, and a column of control buttons to its left. The menu includes File (with save functions), Modify Model (thresholding, paintbrush and other tools), Display Modes (film-

ing setup, light intensity and direction), and Graphics (distance angles and areas). Below this are toggle buttons for anatomy optimized window and level presets. Colored buttons are present to assign a given color to an anatomically significant Hounsfield Unit range. The remaining buttons control panning, rotation, and flips in predetermined increments, rather than the continuous control afforded by the box surrounding the image.

The multitude of viewing modes and image quantification tools can be time consuming to master. Also, when searching for patient studies, one must manually poll the remote ICs or image archives, although this could be ameliorated with a unified external PACS database or casting a single workstation in a server role. Finally, *Advantage Windows* needs more robust error handling. After attempting to print a film for over 30 minutes, no film was produced and no error was reported. It turns out that the workstation was not connected to a laser camera, but this error was not reported. Also, a printing status display would be a welcome addition.

**CEMAX.** The CEMAX workstation consists of a Sun SPARC 10 with a single large monitor running UNIX.<sup>8</sup> The application software is based on a very early implementation of Sun's OpenLook and as such can be difficult to master. Commonly expected features (such as movable and sizable windows with scrollbars) are not available. The main application window takes up the entire screen and presents a row of buttons across the top, a column of buttons down the left, and the remainder of the screen is devoted to image display with the exception of a few special purpose buttons along a bottom row.

The top row buttons consists of Retrieve, View, Create, User Protocols, System, and Status. Selecting Retrieve produces a dialog box with options for fetching studies from tape units, network links to scanners or on-line archives, and other archive media. View, in conjunction with a button from the bottom row, controls the row and column dimensions of the main image area's tile pattern (sizable images in their own window are not available). The Create function allows producing new volume, surface, or orthogonal views from existing image data (however, a 3D construction can take 10 to 15 minutes). Selecting User Protocols produces a list of user customized procedures for 3D reconstruction, organ segmentation, tissue color classification, and more. The System button allows start-up

and allowed network hosts information to be edited, and also provides for shutting down the application. Finally, the Status function is used to report the progress of background jobs such as 3D reconstruction and monitor disk and network conditions.

The column of buttons consists of Region of Interest (ROI) tool, Tissue Color map tool, Annotation, Metrics, Display, Scout, Film, and Save. The ROI tool supports circular, rectangular, and free-form ROIs (in different colors) with area, mean, standard deviation, minimum and maximum pixel value statistics. The Tissue Color Map can be used to assign certain Hounsfield Unit ranges to certain colors, thus delineating bone, muscle, fat, and other user-defined structures in separate colors. Annotation functions include font style and size selection, as well as drawing lines and arrows to highlight structures for teaching or other purposes. Metrics provide 2D and 3D distance measurements, angle and pixel values. Display allows pan, zoom, and reconstruction previews. The Scout tool will generate scout images from either MR or CT axial data sets. The Film button formats the row-column dimensions for film printing, and the Save tool allows either single images, a screen, or entire study to be saved to a user-specified file.

Along the bottom row, the Patient button produces a dialog box listing the patient studies available on the source that the CEMAX is currently addressing. Because there are no scroll bars, movement through the list is accomplished via Forward and Back buttons. Another button allows the user to select from all available study sources. The remaining bottom row buttons control cine' modes, screen tile dimensions, and paging through the study image set, either singly or screen by screen.

In general, the features that one expects on a CT/MR workstation are all present and produce beautiful images, but the time and difficulty involved can inhibit productivity. Table 2 summarizes the features of systems evaluated in this section.

#### *Ultrasound miniPACS Workstation Review*

Within this section, the following offerings are evaluated: UltraPACS V2.43.03 (ALI, Richmond, BC, Canada), Aegis (Acuson Corporation, Mountain View, CA), and Access (ATL, Bothell, WA).

