Published in final edited form as:

Hum Pathol. 2009 August ; 40(8): . doi:10.1016/j.humpath.2009.04.011.

Virtual slide telepathology workstation of the future: lessons learned from teleradiology☆

Elizabeth A. Krupinski, PhD

Department of Radiology and the Arizona Telemedicine Program, University of Arizona, Tucson, AZ 85724, USA

Elizabeth A. Krupinski: krupinski@radiology.arizona.edu

Summary

The clinical reading environment for the 21st century pathologist looks very different than it did even a few short years ago. Glass slides are quickly being replaced by digital “virtual slides,” and the traditional light microscope is being replaced by the computer display. There are numerous questions that arise however when deciding exactly what this new digital display viewing environment will be like. Choosing a workstation for daily use in the interpretation of digital pathology images can be a very daunting task. Radiology went digital nearly 20 years ago and faced many of the same challenges so there are lessons to be learned from these experiences. One major lesson is that there is no “one size fits all” workstation so users must consider a variety of factors when choosing a workstation. In this article, we summarize some of the potentially critical elements in a pathology workstation and the characteristics one should be aware of and look for in the selection of one. Issues pertaining to both hardware and software aspects of medical workstations will be reviewed particularly as they may impact the interpretation process.

Keywords

Telepathology; Workstations; Human factors; Perception

1. Introduction

Viewing images is at the core of diagnostic pathology interpretation whether it is using glass slides and the light microscope or “virtual slides” and a computer display. One can consider the image interpretation process from 2 major perspectives. First, there is the technology used to display the images and how factors such as display calibration affect the quality of the image and thus the perception and interpretation of features in the image. Second is the human observer relying on their perceptual and cognitive systems to process the information presented to them. Each aspect cannot, however, be considered in isolation. With telepathology this becomes even more of a factor because the variety of displays available for viewing virtual slide images is quite large. Thus, it becomes important to understand some of the key issues involved in the image interpretation process and how to optimize the digital reading environment for the effective and efficient image interpretation.

Most studies to date in telepathology have been more concerned with assessing the concordance of diagnosis between the original specimen slides and the digitized or

☆This article was supported in part by grants R01EB008055 and R01EB004987 from the National Institutes of Health (National Institute of Biomedical Imaging and BioEngineering).

photographed versions of them [1–14]. For the most part, these studies have found concordance rates well above 90%, and telepathology is becoming fairly well established in many clinical settings. What has yet to be studied in any significant depth in telepathology is the optimization of the telepathology workstation and digital reading environment. In radiology, however, this has been studied extensively [15–17], and many of the lessons learned can be readily applied to telepathology.

2. Design of a telepathology workstation

In principle, the telepathology workstation is designed to replace the standard display medium, for example, the light microscope, but it also can go beyond the standard of practice and provide new tools that may improve the link between the imaging system and the pathologist for improved interpretation. From the diagnostic point of view, the minimum requirement is that the same (if not better) sensitivity and specificity be achieved using a computer workstation for interpretation instead of the light microscope. From an ergonomic point of view, the minimum requirement is that the workstation improves efficiency while reducing stress and strain for the observer and improving workflow.

Some of the more important workstation requirements will be discussed later in greater detail, but first it may be useful to describe a “typical” radiology workstation. There is no single way to design a radiology reading room and there is no single way to set up the “perfect” workstation. However, over the years since radiology moved from film to computer reading of images, certain basic setups have emerged as being the most useful and practical. Fig. 1 shows a typical radiology workstation.

Most radiology workstations have 2 main display monitors (A and B in Fig. 1) for viewing the clinical images. These are typically medical-grade high-resolution (at least 2-megapixel) monochrome displays, although they are increasingly changing to medical-grade high-resolution color displays. The 2 displays are positioned side by side and angled slightly inward toward each other so the radiologist can sit centrally and view each display orthogonally. Orthogonal viewing is important because many displays still suffer from off-angle viewing problems. As the viewer moves from direct viewing to viewing from the side, contrast and luminance fall off, reducing the visibility of the image being displayed. The same occurs with color displays, and as a consequence of the luminance and contrast changes, color hues change as well which for pathology can be a problem. The slight inward angle also reduces head movements needed to direct the eyes directly at the screen, reducing neck, back, and shoulder strain that can result from prolonged sitting at the display. In the early days of digital radiology, the number of displays varied considerably from 1 to 6, but it quickly settled on 2 diagnostic displays as 3 or more tended to result in too much movement required to view all the displays at the right angle. One display is insufficient because most radiology examinations have more than one image (multiple views) and there is often to need to compare images (different views or current versus priors) simultaneously. It is possible to compare images on a single display, but this requires reducing the size of the images, making it difficult to discern fine details. With 2 displays the images can be viewed at full or near to full resolution and compared easily.

For pathology, it seems likely that only a single diagnostic large display will suffice as pathologists typically view only a single image at a time. There are currently a variety of high-performance color monitors on the market that are likely to be well suited for virtual pathology reading. For example, the medical-grade Coronis Fusion 6-MP color display from Barco Corp (Kortrijk, Belgium) has an active screen width of almost 26 in and height of 16 in. This display is currently being used in our research area and, with 6 megapixels, renders

the high-resolution virtual pathology slides quite nicely and the display size allows the viewer to sit at a reasonable distance and see the image details rendered at a reasonable size.

To one side (C in Fig. 1) of the diagnostic displays, there is typically a general purpose display (color off-the-shelf). This one is used to display the radiologists' work list, of which images are available on the Picture Archiving and Communications Systems for reading. It is connected to the Radiology Information System and possibly the Hospital Information System from which patient data are retrieved. It too is generally tilted slightly inward for optimal viewing. In all likelihood, this type of display will be required in the digital pathology reading room.

The same general purpose display (C in Fig. 1) can also be used for dictation, although sometimes a separate monitor is used and positioned on the other side of the diagnostic displays. As most digital reading rooms have also moved from tape recording and transcriptionists to automatic speech recognition technologies, the radiologist needs a display for viewing and correcting their reports as they are generated. As pathologists also make the move to automatic speech recognition technologies for generating their reports, this type of screen will also be needed at the pathology digital workstation.

Aside from the typical display configuration, a few other points about the radiology workstation itself are relevant here, although others will be discussed later in the text. It is generally recommended that the displays are set on a table that has the ability to be moved up and down to adjust the displays to the user's height (eyes should be about level with the center of the display). A separate desk level for the keyboard and mouse are also recommended (typically slightly lower than the display table) to avoid carpal tunnel syndrome and other repetitive computer injuries. Adjustable, comfortable chairs are also recommended for fine-tuning the user's height with respect to the displays. Wheels on the chairs are useful so the user can move away from or closer to the display without bending over or leaning back (again to avoid strain injuries).

