Choosing a Radiology Workstation: Technical and Clinical Considerations[1]

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Choosing a workstation for daily use in the interpretation of digital radiologic images can be a daunting task. There are numerous products available on the market, but differentiating among them and deciding on what is best for a particular environment can be confusing and frustrating. There is no "one-size-fits-all" workstation, so users must consider a variety of factors when choosing a workstation. This review summarizes the critical elements in a radiology workstation and the characteristics one should be aware of and look for in the selection of a workstation. Issues pertaining to both hardware and software aspects of medical workstations, including interface design, are reviewed, particularly as they may affect the interpretation process.

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In the past decade, the practice of radiology has changed rapidly from the interpretation of filmed images on light boxes (hard copy) to the interpretation of digital images on computer monitors (soft copy) (1,2). Cathode-ray tubes (CRTs) and, recently, liquid crystal displays (LCDs) have become the display media of choice for many radiologic examinations. The transition from hard copy to soft copy was not instantaneous and was based on substantial prior work in the field of medical monitor displays, workstation-user interfaces, and observer perception. Softcopy interpretation is still challenged by technical incompatibilities between medical image acquisition and display systems, nonintegrated and incompatible systems, and cumbersome and user-unfriendly interfaces.

In this review, we will summarize the critical elements of a radiology workstation and the characteristics one should be aware of and should look for in the selection of one. Issues pertaining to both hardware and software aspects of medical workstations, including interface design, will be reviewed, particularly as they may influence the interpretation process.

Understanding Your Workstation Application

It is important to understand how a workstation is going to be used and what type(s) of images it will need to display before purchasing one. This review will deal with primary-read workstations, not secondary-review or referral workstations. In general, the criteria for the latter two are less stringent than are those for primary-read workstations.

One of the first considerations is whether the workstation is going to be multimodality or dedicated to a single modality. A multimodality workstation must be capable of displaying the highest resolution images as close to full resolution as possible. There is a growing body of literature supporting the fact that a large amount of diagnostic information is extracted from radiographic images within the first few seconds of viewing; so, the more useful information that is made available to the viewer during the initial image presentation, the more likely it is that a correct interpretation will be rendered (3–7). For example, if full-field digital mammograms and breast magnetic resonance (MR) images are going to be reviewed on the same workstation, the display device must be capable of displaying the higher resolution full-field digital mammograms (a minimum of 3 megapixels, depending on the mammographic acquisition system) at or near full resolution. The lower resolution MR images will obviously display at full resolution on the high-resolution display. If the single modality option is going to be used, the full-field digital mammograms still need the high-resolution display, but the MR images can be viewed on a display with lower resolution (eg, 1 megapixel). As will be discussed in more detail subsequently, the application and type(s) of cases will also help guide the choice of software for image manipulation and analysis, the options for the hanging protocol, and the amount of storage required for archiving.

Essentials

- Before purchasing a workstation, it is important to assess your reading needs and applications.
- The display links the image to the radiologist and if chosen inappropriately, can lead to errors and fatigue.
- Workstations do not exist in a vacuum, so it is important to consider the entire reading environment and how it affects interpretation accuracy and efficiency.

Design of a Radiology Workstation

It is useful to start with a brief understanding of the design of a medical workstation from the developer's point of view, by considering both technical and clinical aspects. Technical issues include the hardware, the software, the networking capabilities, and the physical environment in which the workstation will operate. Clinical issues include observer perception, human factors and biases, and workflow (8–10). In principle, the radiology workstation is designed to replace the standard display medium—that is, the light box—but the aim is also to go beyond the standard of practice and to provide new tools that may improve the link between the imaging system and the observer for the purpose of providing better health care. As a result, we may define the minimum requirements for a workstation as meeting the standards for screen-film image display and expect to exceed them.

In most applications, the design process is interactive and is based on close cooperation between engineer(s) and typical designated user(s) of the system (11,12). The process begins with careful observation and modeling of radiologists' standard reading practices and work patterns for the modality of interest and the specific application. Each function (eg, selection of a patient name from a work list) is timed and averaged across several readers. The number of images and their sources to be displayed simultaneously is identified. Image quality issues and known problems in the standard of practice are compiled. The working environment is outlined, and ergonomic issues are identified. Questionnaires may be used to obtain feedback in either the design or the selection of a radiology workstation. A survey, such as the one shown in Figure 1, can be used to understand the users' workstation requirements before vendors are consulted or conferences are attended where multiple vendors will be displaying their workstations.

The initial workstation design and

Published online before print
10.1148/radiol.2423051403

Radiology 2007; 242:671–682

Abbreviations:
CRT = cathode-ray tube
DICOM = Digital Imaging and Communications in Medicine
LCD = liquid crystal display
PACS = picture archiving and communication system
QA = quality assurance

Authors stated no financial relationship to disclose.

implementation is usually tested in the laboratory by means of qualitative evaluation by the user and expert; in some cases, quantitative assessment by means of observer studies is also used. The latter are not common in this field, because they are expensive and time consuming. Furthermore, technology changes rapidly, and upgraded newer version of the systems are available long before an observer study is completed, so results risk being outdated.