Several ultrasound (US) miniPACS (a complete PACS for a given practice subspecialty, which may

Table 2. CT/MR Workstation Summary

Test	CEMAX*	Advantage Win*
Archive size	NA	NA
Monitor size, res.	19 in, 1280 × 1024	19 in, 1280 × 1024
Multiple monitor	NA	NA
Send to archive (MB/sec)	NA	NA
Patient list fetch (records/sec)	6.25 (5/.8 local)	36 (18/.5 local)
	1.3 (31/23.7 remote)	10 (34/3.4 remote)
Image fetch from local or remote store (MB/sec)	0.42 (12/15 s, remote)	0.46 (9/10.25 s, remote)
Image fetch from archive (MB/sec)	NA	NA
Screen paint (MB/sec)	1.4 (12/4.5 s)	0.96 (12/6.5 s)
Time to print images (sec)	236	254
Video controls	Window, level	Window, level
Orientation tools	Pan	Rotate, flip, pan
Magnify, cine	Mag, cine	Mag, cine
ROI	Rect, circ (area, mean, std dev, pixel value)	Rect, circ (area, mean, std dev, pixel value)
DICOM I/O	?	Yes
Remote maintenance	?	Yes

\*Images assumed to be 512 × 512 × 2 CT.

or may not link with a departmental PACS) are present at our site. Collectively they show a range of approaches to the US PACS mission, from systems that are tightly coupled to specific US scanners, to a more open (albeit slightly less efficient) approach.

**ALI UltraPACS.** The system consists of DEC (Digital Equipment Corporation) Intel-based PCs running NeXTStep, a UNIX variant with a proprietary X-windows implementation, with a single monitor.<sup>9</sup> Three machine types (acquisition workstation, technologist's review station, and the diagnostic review station) are used. The acquisition workstation is positioned near the US scanner, whereas the technologist's station is located remotely and is intended for basic image review and study recall. Both the acquisition and technologist's workstation use low-resolution (VGA) monitors, whereas the diagnostic station uses a larger and higher resolution monitor.

To scan a patient, the user logs into the acquisition station with their user name and password. They then create a new patient folder, or recall the folder of an existing patient. To enroll a new patient, the user enters patient demographics (which takes about 2 minutes) and commences to scan. To frame grab scanner images, the acquisition station is equipped with two foot pedals; one digitizes in color, the other in black and white for final printing on a laser camera. On study completion, the user closes the patient folder and the study is automatically filmed. At closure the study is also forwarded to the review/archive station where the data resides

for a time on a local hard drive until being archived to a Hewlett-Packard 10-platter optical jukebox.

The review station is equipped with a 20-MB floptical drive for image input from portable US scanners via the Camtronics floptical interface. However, the Camtronics system does not put patient demographic data on the floptical, only images. This means that only one patient should be put on a disk, and that patient information must be retyped into the ALI when the images are uploaded.

Frame grabbing on the ALI can be slow. For example, if the scanner display is frozen and one taps the foot pedal to digitize the image, the ALI beeps, leading one to think that the image is captured, so the user unfreezes and continues scanning. However, the beep does not really mean that the image is fully captured, and by unfreezing the scanner, the ALI may have part of the previous image mixed with part of whatever is currently on the screen. This can result in unintended blended images that (because of the auto filming mentioned above) nevertheless get printed onto the patient film.

Because of its multiuser, multitasking operating system, the ALI system permits remote bug fixes via the Internet (ALI customer support asks which station is at fault and can log in remotely to effect repair). This is an important point and not to be casually dismissed. Other advantages are the capability for Camtronics input, and the portability that comes from not coupling the workstations too tightly to a specific ultrasound scanner. Also, the



ALI system uses the same user interface throughout its workstations.

*Aegis.* The Aegis system takes a completely different approach to its US miniPACS in the sense that there is no distinct acquisition workstation.<sup>10</sup> Rather, the acquisition computer is "built-in" to the scanner. This keyboardless and monitorless CPU (called the QV-100) performs the frame grabbing. Studies are then sent for temporary storage to a SUN workstation with 4 GB of disk (the SUN also acts as the database server). Final disposition of the images occurs via archiving to a single platter magneto-optic drive attached to a Macintosh Quadra. Image review and patient file queries are handled by a large-screen Macintosh. At the time of this review, Aegis had no optical jukebox capability.

The image viewer, Acuson Display Manager, is a simple application with a menu consisting of File and Edit (with the expected Macintosh functions beneath each), a large tiled image area, and a column of buttons down the left. The column buttons include Exam, Worksheet and Report. Exam brings up a listing of the currently stored patients with the examination type, date, ID number and additional demographics. Selecting Worksheet produces a more detailed view of the examination specifics for a given case, and the radiological report if one exists. The Report tool brings up a text tool for typing the radiological report. An Options button allows altering the dimensions of the tiled display by changing the image size to be Small, Normal (the  $3 \times 3$  default), and Large. The remaining buttons control distance measurements, panning, magnification, and window/level.