3. Display resolution

In radiology, the guidelines for interpretation of digital images recommend that the display matrix size should be as close to the raw image data as possible [18] or accessible with magnification. In telepathology the size of the virtual slides is quite large. For example, the DMetrix (DMetrix, Inc, Tucson, AZ) scanner currently samples images at 0.47 μm / pixel (or 54 045 dots per inch). Depending on the amount of tissue on the slide, a single 40 $\times$ objective image can result in 200 MB to 1 GB of data [19]. Some commercial scanners create even larger images [20]. This suggests that for telepathology, the highest-resolution displays on the market should be considered. Although at one point a few years ago, one company did produce a 9-megapixel display, the highest-resolution medical-grade color display now available is 6 megapixels. Such a display can however be rather expensive, so alternatives are being explored. In the future the price of high-performance color monitors will continue to drop and off-the-shelf displays will likely be suitable for nearly all medical imaging applications.

4. Image compression

Compression is one way to deal with this massive amount of virtual slide data [10,20–26]. JPEG2000 is the latest international standard for image compression [27,28]. JPEG2000 offers a number of functionalities that were not available in earlier standards. These functionalities, together with improved rate-distortion characteristics, make JPEG2000 an efficient and functional image compression method. The problem is however, that it is difficult, if not impossible, to define a single “minimum” level of compression (hence image

quality) for use across all clinical questions [29]. Human observer studies are the ideal way to determine what level of compression would be most appropriate (ie, does not impact diagnostic performance), but these studies can be time-consuming and rely on busy pathologists finding time to serve as observers.

Nearly all of the studies looking directly at compression in telepathology applications seem to have been done using JPEG (partly because many were carried out before the JPEG2000 standard being developed and released). JPEG2000 however is quickly becoming the method of choice in many image-based tasks including medical and telemedical imaging [30–34]. Each method has advantages and disadvantages. JPEG artifacts tend to be of the “blockiness” variety, whereas JPEG2000 artifacts are of the “blurring” variety. In addition, there is evidence that at low compression levels, JPEG produces fewer visible artifacts, whereas at higher compression levels, JPEG2000 produces less visible artifacts [35–38]. The trade-offs between the type of artifact and its visibility have yet to be studied with virtual telepathology slide images. Rigorous studies on the effects of compression on diagnostic accuracy are scarce as well. Most studies evaluating the effects of compression have used subjective rather than objective measures. For example, Okumura et al [39] used 7 digitized pathology specimen slides (kidney, uterus, bronchus, colon, prostate) and subjectively determined (not using pathologists or other medical observers) when blurring and changes in color and texture of cell parts could be detected as they compressed the images. Foran and Papathomas used pathologists to evaluate a set of 45 routine surgical pathology slides, asking them (in separate tasks) to determine if there were any perceivable differences in compressed versus uncompressed versions and if they felt the images preserved their ability to diagnose the images (they did not diagnose the images). They found that, subjectively, the pathologists thought they could tolerate high levels of compression, but again this was not confirmed objectively by measuring diagnostic interpretation accuracy [40]. Brox and Huston [41] evaluated the MPEG-4 standard (for use with dynamic and hybrid telepathology systems) and found that the compressed video image sequences had “good quality,” based on their subjective impressions [42].

Marcelo et al [43] carried out a more objective evaluation of the effects of JPEG compression on pathology interpretations. They used a set of 10 different cases using a digital camera to capture images from the glass slides. Ten pathologists read the softcopy images (uncompressed ~1000 kilobytes at 667×500 -pixel resolution and compressed ~100 kilobytes at 90% compression versions), and diagnoses were compared with the reference diagnosis from the glass slides. Only 7% of the cases were judged to be unacceptable for diagnosis. Of the acceptable cases, 76% received diagnoses concordant with the original diagnosis, and the accuracy rates did not differ for the compressed and uncompressed images. Six percent of the cases had minor disagreements with the original and 17% had major disagreements with the original diagnosis. The weaknesses of this study include the small sample size of only 10 images and each case was different (eg, carotid body tumor, nephroblastoma, endometrial carcinoma), and only one level of compression was tested. Gao et al [44] used the JPEG2000 standard to compress a set of prostate biopsy samples that had been previously enhanced (to better visualize nuclei and cytoplasm details) using some novel image processing schemes. To evaluate the effects of compression, however, they did not use any human observers. They used the more common metric of peak signal-to-noise ratio, but this does not directly address the question of whether the compression actually impacts the diagnostic accuracy of the pathologist interpreting the images.

One method that we are exploring to evaluate compression levels for telepathology images is the use of visual discrimination models (VDMs). Applications of the VDM in medical imaging have been evaluated in numerous research projects over the past 10 years mostly in radiology [38,45–50], and using properties of the human visual system in a modeling

approach and/or using perceptual metrics for evaluating the effects of image compression is not new [51–61]; but to our knowledge, these approaches have yet to be applied to telemedicine images in general or to telepathology images in particular. High degrees of correlation have been found between human diagnostic accuracy values and the VDM metrics for the same test images. In an initial test of the VDM, we devised a visual task in which human observers and the VDM had to detect differences in virtual slide images due to lossy compression. The goal is to find the compression level that yields a “visually lossless” image or one that is visually indistinguishable from the uncompressed original, under the presumption that visually lossless means diagnostically lossless.

There are a variety of VDMs being used, but the model we use predicts observer performance on visual discrimination tasks [38,47–50]. Broadly, it begins with 2 paired images as the initial input and ends with a Just Noticeable Difference (JND) map that shows the magnitude and spatial location of visible differences between the 2 images. In the first stage (optics), the 2 original images are convolved with a function approximating the point spread by the optics of the eye. In the second stage, image sampling by the retinal cone mosaic is simulated by a gaussian convolution and point sampling sequence of operations. The raw luminance image is then converted to units of local contrast, and decomposed into a Laplacian pyramid, resulting in 7 frequency band-pass levels. Each level is then convolved with 8 pairs of spatially oriented filters with bandwidths derived from psychophysical data. Oriented filtering is applied and the pairs of filter output images are squared and summed, generating a phase-independent energy response. This process approximates a widely proposed transformation in the mammalian visual cortex from a linear response among simple cells to an energy response among complex cells. This operation has phase independence and thus has some useful properties, such as making the model less sensitive to the edge positions, a property exhibited in human psychophysical performance as well.