It is useful when talking with vendors about their workstations to request any research or white papers on their design evaluation (especially from independent sources). It can also be helpful to talk with people who are using a given product similarly to the way that you intend to use it, to get a realistic idea of the benefits and challenges they have found. If possible, visit their practice and see how it is used in a routine clinical environment. Most important, however, is to have as many of the end users as possible actually sit down and interact with the system being considered. If possible, bring along some typical images from your practice and have the vendor display them on the system configuration that you are considering. Before purchasing a system, find out if the vendor is willing to work with you on potentially modifying the system once it is installed. For example, you may find that a preferred hanging protocol is not an automatic choice with the workstation but that a few software modifications can make it easily available.

Once a system has been selected, a more thorough evaluation of its features will be required shortly after it has been installed and sufficiently used. A relatively early qualitative evaluation of the system based on hands-on testing by several observers is highly desirable. The evaluation needs to include, but is not limited to, the items listed in Figure 2. Again, if the system has unanticipated shortcomings, it is important to work with the vendor as soon as possible to rectify the situation.

The task is not complete merely because a workstation has been developed and a user interface has been designed that meets the technical and clinical specifications related to the user. The set-up and the environment play major roles in the final outcome and need to be included in the design and evaluation. In a multicenter survey of radiologists working mostly in a "filmless" (digital) environment (13), several ergonomic issues were determined as top factors in promoting productivity. These included room lighting, number of monitors per workstation, and monitor brightness. These factors are considered in more detail below.

Selecting an "Appropriate" Radiology Workstation

How does one select an "appropriate" radiology workstation, and how is *appropriate* defined? Before we attempt to define the appropriate workstation, note that our comments are based on two assumptions: *(a)* We are concerned with workstations for primary diagnosis as opposed to those for second review or referral, which may require different specifications since they pose fewer demands on the hardware and software. *(b)* Also, we are looking into systems that will improve current practice and, therefore, offer features above and beyond those of the standard of practice.

Let us go back to the definition. An appropriate workstation should primarily offer high diagnostic power with the most ergonomically efficient human-machine interaction. When compared with the standard of practice, the worksta-

Figure 1

Pre-selection Survey of all System Users

1. How many previous studies of the same patient do you usually need to interpret the current medical examination? How many do you need displayed simultaneously?
2. If you are to replace the light box with monitors, how many monitors do you think would be necessary to display the desired images?
3. Consider a display setup with three monitors (one standard and two high resolution monitors). What is your preferred hanging protocol for a patient? (Possibly ask for a drawing.)
4. What is an acceptable speed (time) for you for the loading, display, and manipulation of the images of one patient?
5. Rank the following workstation/user interface issues in terms of what you think may be the most important (1) to less important (11) for your interpretation.
    - Default image quality
    - Selective automated gray scale adjustments or image enhancement
    - Selective manual gray scale adjustments or image enhancement
    - CAD for ROIs or full image
    - Zoom and pan
    - Annotations
    - Measurements
    - Multimodality image fusion
    - 3D representation
    - Ability to integrate demographics and other lab information with imaging
    - Reporting on same system
6. Do you find a need for generating film or other hardcopies and for what purpose?

Figure 1: Example of preselection survey that can be used when choosing a workstation. *CAD* = computer-aided detection, *ROI* = region of interest, *3D* = three-dimensional.

tion should offer higher efficiency, improved workflow, and integration of previously disparate sources of information and medical imaging modalities.

From the diagnostic point of view, the minimum requirement is that the same (if not better) sensitivity and specificity be achieved by using a computer workstation for interpretation instead of the conventional light box. Clinical and laboratory study reports should be available (either from the vendor or in the general literature) to help assess the diagnostic power of a system. One could identify specific workstation and user interface elements that lead to successful clinical studies and support the diagnostic-potential argument. From the ergonomic point of view, the minimum requirement is that the workstation improve efficiency while reducing stress and strain for the observer and improving workflow. Here, also, one could identify several hardware and software elements that constitute the ergonomics, including number of monitors, type of user-machine interaction, and hanging protocol.

Table 1 lists the major criteria that one should consider and carefully review when selecting a radiology workstation (14–22). The various criteria are discussed in more detail later. Several of these criteria have been addressed quantitatively in observer studies, but many still rely on qualitative assessments.

The criteria can be reviewed in the context of two radiology models: Model 1 involves a single system to integrate all modalities through a dynamic and graphical interface(s) that is guided by PACS; model 2 involves independent systems dedicated to specific imaging modalities that may not necessarily communicate with each other or with a PACS. Today, the drive in major institutions and in many smaller clinics is toward model 1 because, although no formal study has been conducted, it appears to be the most cost and work efficient. Thus, we will discuss the criteria given the assumption that one wants to use model 1. The differences between models are not major. In model 2, the workstation becomes modality specific; thus, it may not be necessary to integrate and network in a filmless radiology environment.