Because the QV-100 is intimately tied to the Acuson scanner, it is not necessary for the technician to reenter patient demographics. By logging the new study on the Acuson, the proper action (creating a new patient record or recalling an existing one) is automatically taken. Furthermore, the integration of the QV-100 into the Acuson chassis means that only one cart needs transport for portable examinations.

*Access/ATL.* The physician/technician review station consists of an Intel-based PC running OS/2 Warp and a single 17-in monitor, although a company representative indicated that a 20-in will be standard shortly.<sup>11</sup> It contains a large hard drive, CD-ROM, and 3.5 inch floptical drive (for Camtronics and ATL input). The review software consists of a single large application window with a simple

menu and tool bar below it. Patient studies are displayed in a folder paradigm, with the "folder tab" displaying the study anatomy and patient ID. Within the folder, images are displayed in a tiled manner in a variety of formats (1/1, 2/1, 4/1, . . . 40/1). Movement through the folder is facilitated via forward and previous arrows in the lower right of the folder. Menu buttons include Lists, Display (changes the tiling dimensions), Print, Cine, Next, Previous, and speed buttons to control the cine rate.

The Access file server is an Intel based computer running OS2. It includes 3.5- and 5.25-in floppy drives, a 3.5-in floptical, an external magneto-optic drive, and an uninterruptible power supply. A TCP/IP network based Network File Server (NFS) handles auto-spooling the studies from the connected data acquisition units. The user interface includes menu choices for mounting and unmounting magneto-optic disks, and for setting the archive frequency and time. ATL representatives report the unit can handle ten acquisition and five review stations.

The data acquisition units are also Intel-based PCs, but have no keyboard or monitor. Rather, a hand-held LCD display unit allows such operations as frame grabbing, printing, selecting a spooling destination and modifying the on-board configuration files. This last is accomplished by modifying the files on an external PC and then using a 3.5 floppy to transfer the files to the acquisition unit. The process of frame grabbing consists of pressing a button on the hand-held unit, the button remains inoperative for about 1 to 2 seconds, and then an additional image can be grabbed. The button "dead time" is independent of how many images are being digitized. Table 3 summarizes the features of systems evaluated in this section.

### *Integrated General Practice Workstation Review*

Within this section, the following offerings are evaluated: Vantage PACS LiteBox V5.3 (Lockheed Martin Medical Imaging Systems, Hoffman Estates, IL), and MagicView VA02D (Siemens Medical Engineering, Erlangen, Germany). The systems described in this section are complete PACS solutions, incorporating image archive, database and image review features, as well as gateways to imaging devices. To a large extent, these systems can be considered to be turnkey digital radiology solutions.

*Vantage PACS.* The Vantage PACS system is capable of integrating the vast majority of functions

Table 3. US Workstation Summary

Test	ALI*	Access/ATL*	Aegist
Archive size	Optical juke box (650 MB/disk)	Server (4 GB) Optical juke box (650 MB/disk)	650 MB
Monitor size, res.	17 in, 1024 × 768	17 in, 1280 × 1024	19 in, 1024 × 768
Dual screen capability	No	No	No
Send to archive (MB/sec)	?	?	?
Patient list fetch (records/sec)	20.8 (25/1.2 local)	7.7 (21/2.7 remote)	15 (30/2 remote)
Image fetch from local or remote store (MB/sec)	1.7 (9/1.6 s, local)	0.07 (9/39.1, remote)	.36 (9/9 s, remote)
Image fetch from archive (MB/sec)	0.06 (9/42.8 s)	0.02 (9/450 s)	?
Screen paint (MB/sec)	2.3 (9/3.9 s)	1.4 (9/2 s)	1.3 (9/2.5 s)
Time to print image (sec)	264	NI	240
Video controls	Window, level	Window, level	Window, level
Orientation tools	No	Rotate, flip, pan	Pan
Magnify, cine	Mag	Mag, cine	Mag
ROI	No	?	No
DICOM I/O	Yes	Yes	No
Remote maintenance	Yes	No	No
Frame grab time (sec)	3.9 (single)	15 (but can regrab every 2)	1-2 (single)
	4.1-6.9 (series)		1-2 (series)
Camtronics input	Yes	Yes	No

\*ALI, access tests assume frame grabbed file size (640 × 480 × 1).