The next stage (transducer) normalizes the energy measure for each pyramid level by a value approximating the square of the grating contrast detection threshold for that level and local luminance. The energy measure is transformed by a sigmoid nonlinearity to reproduce the dipper shape of visual contrast discrimination functions, taking into account nonlinear masking effects that make features less detectable on a nonuniform background. Human foveal sensitivity is accounted for by a pooling stage that averages transducer outputs over a small neighborhood by convolving with a disc-shaped kernel. The model output for each spatial position is an m -dimensional vector (m = number of pyramid levels times the number of orientations). A “distance metric” is computed from the distance between the vectors for the 2 inputs. The degree of discriminability between the images is represented by a spatial map of the JND values that can be reduced to a single, aggregate value by Minkowski normalization.

The focus of our efforts is on the JPEG2000 standard. JPEG2000 is an image coding system that uses state-of-the-art compression/decompression techniques based on wavelet technology. Its architecture lends itself to a wide range of uses from portable digital cameras through advanced prepress, medical imaging, and other key sectors. The advantage of concentrating our efforts on this particular standard is that implementations of the earlier JPEG standard have become commonplace in many medical imaging sectors including radiology (it is currently part of the Digital Imaging and Communications in Medicine [DICOM] standard [62] with respect to lossy/lossless compression) and telepathology [63] and teledermatology [64] applications. Parts of the JPEG2000 standard have already been incorporated into the DICOM standard [27,62].

The data in the telepathology compression study were obtained using a classic psychophysical technique called the staircase method to find the JND point. The observer is

presented with images (original uncompressed and compressed) and must decide which is the different one. We used the odd-man-out paradigm to show the images (Fig. 2). In this study, regions of interest (ROIs) were cropped out of the original virtual slide images for easier presentation. Each region contained diagnostically relevant information as determined by an experienced pathologist. All 4 images (Fig. 1) are the same ROI from a breast biopsy specimen. The top 2 are the original uncompressed version and serve as a reference point for knowing what the image looks like uncompressed. Two identical images are used so the observer simply has to move the eyes up and down rather than make diagonal moves to a central top image. The bottom 2 images are the test images. One of them (left in this example) is compressed and the other (right in this example) is the original uncompressed (same as the top two). The task of the observer is to decide which of the bottom two (2 alternative forced choice) is the different one or the “odd-man-out.” In the staircase method, each image is shown a number of times with various compression rates. If the observer correctly detects the compressed version, the program moves up the staircase and presents an image at a lower (less visible) compression rate. If they incorrectly report the uncompressed version as being different, the staircase moves down and shows a more compressed (more visible) version. This continues up and down the staircase until the observer consistently (eg, 5 times) detects a given compression level 50% of the time (chance). This chance point is called the JND and represents the point where the compression is “visually lossless.”

Fig. 3 shows typical data from a human observer on 4 of the images. The uncompressed pathology images used are shown in the upper left corners. The x-axis shows the bits per-pixel (bpp) or compression rate and the y-axis shows the trial number. Lower bpp on the vertical axis correspond to higher compression levels (more visible), whereas higher bpp correspond to lower levels (less visible). Starting from the left with trial 1, the observer is shown an image with relatively obvious compression artifacts so the next presentation moving to the right goes “up” the staircase and is an image with less compression. As long as the images have noticeable compression artifacts, the staircase continues as is seen in each graph. About halfway over, however, the data start fluctuating up and down as the observer starts to have trouble detecting differences (lower compression levels). Within 50 trials the observers quickly converge on the JND point. The light blue horizontal line shows the threshold for the last 5 reversals and is considered the JND point. In other words, on the first image (upper left), the JND is at 4.1. For image 2 (upper right), it is at 4.9. The visibility of compression artifacts was also predicted with the VDM. When applied to pairs of uncompressed and compressed images, the VDM generates objective measures of the visibility of compression artifacts in standard, perceptually linear units of JND. VDM distortion metrics correlated highly with the human results, suggesting that the VDM could predict compression levels for images. Future studies will use larger sets of images and more observers to further validate the utility of the VDM approach in predicting compression levels that produce visually lossless images.

5. Automatic zoom

Radiology workstations in recent years have started to incorporate more and more tools that automatically present the image in an optimized fashion to the radiologist to reduce the time that the radiologist has to spend manipulating the image. Given the large size of virtual pathology slides, the use of automatic tools to present images in an optimized fashion would also be useful. One question that we have explored is whether it might be possible to predict where pathologists look at an image to extract the most diagnostically relevant information. If there are common features in a virtual slide that attract attention, then perhaps this could be modeled and a computer algorithm written to quickly zoom up these highly relevant locations for the pathologist.

In a recent study [65], 3 pathologists, 3 senior pathology residents, and 3 post sophomore fellows viewed a series of breast biopsy frozen section virtual slides and selected the top 3 locations that they would zoom onto if they were going to view the image in more detail to render a diagnostic decision. Fig. 4 shows one of the images with the 3 marked locations from each of the 9 observers. We classified the marks as common or sporadic. Common marks are locations indicated by more than one person that fell within a 5° circle with most of the marks at the center, with the restriction that they all had to be on the same piece of tissue. Sporadic marks were individual marks (ie, noted by only a single person) without any other marks nearby.

We found that there were significantly more common locations marked per image than sporadic. On average, there were 4.40 common locations and 1.45 sporadic locations indicated per image. What was most interesting is that there were no significant differences in the number of sporadic locations marked as a function of level of experience. The pathologists, residents, and post sophomore fellows reported 20%, 43%, and 37% of the sporadic locations, respectively. To determine if the locations selected were clinically meaningful, an independent senior pathologist reviewed each location to determine whether or not each location contained cellular material that could contribute to a diagnostic decision. Ninety-two percent of the locations did contain information that could have been used to render the original diagnosis. For the common locations, 99% contained useful information, and for the sporadic ones, only 72% contained useful information.

Future studies will be used to further explore exactly what information in these commonly selected areas is attracting the attention of even relatively inexperienced observers. If we can isolate these visually attractive features, it may be possible to use image segmentation and analysis tools to automatically identify these diagnostically rich image locations and selectively display them to pathologists instead of having them search through the entire virtual slide.

6. Display calibration

Radiology serves as an example of why monitor calibration is important in medical imaging. Early in the development of Picture Archiving and Communications Systems and teleradiology, the DICOM standard was developed to facilitate the transfer of digital images. The most visible part of DICOM is the DICOM 14 Grayscale Standard Display Function [66] that determines the display function. Today, it is inconceivable that displays for primary interpretation in radiology are without proper DICOM calibration, as it has been shown that uncalibrated displays do yield poorer diagnostic performance [67]. There are, however, very few color calibration tools available for medical color application areas such as telepathology.