Displays

The display is linked to the user interface (discussed next), but we review these components separately because there are several important issues associated with the display device itself. Guidelines exist with respect to minimum recommended standards for the display of digital images, and these should be consulted and followed (23,24). There are also guidelines for the assessment of display performance that should be utilized for calibration and quality assurance (QA) procedures (25). In terms of calibration and the performance of periodic QA, there are a number of display devices that now include the calibration sensor internal to the device rather than as a separate external sensor "puck." The calibration software can often be set to carry out regular QA functions and to maintain calibration with minimal interaction from the user.

The overall goal in choosing the display device is to match the output of an

Figure 2

Post-selection Survey of all System Users

1. The hanging protocol for the current study was appropriate
2. The hanging protocol for current and prior studies was appropriate
3. Default image quality was adequate for the majority of the images
4. The navigation between studies of the same patient or different patients was appropriate
5. The speed of display and for all interactions was adequate for the application
6. The image manipulation tools helped the interpretation process
7. CAD helped the interpretation process
8. Manual image adjustments were often used
9. The reporting interface was convenient and easy to use
10. Overall, the user interface is very intuitive to use
11. Overall, the interface is very easy to use
12. Overall, the interface meets most of my needs for interpretation
13. The system could replace the current standard of practice without any concerns
14. The system has the potential to improve the current standard of practice

Figure 2: Example of postselection survey that can be used when evaluating a workstation. Most questions can be answered in yes-or-no format, with additional space for elaboration or comments. *CAD* = computer-aided detection.

Figure 3

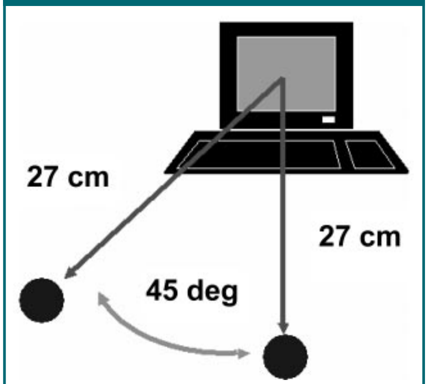

Figure 3: Diagram shows experimental viewing conditions for reference 26, where readers viewed a set of mammograms on axis and 45° off axis. Diagnostic accuracy decreased significantly for off-axis LCD viewing but not for CRT viewing.

Table 1

Guide to Radiology Workstation Selection

Criterion	Specifications*
Display: resolution, no. and type of monitors (15,16)	Match imaging output and display system in terms of both spatial (pixel size) and dynamic (pixel depth) resolution; in model 1, the most demanding imaging modality will determine the display system resolution No. of monitors is defined by no. of images to be displayed simultaneously from current and prior medical examinations and from the reporting requirements (17) P104 vs P45 phosphor selection depends on application and observer preference CRT vs LCD selection depends on technical and cost issues (18,19)
User interface: default image quality, hanging protocol, manipulation tools, accessories; interactive options; speed; software; hardware; single vs multiple user (20,21)	Default image quality, luminance, and tone scale should be adequate in more 95% of cases; manual interactive adjustments or predefined options should be available to user (1,2,22) Hanging protocol, layout, and icons should be easy to use and not detract from interpretation process In model 1, multiple user interfaces may run on same platform to accommodate modality-specific issues Presentation may be the same or different in systems used by different health care providers Speed should be adequate and not notably slow clinical practice
Archive: size and type, compression	Integrated platforms to PACS Large archive and computer space requirements Short- and long-term storage and retrieval requirements
Networking and compatibility	DICOM for display, processing, archiving, and networking
Ergonomics and environment	Space conscious systems Ergonomic setup Ambient light conditions
Quality control	Standards for hardware (particularly display system) and software performance, including image quality, system down time, and maintenance Standards for quality of archiving and networking Standards for physical environment

Note.—Numbers in parentheses are reference numbers.

* DICOM = Digital Imaging and Communications in Medicine, PACS = picture archiving and communication system.

imaging system to the display and then to optimize the display to the observer's visual system in a given reading environment. The former requires that the workstation match the spatial and dynamic resolution of the imaging system. Medical-grade monochrome CRTs and LCDs are available with a resolution of up to 5 megapixels that thus satisfy the spatial requirement for nearly every imaging modality except some full-field digital mammography systems. As already noted, the display should be capable of displaying the images as close to full resolution as possible.