†Aegist tests assume full 750 × 480 × 1 Acuson image size.

necessary for a full-featured digital radiology department including digital image acquisition, image interpretation, report generation, archiving and recall, hard copy output, film digitization, and remote teleradiology.<sup>12</sup> At our institution, the system consists of a CR Acquisition Workstation (CRAW), which is a Macintosh coupled to a Fuji CR unit (for technical reasons the Fuji unit requires a dedicated Macintosh). However, for devices that directly support the DICOM store function, several inputs can be accepted by a single Macintosh based Modality Interface Unit (MIU). The MIUs convert images into an internal format and pass the resulting files to a SUN workstation (which logs the study in the archive database). From there, the images are sent to a 256-GB Redundant Array of Independent Disks (RAID), which can support data transfer rates of 80 MB/sec. On study registration with the database, all studies are available to all image review stations. These consist of Macintosh workstations with one, two, or four monitors. After a study is verified as interpreted by a radiologist, the study is also archived to a Kodak multiplatter optical disk juke box. However, primary image interpretation is always performed from the RAID while the study is maintained there.

Vantage PACS has split LAN communication into two components, text and image. Text (patient information and commands between workstations) is carried on standard ethernet cabling. On receiv-

ing an image request, however, the RAID transmits the actual images to the requesting review station via optical fiber. Although extremely fast, this scheme requires a branching star topology which, although only demanding of cabling at the local network level, cannot be implemented in a cost efficient manner at the WAN level. Hence, image communication over large distances must be accomplished via wire with standard internet protocols.

Users interact with the system via the LiteBox application program. LiteBox performs the functions of database query, image review, and report generation. LiteBox is activated by launching its icon from the Macintosh desktop and logging in with a user name and password. A standard looking menu bar appears with a image tool bar below it. Double clicking on Open produces a list of various work folders (such as academic, daily exams, all exams, etc). After selecting a folder, a large dialog box appears that has its own specialized menu bar (an oddity in the Macintosh world), a scrolled list with all the exams in that folder, and two text windows, one above the other. The lower text window contains patient demographic information, the upper one contains the radiology report if one exists.

Double clicking on a study produces the text associated with it; images are recalled by selecting Image Display from the dialog box's own menu bar. Image layout is controlled by the Display menu

item on the main Macintosh menu. Images can be presented in a tiled manner (with grids varying from  $1 \times 1$  to  $9 \times 10$ ) or as a stack of same-size images each within their own Macintosh window. If images are displayed in stack mode, Next and Previous buttons appear at the bottom of the screen to facilitate viewing.

A nice feature of Vantage PACS is the availability of a dictation mode. The radiologist (or transcriptionist viewing the same study) can select a dictation form within the image viewer. The system provides sufficient word processing functionality to reproduce the appearance of most institution's paper forms. In this way, both hard copy and electronically archived reports are bound to the patient image, and further references to the database will recall the report with the study.

Adherence to GUI standards (ie, the Macintosh interface) is excellent, thus minimizing retraining for users who are already Macintosh adept. Image transfer speeds are superb, and the seamless binding of reports to the image study come very close to the ideal PACS-RIS. Ironically, the very features that are responsible for these strengths may prove cumbersome in the future. Image transfer speed is bought at the price of a proprietary fiber network. Long distance networking may need to adapt to slower TCP/IP based methods. Also, at the time of this report, studies are internally archived in the older American College of Radiology-National Electrical Manufacturers Association (ACR-NEMA) 2, but a native DICOM implementation should soon be available.

A more subtle but potentially serious problem lies in using a Macintosh as the acquisition workstation platform. If one sits at an MIU and attempts any window manipulation, the performance is extremely slow because the Macintosh's processing time is almost completely devoted to background processing. This problem can be circumvented by using one MIU for each image input source, but this is an extravagant use of computers. Furthermore, if imaging systems greatly increase their image input rate to the MIU, it seems likely that the MIU will eventually stall. This limitation may be removed when or if the archive supports direct DICOM inputs. Finally, there is no facility for constructing 3D images from 2D image data, a shortcoming in a general purpose diagnostic workstation that may limit the Vantage PACS utility to MR and CT practitioners.