One approach to consistent color display is the use of the Gretag-Macbeth ColorChecker. This is a pattern of 24 commonly used colors and gray steps. The chart is available as a digital image file. Color display calibration is typically done as follows: on-screen color controls are adjusted until there is *visually* little or no difference between the colors shown on the display and the actual physical chart held in the vicinity of the display and illuminated by the suggested light source [68–70]. The problem is that because it is a visual match, it is highly subjective, user dependent, and quite variable.

The trichromatic theory holds that the retina of the eye consists of a mosaic of 3 different receptors. Each responds to specific wavelengths corresponding to blue, green, and red. These 3 elements, which overlap considerably in response, are separately connected through nerves to the brain where the sensation of color is derived by the brain's analysis of the

relative stimuli [71,72]. The operation of color displays is based on the fact that the mixture of 3 primary colors in suitable quantities can produce many color sensations. Color coordinates and temperatures can be measured with colorimeters or spectroradiometers. We are currently exploring ways to use off-the-shelf colorimeters to develop standardized methods (similar to the DICOM Grayscale Standard Display Function) for calibrating color displays.

To illustrate the importance of calibrating color displays, we conducted a preliminary study [73]. The sensor was first calibrated using a standard colorimeter. Two Nippon Electric Company, Ltd 2-megapixel color displays (LCD2180UX-BK-SV) were placed side by side. Fig. 5 shows a bar pattern displayed on the 2 color displays before (A and B, top) and after (C and D, bottom) calibration. One can clearly appreciate the difference between the 2 displays (although they are much more obvious on the actual displays). For example, in Fig. 5A, the sixth bar from the left in the top row (arrow) looks deep purple on the left image and pink on the right. After a simple calibration (Fig. 5C), they both look closer to purple. For pathology, color calibration such as this is important because the common stains used are pink (eosin) and purple (hematoxylin). If these colors are not rendered properly on the computer screen, it could impact the diagnostic decision process. The colorimeter however reveals that they are not perfectly matched, so we are still working on a better method to accurately calibrate color displays. In the future, there will be a standard color display calibration methods with sensors and measurement devices built into the displays for automatic calibration.

7. User interface

One of the keys to a successful softcopy presentation is the design of the user interface. It is the core of the workstation and represents the portal through which the pathologist accesses the image data. Its design covers a wide range of technical and clinical issues, human factors, and is affected by both hardware and software. The user interfaces should be fast, intuitive, user friendly, able to integrate and expand, and reliable.

In radiology, one of the main issues that arose in the transition from film to digital was whether to replicate the film-hanging protocol (how the films were hung on the film alternator) or were there better ways to arrange the images on a computer display. The same challenges are now being faced by telepathology, but there have been few if any studies to date exploring this topic in depth. The success of the image arrangement protocol relies on the quality of the default display [74]. This is a critical element in the implementation and clinical acceptance of a workstation. Ideally, the quality of the first displayed images should meet or exceed diagnostic standards in 95% or more of the cases, and manual adjustments should be available for cases where the default settings failed.

Image processing and manipulation tools are also very important in optimizing a clinical workstation. Again, the work in pathology is just beginning, although image manipulation software in general is much more advanced than it was when radiology went digital so the tools are much more advanced and commonplace today. However, in reviewing image processing options, the pathologist should consider the following. The user should be able to use the basic navigation tools of the interface without any training and without any prior exposure. The system should be user friendly and easy to customize. Simple menus and file managers, single mouse-click navigation, visually comfortable colors or gray scales, and an uncluttered workspace are all recommended. Customization means that images should be easily adjustable to meet personal visual preferences and interpretation patterns plus easy restoration of default values and setup.

Perceptually speaking, the quality of the default image presentation is extremely important. A substantial amount of diagnostic information is processed 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 pathologist to make correct decisions with as little unnecessary image manipulation as possible so as not to prolong viewing times. Many image acquisition devices actually preprocess the images to improve appearance before they even get to the workstation. If the preprocessing actually does what it intends, it can greatly reduce viewing times and the number of image manipulations (eg, window/level or zooming) the user needs to carry out [75,76].

The digital reading environment includes not just the display but a variety of peripheral devices as well. One of the most important is digital voice recording to report transcription or voice input into digital reporting forms. Advances in continuous voice recognition technologies [77] have been important and many, although not all [78], of the problems with the early systems have been eliminated. Voice recognition reporting systems can improve productivity by decreasing significantly report turn-around times [79]. 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 accents and those with very slow or very fast speech patterns. If too many corrections need to be made manually after the report is dictated, satisfaction will be low [78].

8. Ergonomics and human factors

The typical radiology workstation was described previously, but there are a number of other human factor issues related to the environment in which the workstation will be placed that are important. In general, the type of input device one uses with a workstation is a matter of personal preference. Some common alternatives include keyboards (typically with hot key options), mouse (with or without a scroll wheel and with various number and types of buttons), and track balls. The keys to choosing the input device relate to user comfort and task. The input device is going to be used by the pathologist for every case all day and as with any other computer interaction, the task is repetitive and continuous. The risk of carpal tunnel syndrome and other repetitive musculoskeletal injuries is not insignificant [80]. An input device should be chosen that is physically comfortable, and users should review the computer workstation user tips provided by such organizations as the Occupational Safety and Health Administration [81]. 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.

Other environmental issues that should be considered are how much heat does the workstation produce, how much noise does it produce, and what kind of ambient lighting is appropriate. Each of these factors can influence the choice of workstation configuration because they may necessitate altering the existing environment [82]. If the workstation produces too much heat, it may be necessary to improve airflow both for the computer and the pathologist. Most computer systems are fairly quiet, but fan-cooled systems are common with high-performance workstations and they do generate noise levels that might be distracting.

Noise in general can be an issue, and efforts should be made to reduce extraneous noise as much as possible. This includes “noise” generated by other clinicians in the room that are either dictating reports or holding conferences. One way to reduce noise is to install noise-reducing ceiling tiles and carpet. Installing cloth-covered room separators between workstations (slightly taller than the workstation area to promote privacy but not to the

ceiling so that airflow can be preserved) is also useful for reducing noise. If noise is still a problem after measures have been taken to reduce it, noise-canceling headphones can be considered or even piping white noise into the reading room can be used to help mask other sounds.

In radiology, it is recommended that 20 lux of ambient light be used because this is generally sufficient to avoid most reflections and still provide sufficient light for the human visual system to adapt to the surrounding environment and the displays [18]. The ambient lighting should be indirect, and backlight incandescent lights with dimmer switches rather than fluorescent are recommended. Light-colored clothing and laboratory coats can increase reflections and glare even with today's LCDs so they should be avoided if possible. The intrinsic minimum luminance of the device should not be smaller than the ambient luminance.