There are a number of display properties that are important for good image quality, and the ways to characterize these properties with both CRTs and LCDs have been well documented (26–31). Recommended values for such key display parameters as minimum and maximum luminance, contrast ratio, matrix size, display size, bit depth, spatial resolution, pixel size, noise, veiling glare, and reflections can be found in the literature (26–31) and in the various standards documents (23–25). Again, when reviewing the recommendations it is important to keep the application in mind. Full-field digital mammography and projection radiography (ie, computed and direct digital radiography) typically require high-resolution monochrome displays, but computed tomography (CT), MR imaging, ultrasonography, and nuclear medicine applications do not need high-resolution displays, and many institutions use color displays for these modalities. Whether or not color displays can be used for the higher-resolution modalities is yet to be answered definitively (32–34), so it may be prudent to wait until more studies have been performed.

Until about 5 years ago, there was still some question regarding the use of LCDs instead of CRTs, but today there is little debate. LCDs now have sufficient luminance levels and contrast ratios and are being used widely in many radiology departments, even for full-field digital mammogram viewing. There is still some concern regarding the decrease in luminance and contrast with LCDs as the viewing angle increases; but for on-axis viewing, diagnostic accuracy is at least as good as that with CRTs (35,36). If the viewer is as little as 45° off center (Fig 3), however, diagnostic accuracy has been shown to decrease substantially with LCDs but not with CRTs (35). This type of viewing situation could arise, for instance, when multiple monitors are set up side by side for viewing or when more than one person (eg, an attending physician and a resident) are viewing the same display and one must sit to the side at an angle.

Aside from considering the technical parameters of displays from the perspective of image quality, it is also useful to realize that most of these parameters have been shown to affect diagnostic and visual search efficiency. For example, the faceplate of a CRT contains phosphors that emit visible light when hit by electrons emerging from an electron gun. Medical-grade monochrome CRTs typically use either the P45 or the P104 phosphor. The P104 phosphor is more efficient in terms of light emission (ie, is brighter) but has greater spatial noise than the P45 phosphor (see Fig 4).

In a study (32) in which six radiologists searched a series of chest radiographs for subtle pulmonary nodules on both a P45 and a P104 phosphor CRT, diagnostic accuracy as measured according to area under the receiver operating characteristic curve (A_z) was higher with the P45 (mean A_z = 0.9235) than with the P104 (mean A_z = 0.8742) phosphor display. Visual search efficiency was measured by recording the eye positions of the radiologists as they scanned the images. Total average viewing time per image was 33.96 seconds for the P45 display and 35.12 seconds for the P104 display. More important, however, median time spent examining the nodules that were eventually reported correctly was 1200 msec for the P45 display, compared with nearly 1800 msec for the P104 display. It also took more time after the images first appeared for foveal (ie, high-resolution) gaze to land on the lesion targets with the P104 CRT than it did with the P45 display. In sum, visual search efficiency as measured with various eye-position metrics was reduced with the noisier P104 display compared with the P45 display.

Similar degradations in diagnostic accuracy and visual search efficiency have been observed for displays that have not been calibrated to the DICOM-14 gray-scale display function standard (37,38) and for those with low luminance (39). Although the visual search efficiencies may not seem important when a single image is concerned, the inefficiency adds up more than an entire day's worth of reading numerous images, and the end result is that fewer images are read in the same amount of time than with displays that have been optimized to the user's visual system capabilities.

One potential concern with digital displays in radiology that has not been considered very much yet is visual fatigue (computer vision syndrome) that may result from the long hours that radiologists spend viewing very large data sets every day. As a first step in finding out whether fatigue is a common and important problem in the radiology reading room, we developed a short survey to assess the fatigue of radiologists at different times during the day. We asked about symptoms of visual and postural fatigue, the types and numbers of cases they had been interpreting (as well as modality—hard copy, soft copy, or both), and total reading time that day. The survey was given to radiologists and residents at various times in the morning and afternoon over a number of days. Table 2 presents correlations between number of cases, reading time, and symptoms of fatigue.

There was a significant positive correlation (z test) between the time spent reading studies and the severity of visual fatigue symptoms. There appears to be a trend toward higher fatigue when radiologists view both filmed and digitally displayed images during the same day. Hard-copy–only reading yielded the lowest fatigue ratings, followed closely by digital-only reading. Figure 5 shows the ratings for the question on blurred vision, but all of the questions showed similar results: Reading filmed images resulted in fewer re-

Figure 4

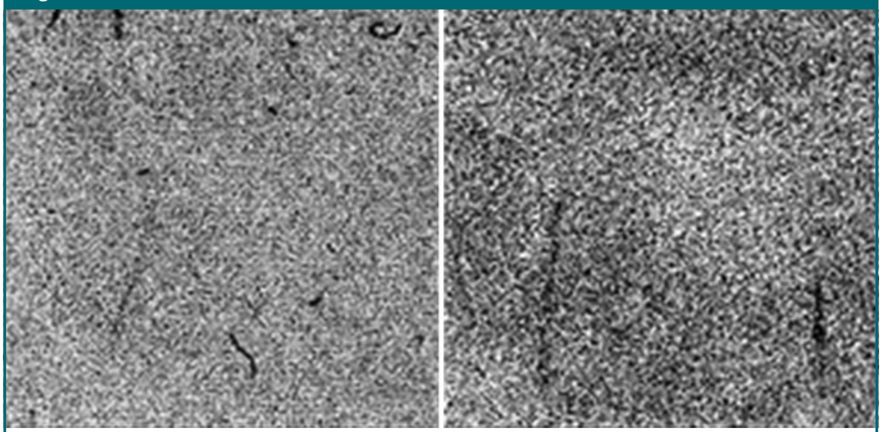

Figure 4: Examples of P45 (left) and P104 (right) CRT faceplate phosphors. P45 phosphors are less noisy than P104 phosphors.