*Siemens' Sienet and MagicView.* MagicView workstations are based on Sun SPARC UNIX computers, running the X-OpenLook window system.<sup>13</sup> The Sienet system accepts DICOM inputs from all modalities except color ultrasound (according to the Sienet DICOM conformance statement) via DICOM software gateways on the workstation associated with an imager. Several software gateways can be run on a single workstation to accept inputs from different imaging sources. Once in Sienet, images are passed in ACR-NEMA 2.0 format, but may be exported in DICOM format if required. During interpretation, and for a configurable time thereafter, image studies exist on a RAID, but ultimately are archived to an optical disk juke box with an integral database. RAID-archive clusters can be built around specific practices or locations, but internet worked so that any MagicView workstation can access studies anywhere within Sienet.

The user starts the MagicView application by logging onto the system with an account name and password. The MagicView application runs on paired monochrome monitors with a single mouse controlled cursor that roves between the two displays. The left monitor has a column running down the left side, which displays the software version, patient name and identification number, the referring physician, exam description, a Log button, which can be used to produce a text window describing running background processes, and finally two button grids near the lower left, which provide the majority of the user functions. The remaining 80% of display area to the right of the column is used for images. The right monitor is a mirror of the left, so that the patient images on each monitor are adjacent.

The upper  $3 \times 6$  grid of buttons has vendor defined functions attached to them. The first row contains Patient Select, Patient Next, and Work List. Row 2 has Folder Next, Folder Previous, and Folder Close. The third row has Image Next, Image Previous, and Undo All Edits. Row 4 contains the Cut, Copy, and Paste functions. Row 5 permits Select All, Deselect All, and Select Inclusive. The sixth and final row contains Multi Select, Single Select, and Display Mode. Many of these functions are redundant methods of performing actions that come more naturally with the mouse.

Most often, the user will start a session by pressing the Work List button. This brings up a

scrolled list of patient names and all their current image studies. Image studies are considered folders, hence, clicking on a patient name and specific exam highlights and selects that folder for display. Clicking and dragging over several studies selects all the ones that are highlighted. (The bulk of the Row 5 and 6 buttons (with Select in their name) are simply an alternative to the mouse for this same action.) Beneath the scroll list are a variety of buttons Open, Query, Send, Archive, Print, Merge, Delete, and Settings. Open fetches any selected exams, whereas Send and Query can be used to push studies to, or retrieve from, remote hosts. Archive pushes the current study to the archive. Print and Delete perform the indicated functions. Merge permits one or more exams to be merged under one heading and Settings allows the user to configure whether the Work List sorts patients and their exams alphabetically, chronologically or reverse chronologically.

The remaining first row buttons (Select Patient and Patient Next) simply provide shortcuts for the same functions via the Work List. The second row Folder operations provide the ability to step forward and back through the exams for a given patient, and allow closing the folder when the review is completed, thus freeing up image memory for other studies. The last button in the sixth row, Display Mode, produces a scrolled list of various scripts that define the behavior of the viewing area, including the window and level defaults and whether images are viewed singly or in a user dimensioned array. Scripts may be created, edited, or destroyed for optimal window, level, and image layout of T1 or T2-weighted MRI, soft tissue, or bone CT, monochrome ultrasound, and CR images.

The lower  $2 \times 7$  grid of buttons are known as soft keys and assume user-defined functions. At our site, buttons are defined to perform various multiples of  $90^\circ$  rotation, vertical and horizontal mirroring, image annotation, image transmission to other recognized hosts in Sienet, window and level control, Region of Interest (ROI) tools, Digital Luminance Radiography (DLR) processing, and a Logout button. The ROI tool produces a dialog box that permits rectangular and circular region pixel quantification (such as area, mean, and standard deviation). The DLR processing tool permits non-linear modification of an image's gray scale map to optimize its hard copy appearance on a laser camera.

Last, almost as a footnote below the last button

row, lie three icons: four arrows arranged in a compass pattern, a magnifying glass, and the Pixel Lens. Clicking on the arrows and then clicking and dragging on an image permits one to slide the image about the screen. The magnifying tool provides spot magnification around the cursor, whereas the Pixel Lens reports the brightness of the pixel directly under the current cursor location. A nice touch is the addition of some graphical information to the image area. These data include the patient name and identification number, the display script being used, and the scale of the image relative to its native size.