One potential concern with digital displays in medical imaging that has not been considered very much yet is visual fatigue (ie, computer vision syndrome) that may result from the long hours that clinicians are spending in front of a computer every day. Close work of any kind for hours on end can overwork the eyes, resulting in eyestrain (known clinically as asthenopia) [83,84]. With nonmedical computer displays, just 4 hours is sufficient to produce asthenopia [85], and there is evidence that prolonged computer use may even induce myopia in many computer users [86,87]. Oculomotor fatigue caused by close work with digital displays may add to the effects of extended workdays and aging eyes [88]. We are currently investigating the effects of visual fatigue on diagnostic accuracy in radiology, and it is likely that the results found here will apply to telepathology as the digital reading environments and requirements are quite similar.

As a first step, we are using the common objective measure of accommodation to assess visual fatigue [89]. The lens of the eye alters the refractive index of light entering the eye to focus images on the retina. It is covered by an elastic capsule whose function is to mold the shape of the lens—varying its flatness and therefore its optical power. The variation in optical power is called *accommodation*, and it occurs as the eye focuses on a close object. We measure accommodation using a device that collects refractive measurements and pupil diameter measurements as the subject fixates a series of targets at 20, 25, 33, 40, 50, 61, 91, 122, 152, and 183 cm from the subject's eye. Fig. 6 shows the early results from 4 radiologists who had their accommodation measured first thing in the morning before doing any reading and then late in the afternoon after a day of digital reading. There was a significant difference in the data as a function of time of reading (before versus after near work) and as a function of target distance. As the target progressively gets closer and closer to the readers' eyes (ie, as it simulates near work reading), the ability to accommodate gets progressively worse as well (to the left in Fig. 5). As the target gets farther away (to the right in Fig. 6) and the reader is no longer required to focus on a close target, the ability to accommodate improves. It is interesting to note that the ability to accommodate to the far targets is also worse after a day of near viewing compared to before starting to read cases. The step is to correlate the accommodation measurements with diagnostic accuracy.

9. Decision support tools

Workflow and efficiency have recently become very important issues in radiology [15] because there are more and more images being acquired without a significant increase in the number of radiologists and it likely will with pathologists in the very near future as digital images become much more prominent. In radiology, a number of computer analysis and interpretation tools have been approved by the Food and Drug Administration and are being used clinically [90–94]. Similar tools are being developed for use with virtual pathology

images and are likely to be used just as extensively to facilitate navigation through large data sets, generate “second opinion” diagnoses, and improve workflow, reader efficiency, and reader accuracy [95–98]. With respect to choosing and using computer-based decision aids, it is important to get 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 realize that there will be a learning curve associated with its use, so workflow may initially slow down but then will improve.

10. Quality control

A quality assurance program for the telepathology workstation is an important and critical part of the entire implementation. When choosing a workstation, it is necessary to understand what QC procedures have been taken by the manufacturers 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 or whether they must be purchased separately (and from whom if the vendor does not provide them). As already noted, the key device in a telepathology workstation is the display, but there are few if any standardized methods available for calibrating color displays and thus there are few if any QA/QC procedures in place for telepathology. QA/QC will be an important area of research in telepathology in the very near future.

11. Future considerations

As telepathology and pathology practices in general become entirely digital, there are several new issues that will appear and will need to be considered by the user in the selection of a workstation. Now that pathology images are digital, the field will likely experience the same sort of explosion in the development of advanced image presentation and manipulation techniques that radiology has seen in recent years. Specifically, workstation will have to handle multiscale and multimodality imaging including image fusion, 3-dimensional imaging, management of large volumetric data, standardization and integration of different imaging and computing platforms and data sources, standardization of reporting across modalities, and database integration, for example, demographics, radiology, pathology, and ambulatory. No matter what the future brings, 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.

References

1. Dunn BE, Choi H, Almagro UA, Recla DL, Krupinski EA, Weinstein RS. Routine surgical telepathology in the Department of Veterans Affairs: experience-related improvements in pathologist performance in 2200 cases. *Telemed J*. 1999; 5:323–337. [PubMed: 10908448]
2. Weinstein RS, Bloom KJ, Krupinski EA, Rozek LS. Human performance studies of the video microscopy component of a dynamic telepathology system. *Zentrabl Pathol*. 1992; 138:401.
3. Weinstein RS, Descour MR, Liang C, et al. Telepathology overview: from concept to implementation. *Hum Pathol*. 2001; 32:1283–1299. [PubMed: 11774159]
4. Steinberg DM, Ali SZ. Application of virtual microscopy to cytopathology. *Diagn Cytopathol*. 2001; 25:389–396. [PubMed: 11747236]
5. Montironi R, Thompson D, Scarpelli M, et al. Transcontinental communication and quantitative digital histopathology via the internet: with special reference to prostate neoplasia. *J Clin Pathol*. 2002; 55:452–460. [PubMed: 12037030]