Table 2

Correlation between Subjective Visual Fatigue, Reading Time, and Number of Examinations Read by Radiologists

	Reading Time		No. of Examinations	
Variable	*R* Value	*P* Value	*R* Value	*P* Value
Blurred vision	0.34	<.02	0.42	<.002
Eyestrain	0.43	<.002	0.48	<.001
Difficulty in focusing	0.38	<.005	0.45	<.001
Headache	0.24	.09	0.43	<.002

Figure 5

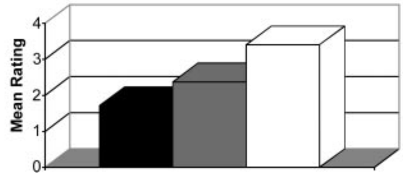

Figure 5: Bar graph shows average ratings for survey question about blurred vision in radiologists reading hard-copy (black bar), soft-copy (gray bar), and both (white bar) types of images in a single day. Higher ratings reflect increased blurred vision.

ports of blurred vision than when digital images were read and many fewer reports than when both display types were read. A similar study (40), however, showed no significant differences in eyestrain for hard-copy versus soft-copy image reading, so there is clearly the need for more study in this area.

User Interface

One of the keys to a successful soft-copy presentation is the design of a clever workstation-user interface. The interface is the backbone of the workstation, covers a wide range of issues both technical and clinical, incorporates machine and human factors, and is affected by both hardware and software aspects of the workstation. Observer studies (1,2, 9,10,12) have shown that user interfaces should be fast, intuitive, user friendly, able to integrate and expand, and reliable. These studies have also shown that a user interface that has all of the above could compensate for many technical shortcomings of the workstation, including, for example, display resolution and mismatch and, in some cases, even speed and processing or computer-aided detection weaknesses. In selecting a user interface, several aspects need to be considered and reviewed.

Hanging Protocol and Default Display

There are two approaches in the design of the hanging protocol. One, the first to be adopted in workstation development, attempts to imitate hard-copy practice in the digital environment. The other slowly evolved from the first efforts and attempts to overcome the limitations of the first by changing the process to offer more options and be faster. The first approach propagates not only current strengths but also weaknesses and certainly limits the potential of the digital environment. The second approach introduces another new interpretation process and, hence, requires a longer learning curve and may generate biases and longer interpretation times, but it appears to offer better integration, ability to expand, and, in the end, an improved method of practice.

Figure 6

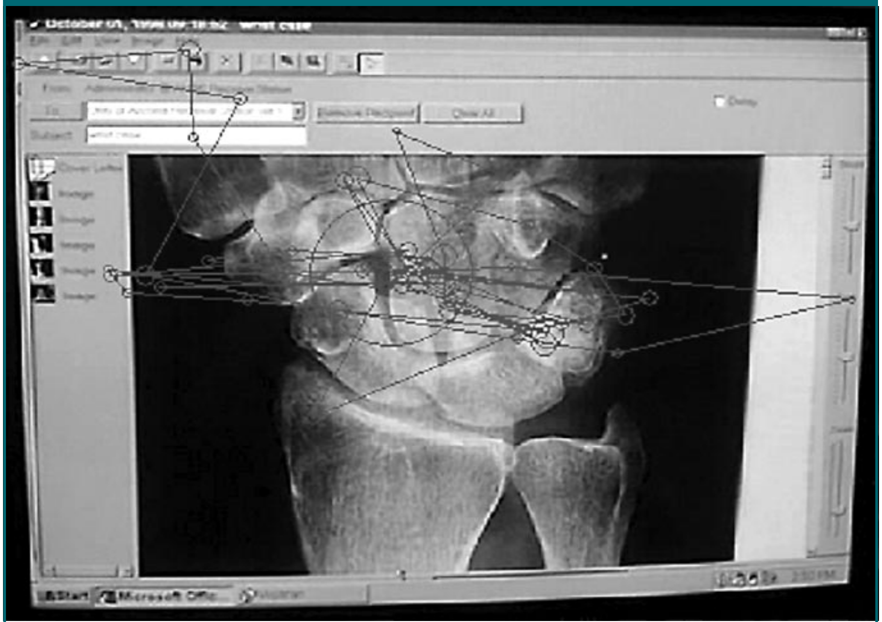

Figure 6: Screenshot shows scanning pattern of a radiologist viewing a bone radiograph with a nonoptimized software interface. Eyes were fixated for 20% of the time on the nondiagnostic menu areas rather than on the diagnostic content of the image. Circles are points where the eye stops (fixations); lines show the order in which fixations were generated.