In its present form, the MagicView interface can be clumsy and unintuitive. Many of the buttons are redundant, and a pull down menu system would save space and be more natural to many users. However, the ability to program the soft keys can be an important boost to productivity and provides a natural growth path for modular addition of new features (such as 3D reconstruction and edge enhancement routines). Table 4 summarizes the features of systems evaluated in this section.

We complete the Results section with several plots that compare compatible features of the reviewed systems, particularly as they will affect the radiologist's productivity. These features are Patient List Fetch, Study Fetch from Fast Store, Study Fetch from Archive, and Image Painting performance. Figs 1-4 illustrate the performance of the reviewed systems in each of these areas. Workstations of the same class are grouped together.

In reviewing the plots, one should note the accompanying captions and associated tables that describe the conditions under which the measurements were made. Although all efforts were made to keep the conditions identical, in some cases (namely Fig 2) such rigor was not possible. Also, it is extremely difficult to say with certainty what the file size actually is when computing MB/sec in the transfer and painting tests. File sizes may vary from the acquisition device, to the archive, and between different hosts on the network. These changes occur for a variety of reasons: an image that is acquired with 10 to 12 bit gray scale may have this figure padded to two bytes for network portability, an identical file may take on different sizes on different hard drives because of sector size differences on the hard drives, and compression may also be used. In light of this uncertainty, all MB/sec tests listed in the Tables contain the actual number of

Table 4. General Practice Workstation Summary

Test	Vantage PACS*	Magic View†
Archive size	Optical juke box	Optical juke box
Monitor size, res.	12 × 14 in, 2048 × 1760	21 in, 2300 × 1760
Multiple monitor	Max 4	Max 2
Send to archive (MB/sec)	?	NI
Patient list fetch (records/sec)	9.5 (18/1.9 remote)	10 (8/.8 local) 6 (3/.5 remote)
Image fetch from local or remote store (MB/sec)	4.1 (2/3.9 s, remote)	4 (4 extrem CR/7.9)
Image fetch from archive (MB/sec)	0.2 (5/194 s)	NI
Screen paint (MB/sec)	5.7 (1/1.4 s)	13 (2 CR LSp/1.2)
Time to print images (sec)	NI	NI
Video controls	Window, level	Window, level
Orientation tools	Rotate, flip, pan	Rotate, flip, pan
Magnify, cine	Magnify, cine	Magnify, cine
ROI	Rect, circular (area, mean, std dev)	Rect, circular (area, mean, std dev, pixel value)
DICOM I/O	Yes	Yes
Remote maintenance	For database, not workstations	Yes

\*Images were AP CR chests, assumed to be 8 MB.  
†Both extremity and Lspine images were assumed to be 8 MB.

records passed per second in parentheses, and the assumed file size is listed in the Table caption.

DISCUSSION

In this review we have seen the design philosophies of several systems designed for teleradiology, CT-MR, ultrasound, and general purpose radiology. Although general purpose systems such as LiteBox

and MagicView attempt to satisfy all users, it is probably safe to say that some large practice sites will desire workstations that are optimized for certain functions, and a single platform that would meet all criteria would likely have a prohibitively complex user interface. The question then becomes, how does one assemble a logically unified PACS from physically distinct miniPACS? The answer can be seen in the approach EMED has taken with its StatView teleradiology suite. A single large PACS database may be constructed with links to centrally archived studies, or to studies stored on distributed miniPACS archives. In this paradigm, an arbitrary diagnostic workstation could by default search its local miniPACS for a study, but extend the search to the central database if the search failed or if correlative images from other

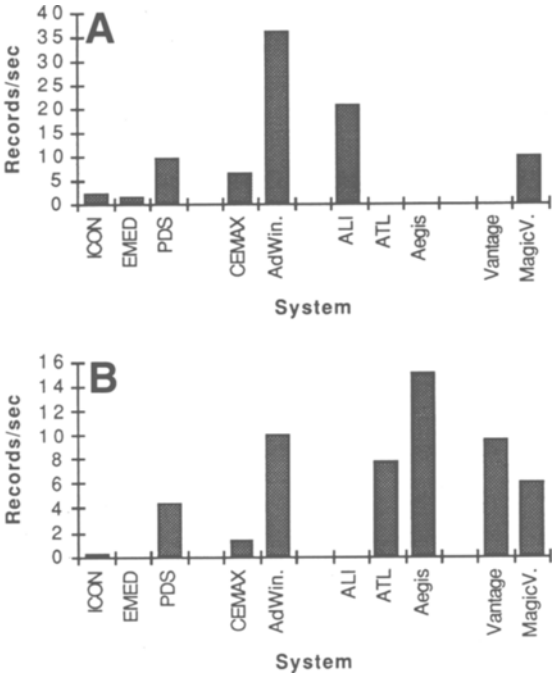


Fig 1. The performance (in records/sec) in retrieving patient listings from local (A) and fast remote (B) storage.