6. Leinweber B, Massone C, Kodama K, et al. Teledermatopathology: a controlled study about diagnostic validity and technical requirements for digital transmission. *Am J Dermatopathol*. 2006; 28:413–416. [PubMed: 17012916]
7. Crimmins D, Crooks D, Pickles A, Morris K. Use of telepathology to provide rapid diagnosis of neurosurgical specimens. *Neurochirurgie*. 2005; 51:84–88. [PubMed: 16107083]
8. Della Mea V, Forti S, Puglisi F, et al. Telepathology using Internet multimedia electronic mail: remote consultation on gastrointestinal pathology. *J Telemed Telecare*. 1996; 2:28–34. [PubMed: 9375039]
9. Eichhorn JH, Brauns TA, Gelfand JA, Crothers BA, Wilbur DC. A novel automated screening and interpretation process for cervical cytology using the internet transmission of low-resolution images: a feasibility study. *Cancer*. 2005; 105:199–206. [PubMed: 15937917]
10. Lee ES, Kim IS, Choi JS, et al. Practical telepathology using a digital camera and the internet. *Telemed J E Health*. 2002; 8:159–165. [PubMed: 12079605]
11. Molnar B, Berczi L, Diczfazy C, et al. Digital slide and virtual microscopy based routine and telepathology evaluation of routine gastrointestinal biopsy specimens. *J Clin Pathol*. 2003; 56:433–438. [PubMed: 12783970]
12. Okada DH, Binder SW, Feletn CL, Strauss JS, Marchevsky AM. Virtual microscopy and the internet as telepathology consultation tools: diagnostic accuracy in evaluating melanocytic skin lesions. *Am J Dermatopathol*. 1999; 21:525–531. [PubMed: 10608244]
13. Singson RP, Natarajan S, Greenson JK, Marchevsky AM. Virtual microscopy and the internet as telepathology consultation tools. A study of gastrointestinal biopsy specimens. *Am J Clin Pathol*. 1999; 111:792–795. [PubMed: 10361515]
14. Strauss JS, Felten CL, Okada DH, Marchevsky AM. Virtual microscopy and public-key cryptography for internet telepathology. *J Telemed Telecare*. 1999; 5:105–110. [PubMed: 10628020]
15. Krupinski EA, Kallergi M. Choosing a radiology workstation: technical and clinical considerations. *Radiology*. 2007; 242:671–682. [PubMed: 17229874]
16. Krupinski EA. Medical image perception issues for PACS deployment. *Semin Roentgenol*. 2003; 38:231–243. [PubMed: 14513727]
17. Reiner, BI.; Siegel, EL.; Krupinski, EA. Advances in digital radiography: RSNA categorical course in diagnostic radiology physics. Oak Brook (Ill): RSNA Publications; 2003. Digital radiographic image presentation and display; p. 79-89.
18. Krupinski EA, Williams MB, Andriole K, et al. Digital radiography image quality: image processing and display. *JACR*. 2007; 4:389–400. [PubMed: 17544140]
19. Weinstein RS, Descour MR, Liang C, et al. An array microscope for ultrarapid virtual slide processing and telepathology. Design, fabrication, and validation study. *Hum Pathol*. 2004; 35:1303–1314. [PubMed: 15668886]
20. Rojo MG, Garcia GB, Mateos CP, Garcia JG, Vicente MC. Critical comparison of 31 commercially available digital slide systems in pathology. *Intl J Surg Pathol*. 2006; 14:285–305.
21. Demichelis F, Della Mea V, Forti S, Dalla PP, Beltrami CA. Digital storage of glass slides for quality assurance in histopathology and cytopathology. *J Telemed Telecare*. 2002; 8:138–142. [PubMed: 12097174]
22. Felten CL, Strauss JS, Okada DH, Marchevsky AM. Virtual microscopy: high resolution digital photomicrography as a tool for light microscopy simulation. *Hum Pathol*. 1999; 30:477–483. [PubMed: 10208472]
23. Flandrin G. Image bank, diagnostic codification and tediagnosis in hematology. *Leuk Lymph*. 1997; 25:97–104.
24. Furness PN. The use of digital images in pathology. *J Pathol*. 1997; 183:253–263. [PubMed: 9422979]
25. Molinie V, Epardeau B, Bernier M, Felgeres A, Beaufils H, Baglin AC. Low cost telepathology. *Ann de Path*. 2001; 21:361–366.
26. Vari SG, Muller G, Lerner JM, Naber RD. Telepathology and imaging spectroscopy as a new modality in histopathology. *Stud Health Tech Inform*. 1999; 68:211–216.

27. Supplement 61: JPEG 2000 Transfer Syntaxes. Rosslyn: National Electrical Manufacturers Association; 2002. DICOM Digital Imaging and Communications in Medicine (DICOM).
28. Taubman, DS.; Marcellin, MW. JPEG2000: image compression fundamentals, standards and practice. New York: Kluwer Academic Publishers; 2002.
29. Yagi Y, Gilbertson JR. Digital imaging in pathology: the case for standardization. J Telemed & Telecare. 2005; 11:109–116. [PubMed: 15901437]
30. Krishnan K, Marcellin MW, Bilgin A, Nadar MS. Efficient transmission of compressed data for remote volume visualization. IEEE Trans Med Imag. 2006; 25:1189–1199.
31. Punione J, Punys V, Punys J. Medical image compression by cosine and wavelet transforms. Stu Health Tech Inform. 2000; 77:1245–1249.
32. Sung MM, Kim HJ, Kim EK, Kwak JY, Yoo JK, Yoo HS. Clinical evaluation of JPEG2000 compression for digital mammography. IEEE Trans Nucl Sci. 2002; 49:827–832.
33. Sung MM, Kim HJ, Yoo SK, et al. Clinical evaluation of compression ratios using JPEG2000 on computed radiography chest images. J Digit Imaging. 2002; 15:78–83. [PubMed: 12297972]
34. Szot A, Jacobson FL, Munn S, et al. Diagnostic accuracy of chest x-rays acquired using a digital camera for low-cost teleradiology. Int J Med Inform. 2004; 73:65–73. [PubMed: 15036080]
35. Bernas T, Asem EK, Robinson JP, Rajwa B. Compression of fluorescence microscopy images based on the signal-to-noise estimation. Micros Res Tech. 2006; 69:1–9.
36. Ebrahimi F, Chamik M, Winkler S. JPEG vs JPEG2000: an objective comparison of image encoding quality. App Dig Imag Proc XXVII. 2004; 5558:300–308.
37. Fidler A, Likar B, Pernus F, Skaleric U. Comparative evaluation of JPEG and JPEG2000 compression in quantitative digital subtraction radiography. Dento-Maxillo-Facial Radiol. 2002; 31:379–384.
38. Johnson JP, Krupinski E, Nafziger J, Lubin J, Wus J, Roehrig H. Perceptually optimized compression of mammograms. Proc SPIE Med Img. 2002; 4686:256–262.
39. Okumura A, Suzuki J, Furukawa I, Ono S, Ashihara T. Signal analysis and compression performance evaluation of pathological microscopic slides. IEEE Trans Med Imag. 1997; 16:701–710.
40. Foran DJ, Meer PP, Papathomas T, Marsic I. Compression guidelines for diagnostic telepathology. IEEE Trans Inf Tech Biomed. 1997; 1:55–60.
41. Weinstein RS, Lopez AM, Barker GP, et al. The innovative bundling of teleradiology, telepathology, and teleoncology services. IBM Sys J. 2007; 46:69–84.
42. Brox GA, Huston JL. The application of MPEG-4 standard to telepathology images for electronic patient records. J Telemed Telecare. 2003; 9:S19–S21. [PubMed: 12952709]
43. Marcelo A, Fontelo P, Farolan M, Cualing H. Effect of image compression on telepathology. Arch Pathol Lab Med. 2000; 124:1565–1653. [PubMed: 11035602]
44. Gao M, Bridgman P, Kumar S. Computer aided prostate cancer diagnosis using image enhancement and JPEG2000. Proc SPIE Dig Imag Proc. 2003; 5203:323–334.
45. Jackson WB, Beebe P, Jared DA, Larimer JO, Gille JL, Lubin J. X-ray image system design using a human vision model. Proc SPIE Med Img. 1996; 2708:29–40.
46. Jackson WB, Said MR, Jared DA, Larimer JO, Gille JL, Lubin J. Evaluation of human vision models for predicting human-observer performance. Proc SPIE Med Img. 1997; 3036:64–73.
47. Johnson JP, Lubin J, Krupinski EA, Peterson HA, Roehrig H, Baysinger A. Visual discrimination model for digital mammography. Proc SPIE Med Img. 1999; 3663:253–263.
48. Johnson JP, Nafziger JS, Krupinski EA. Effects of grayscale window/ level parameters on lesion detectability. Proc SPIE Med Img. 2003; 5034:462–473.
49. Krupinski EA, Johnson JP, Roehrig H, Lubin J. Using a human visual system model to optimize soft-copy mammography display: influence of display phosphor. Acad Radiol. 2003; 10:161–166. [PubMed: 12583567]
50. Krupinski EA, Johnson JP, Roehrig H, Lubin J, Engstrom M. MTF correction for optimizing softcopy display of digital mammograms: use of a vision model for predicting observer performance. Proc SPIE Med Img. 2003; 5034:323–327.
51. Barrett, HH.; Myers, K. Foundations of image science. Hoboken (NJ): John Wiley & Sons; 2004.