The success of a hanging protocol relies heavily on the quality of the default display (41). This is a critical element in the implementation and clinical acceptance of a workstation. The quality of the first displayed images should meet or exceed diagnostic standards in 95% or more of cases. Manual adjustments should be available for cases where the default settings failed. Alternatively, few preset alternative presentations seem now to be preferred, depending on the image source, the type of abnormality, and the application. For example, a mammogram display may be customized and adapted for better viewing of one type of findings (eg, calcifications or masses), and a lung CT display may similarly be customized for better viewing of nodules or pneumothorax.

Image Processing and Analysis Tools

This part of the interface was relatively undervalued in the early workstation development and was not considered a high priority. Currently, after almost three generations of digital workstations, the functionality offered by the interactive processing and analysis tools often outranks image quality in importance. In reviewing these options, the user should consider the following: *(a)* The user should be able to use the basic navigation tools of the interface without any training or prior exposure, and *(b)* the system should be user friendly—that is, it should be easy to use and customize. Ease of use implies simple menus and file managers; single-mouse-click navigation; visually comfortable colors or gray scale; an uncluttered screen work space; ergonomically positioned input devices such as mouse, keyboard, and pad; and ergonomically positioned monitors. User-friendly customization implies easy manual adjustment of images to meet personal visual preferences and interpretation patterns (Fig 6) (42), as well as easy restoration of default and set up values.

From a perceptual point of view, the quality of the default image presentation is extremely important. As was noted earlier, the radiologist processes a substantial amount of diagnostic information in a very short amount of time (the initial global, or "gist," view), so it is crucial to provide the best, most perceptually useful information in the initial default presentation. Part of the reason for this lies in the desire to allow the radiologist to make correct decisions with as little unnecessary image manipulation as possible, so as not to prolong viewing times. Many acquisition devices actually preprocess images to improve their appearance before the images are even sent to the workstation. If the preprocessing actually accomplishes what is intended, it can greatly reduce viewing times and the number of image manipulations (eg, window level or zooming) the user needs to carry out (43,44).

Reporting Options

Although traditional dictation and transcription methods are still widely used, the move to digital imaging has fostered the move to digital reporting. Advances in continuous voice recognition technologies (45) have been important, and many, although not all (46), of the problems with the early systems have been eliminated. Use of voice recognition reporting systems can improve productivity by substantially decreasing report turnaround times (47). When choosing a voice recognition system, it is important to test it with as many people as possible who are going to use it—especially those with an accent and those with a very slow or a very fast speech pattern. If too many corrections need to be made manually after the report is dictated, satisfaction will be low (46). On the technical side, it is important to choose a system that will integrate not only with the PACS and radiology information system, but also with the hospital information system for billing purposes (45,48).

Speed

The processor characteristics that affect clinical practice include speed, reliability, cost, compatibility and ability to integrate with PACS and other systems, and quality control, service, and upgrade issues. Speed is determined by the programming, the number of processors, the power, and the amount of memory of the system. Current experience shows that speed is a determining factor in the acceptance of a workstation. Observer studies have demonstrated that major operations (eg, loading of images from same patient for display) should take no more than 2 seconds per operation. Operations executed during the interpretation of a case should be on the order of milliseconds. Longer times may be justifiable and acceptable for certain off-line operations, depending on the environment and the workflow (49). To increase speed, multiprocessor systems are usually employed. To date, UNIX-based machines were the systems of choice because they offered greater capabilities. Now, however, technologic developments in personal computer–based hardware allow the replacement of the traditionally used UNIX systems owing to the lower cost and increased power of the former.

Means of Interaction

For the most part, the type of input device one uses with a workstation is a matter of personal preference. Some of the most common alternatives include a keyboard (typically with "hot-key" options), a mouse (with or without a scroll wheel and with various numbers and types of buttons), and a trackball. Some of the more creative input devices being investigated for use with radiology workstations are foot pedals, joysticks, modified keyboard-mouse combinations, and even voice-controlled technologies (50–54).

The keys to choosing the input device relate to user comfort and to the task. The radiologist is going to be using the input device for every case all day, and, as with any other computer interaction, the task is repetitive and continuous. The risk to radiologists of carpal tunnel syndrome and other repetitive musculoskeletal injuries is not insignificant (55). Users should choose an input device that they are physically comfortable with and should review the computer workstation user tips provided by such organizations as the Occupational Safety and Health Administration (56). Users should also choose an input device appropriate to the task. If one is reviewing very large data sets of CT or MR images with software viewing tools that allow rapid scrolling for navigation, then a joystick would be appropriate and useful. If computed radiography chest images are reviewed, however, a joystick would not likely provide any advantage over a mouse. One final point regarding input devices and comfort is that many of the devices, other than the mouse, will require a learning period, so there may be an initial period in which workflow actually slows down before it speeds up with familiarity.