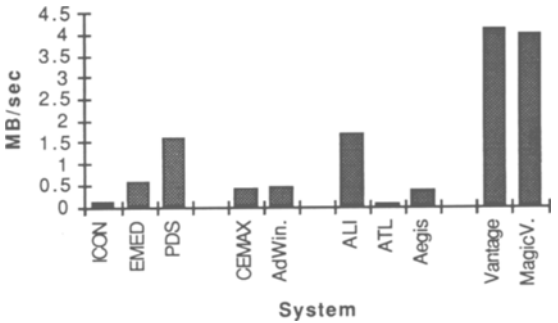


Fig 2. Performance (in MB/sec) of image study retrieval from fast storage. The teleradiology (ICON, EMED, PDS) numbers reflect local retrieval, remote retrieves are listed in Table 1. All other systems reflect study retrievals from remote servers.

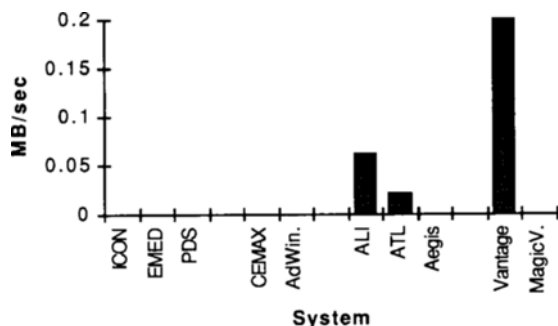


Fig 3. Archive retrieval performance.

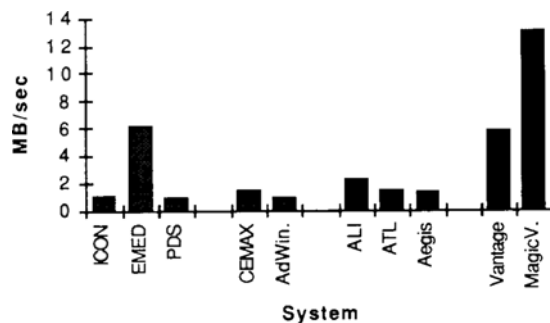


Fig 4. Image painting performance in nominal image MB/sec painted to the monitor.

modalities were needed. Similarly, electronic medical records workstations (making up part of the Hospital Information System) could search one location to access studies on all miniPACS.

Given the previous discussion, it becomes obvious that future radiology departments may well evolve along the lines of specialized radiology workstations and miniPACS, each optimized to a given task. In that environment, interconnectivity will be the watchword, and performance comparisons among diagnostic workstations may only make sense for the several common parameters defined in the Results section. Of equal or even greater importance will be the ability of workstations, regardless of their intended arena of operation, to be capable of seamlessly viewing images stored among multiple physical archives in a way that is utterly transparent to the user. Furthermore, such workstations should be capable of viewing DICOM images from modalities outside their particular specialty (albeit perhaps without the tools that a workstation tailored for that modality would have) when multiple modality consultations are required to make the diagnosis.

## CONCLUSIONS

It is notoriously difficult to perform reviews of computer software and hardware because the target is constantly in motion, and not always in the same direction. Any reader of the monthly computer trade magazines will be familiar with the opening words "as this goes to press. . . ." The pace of innovation, mergers and buyouts in the industry assures that many "facts" will be obsolete by the time the work is published. Nevertheless, it is hoped that the snapshot of systems reviewed in this article will inform the reader on what is near state-of-the-art (in both performance and features) as of the spring of 1996. Furthermore, the tests and methodology used will have general applicability in evaluating all systems, present and future. Armed with the concepts and baseline data contained in this article, the reader should be well equipped to perform technical comparisons of digital imaging systems pursuant to a fully informed equipment purchasing decision.

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