52. Eckert MP, Bradley AP. Perceptual quality metrics applied to still image compression. *Sig Proc.* 1998; 70:177–200.
53. Eskicioglu AM, Fisher PS. Image quality measures and their performance. *IEEE Trans Commun.* 1995; 43:2959–2965.
54. Girod, B. What' wrong with mean-squared error. In: Watson, AB., editor. *Digital images and human vision*. Cambridge (Mass): MIT Press; 1993. p. 207-220.
55. Teo PC, Heeger DJ. Perceptual image distortion. *Proc SPIE.* 1994; 2179:127–141.
56. Wang J, Naghdy G. Three novel lossless image compression schemes for medical image archiving and telemedicine. *Telemed J.* 2000; 6:251–260. [PubMed: 10957738]
57. Wang, Z. PhD Dissertation. Dept ECE Univ TX Austin; 2001. Rate scalable foveated image and video communications.
58. Wang Z, Bovik AC. A universal image quality index. *IEEE Sig Proc Letters.* 2002; 9:81–84.
59. Wang Z, Bovik AC, Lu L. Why is image quality assessment so difficult. *Proc IEEE Int Conf Acoustics Speech Sig Proc.* 2002; 4:3313–3316.
60. Wang Z, Bovik AC, Sheikh HR, Simoncelli EP. Image quality assessment: from error visibility to structural similarity. *IEEE Trans Image Proc.* 2004; 13:600–612.
61. Winkler S. A perceptual distortion metric for digital color video. *Proc SPIE.* 1999; 3644:175–184.
62. [Last accessed October 10, 2008] DICOM Standard. <http://medical.nema.org/>
63. Balis UJ. Digital imaging standards and system interoperability. *Clin Lab Med.* 1997; 17:315–322. [PubMed: 9243076]
64. Chartier, TK. DICOM in dermatology. In: Wootton, R.; Oakley, A., editors. *Teledermatology*. Great Britain: The Royal Society Medicine Press; 2002. p. 205-219.
65. Krupinski EA, Tillack AA, Richter L, et al. Eye-movement study human performance using telepathology virtual slides. Implications for medical education and differences with experience. *Hum Pathol.* 2006; 37:1543–1556. [PubMed: 17129792]
66. [Last accessed October 10, 2008] DICOM-14 Digital Imaging and Communications in Medicine (DICOM), Part 14: grayscale standard display function PS 3.14-2006. <http://medical.nema.org>
67. Krupinski EA, Roehrig H. The influence of a perceptually linearized display on observer performance and visual search. *Acad Radiol.* 2000; 7:8–13. [PubMed: 10645452]
68. McNeill KM, Major J, Roehrig H, Krupinski E. Practical methods of color quality assurance for telemedicine systems. *Med Imag Tech.* 2002; 20:111–116.
69. Shepherd AJ. Calibrating screens for continuous colour displays. *Spat Vis.* 1997; 11:5774.
70. Gossieaux F. Color Calibration: which approach is right for you now? *Adv Imaging.* 1994:67–70.
71. Malacara, D. Color vision and colorimetry: theory and applications. Bellingham (Wash): SPIE Press; 2002.
72. Bass, M. Handbook of optics. Vol. Volume I. R.R. McGraw-Hill, Inc; 1995.
73. Roehrig, H.; Hareyama, K.; Kanzaki, M.; Hoddinott, A.; Hasegawa, M.; Fan, J. Local and remote QA/QC for color monitors. Yokohama, Japan: 65th Congress of the Japan Radiological Society, Cyber-RAD Exhibit, Presentation on Color Calibration Issues; 2006 Apr.
74. Moise A, Atkins S. Designing better radiology workstations: impact of two user interfaces on interpretation errors and user satisfaction. *J Digit Imaging.* 2005; 18:109–115. [PubMed: 15827830]
75. Krupinski EA, Radvany M, Levy A, et al. Enhanced visualization processing: effect on workflow. *Acad Radiol.* 2001; 8:1127–1133. [PubMed: 11721812]
76. Thrall JH. Reinventing radiology in the digital age Part II. New directions and new stakeholder value. *Radiol.* 2005; 237:15–18.
77. Langer S. Radiology speech recognition: workflow, integration, and productivity issues. *Curr Probl Diagn Radiol.* 2002; 31:95–104. [PubMed: 12140513]
78. Gutierrez AJ, Mullins ME, Novelline RA. Impact of PACS and voice-recognition reporting on the education of radiology residents. *J Digit Imag.* 2005; 18:100–108.