Service and Upgrade Issues

With technology (both hardware and software), there are two things one can be sure of: The system will break down, and there will be upgrades. When choosing all workstation components, it is important to find out what the service and upgrade policies are; if they are not satisfactory, one must either negotiate (and contract) for acceptable services or find another vendor. In terms of service, it is important to know *(a)* how quickly the provider can guarantee that someone will address the problem, *(b)* whether the provider has a phone help line (and what the hours are), *(c)* if online support is available, and *(d)* are local support personnel available. With respect to upgrades, three important points are to find out if upgrades are included in the service contract, at what point will the company stop supporting older versions, and how much training is included with each upgrade.

Compatibility and Integration

The selection of a workstation and user interface is not an isolated action but a piece of a big puzzle that has to "fit." Efficiency in the filmless clinical practice now demands compatibility and integration of the various imaging modalities and diagnostic systems. A diagnostic radiology workstation should be able to integrate with systems from other vendors, other imaging modalities, other applications, and PACS (57,58).

A dedicated system (ie, one designed for interpretation of images from a particular modality and application) often has the advantage of being fast, error free, and optimized for displaying and handling the specific images and related data. Most workstations today have followed this approach and offer interfaces and architectures, copyright protected and closed, for specific applications and imaging modalities. These usually possess specific features, image manipulation options, and processes that are highly successful for the targeted application or family of applications. The downside of this approach is that these systems are hardly compatible with others operating in the same environment, cannot import or export outside images of any type, and, hence, cannot be easily integrated in a practice where one may need to incorporate multiple workstations or fuse and interpret multisource data simultaneously (59).

Ideally, one would like to have a single system and a single interface that will accommodate all types of radiology data and will be highly successful in all cases. This does not seem achievable at the moment because of differences in image characteristics, user preferences, and interpretation patterns, as well as technical limitations in terms of computer power and processing. It is certainly a noble cause, and researchers will continue toward this goal, which is both software and hardware dependent. Until such a single tool is available for all radiologic modalities and all users, the next best alternative is the development of systems with open architectures that can host a series of modality-specific interfaces and have full DICOM compliance for optimum communication with similar platforms from different vendors or with platforms designed for other applications.

Archiving

Data archiving is indirectly linked to the radiology workstation, but it affects workflow and overall clinical operations. There are several technical layers to consider and review in selecting a commercially available product for the storage and retrieval of image and nonimage information. From high level to low level, these include the application, data management, file type and file system, storage management, and physical storage layers. These technical issues are discussed in detail in reference 60. Here, we will focus more on some practical aspects that are not yet fully explored and have that a major effect on archiving and overall radiology workflow.

Long versus Short-term Storage

A clear understanding and relatively detailed estimate are required for the amount and type of data that need to be available online (ie, immediately) and the data that may be retrieved but not in real time (ie, data that may be stored off line and will require a certain period to be retrieved and loaded on the system for review). The former defines the needs for short-term storage, and the latter defines the needs for long-term storage. When considering the two types of storage, one reviews aspects of the type of medium and the size, on the basis of the source of the images and the amount of nonimage information that needs to be stored, of the location of the archives (remote vs local), and of the retrieval processes, including the speed of both short- and long-term systems.

Image Data Compression

Reducing the amount of data that need to be stored and retrieved affects speed, efficiency, and cost. We now have several image-compression methods that offer attractive solutions to reducing the size of image data sets. Lossless methods result in file sizes two to three times smaller without any loss in the image data and, hence, without reduction in the diagnostic quality of the data. Lossy methods result in substantially smaller files at the expense of losses that affect diagnostic quality and, hence, result in images that can no longer be used for diagnosis. They may, however, be used for referral purposes. Visually lossless methods also result in much greater reduction of data set size (often more than 10 times) than true lossless techniques, at the expense of some loss to the image data that do not seem, however, to reduce diagnostic quality. The implementation of the latter techniques and their role in clinical practice is still under investigation, but initial results from observer studies involving wavelet-based compression approaches are promising (61,62).

Integration of Image and Nonimage Information

To date, there are no commercially or publicly available packages that offer integration of both the original image and the nonimage information for a patient, either for storage or for interpretation. Information technology departments at large institutions occasionally develop their own in-house tools for this integration, but most often the two databases reside on separate platforms that are often incompatible. The merger of all of the information sources, however, is becoming more and more important to the efficiency of the filmless radiology department. Hence, one needs to be aware of the current state of the art and the plans for future upgrades in system software and hardware.

Human Factors and Ergonomics

Reading Environment

A number of examples have already been provided that demonstrate the ways in which workstation technologies (particularly the display and user interface) affect diagnostic accuracy, visual searching, and interpretation efficiency (19,32,38,39,42,43). Many of the guidelines for characterizing the physical properties of displays that were discussed previously were derived, in part, by considering the capabilities of the human visual system, especially with respect to spatial and contrast sensitivity and the number of just noticeable differences, or discriminable levels, for grayscale and color vision (9,10). The importance of optimizing the presentation of the default image was also stressed.

There are also factors related to the environment in which the workstation will be placed that are important. One important issue is the number of monitors per workstation. To some extent, this depends on the amount of space available, but there is some evidence not only that two monitors will suffice for most reading situations, but that in many ways this represents the optimal set-up (63). Compared with the most common alternative, the four-monitor workstation, reading times and reported fatigue levels were comparable, providing no advantage for the use of more than two displays. A four-monitor workstation also requires more head and body movement to navigate through and search the displays, which potentially increases the risk of postural and visual fatigue and musculoskeletal problems (40,55,64,65).

Other issues related to the environment that should be considered are the amount of heat generated by the workstation as a whole, the level of noise produced by the system, and the kind of ambient lighting that will be used. Each of these factors could influence one's choice of workstation configuration since they may necessitate alterations to the existing environment (66). If the workstation produces too much heat it may be necessary to improve air flow, both for the computer and for the radiologist. Most computer systems are fairly quiet today, but fan-cooled systems do generate noise levels that might be distracting. LCDs are much more flexible than CRTs with respect to ambient lighting conditions because the faceplate is not very reflective and veiling glare is minimal, but it is important to find out if the LCD manufacturer adds a protective cover to the front of the display (to prevent fingerprints and dirt accumulation), since this will bring the reflection problem back. With CRTs it is important to make sure an antireflective coating is included; otherwise, one could consider a flat-screen CRT rather than the more familiar curved surface (67).

Workflow and Decision Support Tools

Workflow is clearly important as radiologists are faced with more and more cases to read and the proliferation of images generated with advanced technologies such as helical CT. The ergonomics of workflow include personnel, equipment, and environmental components (68), and there are even modeling tools available to simulate and design workstation set-up and reading rooms (69). An excellent summary of the state of the art of techniques for image processing, computer-aided detection, and methods for dealing with large data sets can be found in reference 70. The manner in which these tools are integrated into the user interface has already been covered.

In terms of workflow, it is clear that the various tools should be easy to access and easy to use. When reviewing the tools offered by a given workstation vendor, it is also important to get as much detail as possible regarding precisely what the tools do (ie, what is a tool doing to the image data). It is not necessary to understand the underlying algorithms, but the processes should not simply be "black boxes" either. This is true both for tools that can be accessed during viewing and for any preprocessing that is performed on the images. With respect to decision aids such as computer-aided detection, it is important to obtain details regarding the expected true- and false-positive rates of the scheme and under what conditions it may not perform at those levels.

As with any new tool, the user needs to accept the fact that there will be a learning curve associated with its use, so workflow may initially slow down but will hopefully improve. The learning curve with image-processing techniques and computer-aided detection is related not only to how to access and use the tools but also to a perceptual and cognitive learning curve that radiologists should be aware of. Radiologists have to learn not only what the various tools do to the appearance and conspicuity of the lesions, but also what they do to the appearance of normal tissues and structures. In many cases, image processing seems to improve reader confidence and the ability to discriminate lesion characteristics rather than contribute to a large increase in detection performance (71,72).

Quality Control

A QA program for the radiology workstation is an important and critical part of the entire implementation (reference 73 provides an excellent summary of various quality control and QA components in the digital enterprise). Currently, quality control tests are designed by the manufacturers and cover all parts of the workstation; these tests are designed to ensure the reliability and high performance of the system. The digital environment offers the opportunity and, hence, the advantage over film systems to standardize, automate, and simplify several of the traditional quality control tests found in film applications (23,25). This does not diminish the need for QA processes or the thoroughness with which quality control tests should be executed.

When choosing a workstation, it is necessary to understand what quality control procedures have been performed by the manufacturer and what types of QA procedures need to be implemented (and how often) once the workstation has been installed. It is also important to determine if any of the tools necessary to carry out the QA procedures are included with the workstation component being considered (eg, an internal sensor and software for display calibration) or whether they must be purchased separately (and from whom if the vendor does not provide them).

Future Considerations

As radiology practices become entirely digital and as modalities fuse and integrate, several new issues have appeared or will appear and will need to be considered by the user in the selection of a workstation (9,10). Specifically, workstations will have to handle multiscale and multimodality applications, including image fusion imaging, three-dimensional imaging, management of large volumetric data sets, standardization and integration of different imaging and computing platforms and data sources, standardization of reporting across modalities, and database integration (eg, demographics, radiology and pathology reports, ambulatory status). No matter what the future brings, however, the keys to successfully choosing a workstation are being an informed consumer and having a clear understanding of the application(s) for which the workstation will be used and the environment into which it will be placed.

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