79. Cavagna E, Berletti R, Schiavon F, Scarsi B, Barbato G. Optimized delivery radiological reports: applying Six Sigma methodology to a radiology department. *Radiol Med*. 2003; 105:205–214. [PubMed: 12835644]
80. Ruess L, O'Connor SC, Cho KH, et al. Carpal tunnel syndrome and cubital tunnel syndrome: work-related musculoskeletal disorders in four symptomatic radiologists. *AJR Am J Roentgenol*. 2003; 181:37–42. [PubMed: 12818826]
81. OSHA. [Last accessed October 10, 2008] <http://www.osha.gov/SLTC/etools/computerworkstations/index.html>
82. Thrall JH. Reinventing radiology in the digital age Part III. Facilities, work process, and job responsibilities. *Radiol*. 2005; 237:790–793.
83. Ebenholtz, SM. Oculomotor systems and perception. New York (NY): Cambridge University Press; 2001.
84. On asthenopia or weak-sightedness. *Edinburgh J Med Surg*. 1843; 60:73–103.
85. Sanchez-Roman FR, Perez-Lucio C, Juarez-Ruiz C, Velez-Zamora NM, Jimenez-Villarruel M. Risk factors for asthenopia among computer terminal operators. *Salud Publica de Mexico*. 1996; 38:189–196. [PubMed: 8757544]
86. Komiushina TA. Physiological mechanisms of the etiology of visual fatigue during work involving visual stress. *Vestnik Oftalmologii*. 2000; 116:33–36.
87. Mutti DO, Zadnik K. Is computer use a risk factor for myopia? *J Am Optometric Assn*. 1996; 67:521–530.
88. Heron G, Charman WN, Gray LS. Accommodation responses and ageing. *Invest Ophthal Visual Sci*. 1999; 40:2872–2883. [PubMed: 10549647]
89. Krupinski EA, Johns A, Berbaum K. Measurement of visual strain in radiologists. *Proc SPIE Med Imag*. 2007; 6917:6917141–69171416.
90. Freedman M, Osicka T. Reader variability: what can we learn from computer-aided detection experiments. *J Am Coll Radiol*. 2006; 3:446–455. [PubMed: 17412100]
91. Doi K. Current status and future potential of computer-aided diagnosis in medical imaging. *Br J Radiol*. 2005; 78:S3–S19. [PubMed: 15917443]
92. Awai K, Murao K, Ozawa A, et al. Pulmonary nodules: estimation of malignancy at thin-section helical CT—effect of computer-aided diagnosis on performance of radiologists. *Radiol*. 2006; 239:276–278.
93. Li Q, Li F, Suzuki K, et al. Computer-aided diagnosis in thoracic CT. *Semin Ultrasound*. 2005; 26:357–363.
94. Horsch K, Giger ML, Vyborny CJ, Lan L, Mendelson EB, Hendrick RE. Classification of breast lesions with multimodality computer-aided diagnosis: observer study results on an independent clinical data set. *Radiol*. 2006; 240:357–368.
95. Feldman MD. Beyond morphology: whole slide imaging, computer-aided detection, and other techniques. *Arch Pathol Lab Med*. 2008; 132:758–763. [PubMed: 18466019]
96. Ficsor L, Varga VS, Tagscherer A, Tulassay Z, Molnar B. Automated classification of inflammation in colon histological sections based on digital microscopy and advanced image analysis. *J Intl Soc Anal Cytol*. 2008; 73:230–237.
97. Mete M, Xu X, Fan CY, Shafirstein G. Automatic delineation of malignancy in histopathological head and neck slides. *BMC Bioinform*. 2007; 8:S17.
98. Sharangpani GM, Joshi AS, Porter K, et al. Semi-automated imaging system to quantitate estrogen and progesterone receptor immunoreactivity in human breast cancer. *J Microsc*. 2007; 226:244–255. [PubMed: 17535263]

Fig. 1.
A typical radiology workstation. The 2 center displays (A and B) are medical-grade high-resolution displays for viewing clinical images. The display on the left (C) has the radiologists' work list of cases to be read and is also used with the speech recognition system and is used for viewing and correcting reports.

Fig. 2.

Odd-man-out paradigm for the staircase JND data collection procedure used for establishing visually lossless compression levels in virtual slides. All 4 images are the same ROI from a breast biopsy specimen. The top 2 are the original uncompressed version and serve as a reference point for knowing what the image looks like uncompressed. Two identical images are used so the observer simply has to move the eyes up and down rather than make diagonal moves to a central top image. The bottom 2 images are the test images. One of them (left in this example) is compressed and the other (right in this example) is the original uncompressed (same as the top two). The task of the observer is to decide which of the bottom 2 (2 alternative forced choice) is the different one or the “odd-man-out.” In the

staircase method, each image is shown a number of times with various compression rates. If the observer correctly detects the compressed version, the program moves up the staircase and presents an image at a lower (less visible) compression rate. If they incorrectly report the uncompressed version as being different, the staircase moves down and shows a more compressed (more visible) version. This continues up and down the staircase until the observer consistently (eg, 5 times) detects a given compression level 50% of the time (chance). This chance point is called the JND and represents the point where the compression is “visually lossless.”

Fig. 3.

Observer results on 4 selected virtual pathology slides from the 2 alternative forced choice JND study described in Fig. 1. The x-axis shows the bpp or compression rate and the y-axis shows the trial number. Lower bpp on the vertical axis correspond to higher compression levels (more visible), whereas higher bpp correspond to lower levels (less visible). Starting from the left with trial 1, the observer is shown an image with relatively obvious compression artifacts so the next presentation moving to the right goes “up” the staircase and is an image with less compression. As long as the images have noticeable compression artifacts, the staircase continues as is seen in each graph. About halfway over however, the data start fluctuating up and down as the observer starts to have trouble detecting differences (lower compression levels). Within 50 trials the observer quickly converges on the JND point. The light blue horizontal line shows the threshold for the last 5 reversals and is considered the JND point. In other words, on the first image (upper left graph), the JND is at 4.1. For image 2 (upper right), it is at 4.9.

Fig. 4.

One of the specimen (unpublished) images from the study of Krupinski et al entitled “Eye-movement study and human performance using telepathology virtual slides. Implications for medical education and differences with experience” (*HUM PATHOL.* 2006;37:1543–1556). It shows the locations marked by the pathologists (red), residents (green), and post sophomore fellows (blue) as being somewhere they would want to zoom to obtain more diagnostic information. They were told to select 3 locations for zooming. Triangles indicate the first location preferred, squares the second preferred, and circles the third preferred. The large black circles indicate common reported areas (ie, those reported by more than one person). Marks not included in a circle are sporadic marks (ie, those reported by only one person).

Fig. 5.

A bar pattern displayed on 2 color displays before (top) and after (bottom) calibration. Before calibration the sixth bar from the left in the top row (arrow) looks deep purple on the left image and pink on the right. After a simple calibration, they both look closer to purple. For pathology, color calibration such as this is important because the common stains used are pink (eosin) and purple (hematoxylin). If these colors are not rendered properly on the computer screen, it could impact the diagnostic decision process. Please see Figure 1 in the “Overview of Telepathology” paper by Weinstein et al. in this issue for an illustration in color of how color calibration is conducted.

Fig. 6. Error in accommodation measures at near and far distances for 4 radiologists before and after a day of near viewing reading from computer displays.