Small Animal Radiographic Techniques and Positioning

Section 1

Theory and Equipment

Introduction to Digital Imaging

Small animal radiography has changed dramatically in the past decade with the appearance of digital radiography in veterinary medicine. Many small animal practices that were hand developing x-ray film have taken the next step to automatic x-ray film processing due to the availability of affordable used and new tabletop x-ray film processors and faster x-ray film-screen cassette combinations. Switching to 400 speed rare earth film-screen combinations has decreased radiation exposure to technical staff and the patient, as well as improved the quality of the images due to shorter x-ray exposure times.

As digital radiography (**DR**) has become more affordable, an increasing number of small animal practices have switched from film-screen imaging to digital radiography. The list of vendors marketing veterinary digital radiographic systems is growing, so a variety of options are available from an economic perspective. Some vendors have products utilizing older digital technology; therefore it is important for small animal practitioners and their technical staff to have a basic understanding of digital radiography to assist in choosing the right digital radiographic system for their practices and also to have the needed knowledge to improve the quality of the digital radiographic images being taken.[6]

Definition and Principles of Digital Imaging

Digital imaging is simply an imaging acquisition process that generates an electronic image to be viewed and manipulated on a computer. All types of medical images are produced in a digital format including computed tomography (**CT**), ultrasound, magnetic resonance imaging (**MRI**), nuclear medicine, digital fluoroscopy, computed radiography (**CR**), and digital radiography direct and indirect capture.[4,5]

Digital Radiography

Digital radiography is a term used to reference the two main systems used in both human and veterinary medicine, computed radiography and digital (direct capture or indirect capture) radiography.[1,4,5] Digital radiography is constantly changing as improvements to this technology are being made through both software and hardware.

Digital Imaging Communications in Medicine

Digital imaging communications in medicine (**DICOM**) is the image file format that standardizes medical digital images from all imaging modalities and picture archiving and communication systems from different manufacturers. If different vendors used proprietary formats, images could not be sent to other facilities using different software to view the images. When purchasing a digital radiographic system, it is important to make sure the system comes with a DICOM conformance statement.[1,5,8] A DICOM conformance statement describes exactly how the software or device conforms to the DICOM standard. The statement follows a standard format to allow a user or vendor to determine if two devices will communicate and are compatible by comparing conformance statements.

Picture Archiving and Communication System

A picture archiving and communication system (**PACS**) provides image capture, display, annotation, archival, and communication functions allowing the images to be viewed at multiple computer workstations in a practice. Long-term storage of digital images is important because the data is part of the patient's medical record. Veterinary practices can purchase affordable small PACS to permit viewing in exams rooms and surgery. Since the image format is DICOM, there will be no problem sending the images to another practitioner or a referral facility.

There is a rather wide selection of storage device options to choose from, each differing in data access, storage capacity, and cost for both onsite and off-site storage.[7] For onsite storage, some practices just choose to use hard disk drives with a backup and invest in a web-based PACS service. Using a web-based PACS provides the small animal practitioner with the capability to permit a referral practice to view the DICOM images taken on a patient from anywhere in the world. An email can be sent to the specialty veterinary practice with the link to download the DICOM images for review, thereby allowing the specialist quick access to DICOM images. It should be noted it may take up to 24 hours before images are available for viewing on some web-based PACS services. This isn't a common problem in recent years, but it is an important question to ask when planning to purchase a contract with a web-based PACS service. Emailing images is not recommended if it is necessary to convert the DICOM image to a jpeg or tiff due to loss of detail in the image. Sending DICOM images via CD or DVD is the secondary preferred method when it is necessary to send images to a specialty practice that is not set up to accept emailed DICOM links.

Workstation Monitors

To adequately review images taken, it has been recommended to have a medical grade grayscale monitor as part of the primary display workstation, particularly in a specialty practice. This thought has been changing over the past 5 years because the newer high-end consumer grade color monitors are just as bright as their medical grade counterparts and they also have an acceptable resolution. At the 2006 Radiological Society of North America (**RSNA**) conference, Dr. David Hirshorn MD stated in a presentation that the differences in interpretation between a properly calibrated high-end consumer grade display and a medical grade grayscale display were not statistically significant.[19] Top-quality color monitors are brighter than the normal grade consumer monitor and have a brightness greater than 400–500 cd/m^2 and a contrast ratio of at least 800:1–1000:1.[19] The advantage of the medical grade grayscale monitor over the consumer grade high-quality display monitor is greater monitor stability. Thus a consumer grade monitor may be sufficient for the basic small animal practice. The choice depends upon the type of practice and the financial investment the practice can afford.

For a practitioner to visualize a digital image of similar quality to a film image necessitates the display monitor to have high spatial resolution (recorded detail).[3] For the primary display workstation utilizing a medical grade monitor, the small animal practitioner should ideally use a 2K (2MP) resolution portrait monitor. The common screen resolutions for medical display monitors are 1280 × 1024 (1K/1MP), 1600 × 1200 (2K/2MP), 2048 × 1536 (3K/3MP), and 2048 × 2560 (5K/5MP).[1,3] CR and DR images are generally best viewed on at least a 2K/2MP monitor, whereas cross-sectional images can be viewed on a 1K/1MP monitor. Radiologists generally use at least a 3K/3MP or above for reading digital images. Viewing on a 3MP monitor eliminates the need to zoom or pan the images to review all of the details in the image (Figs. 1.1a and 1.1b).

There are some basic terms that need to be defined to allow a better understanding of how these monitors work. A basic picture element is called a **pixel**. Each pixel is a set of **dot triads**. A dot triad is a grouping of one red dot, one green dot, and one blue dot. **Bit depth** is used to describe the number of bits used to store information about each pixel of

(a)   (b)
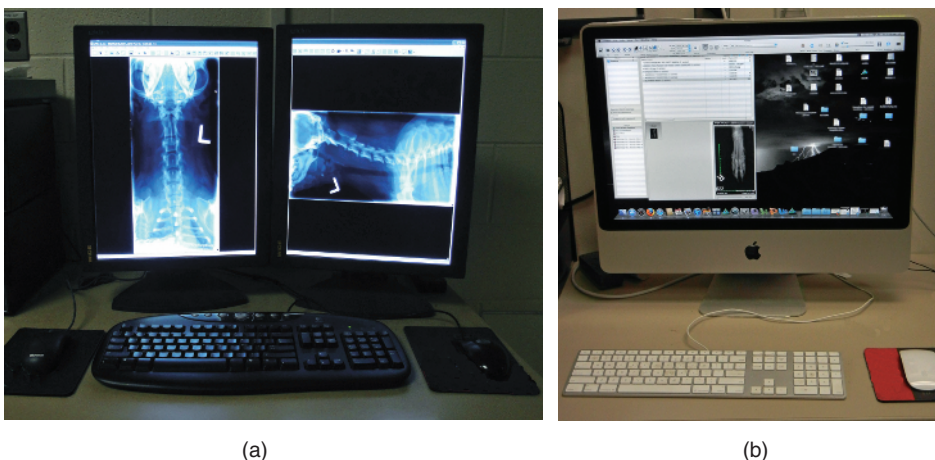
Figure 1.1   a. DR workstation with medical grade monitors. b. Mac workstation.

an image.[19] The bit depth of an image will determine how many levels of gray or color can be generated. For example, a digital camera generally has 24- to 32-bit color. Digital radiographic systems have only 10–16 bits of grayscale. So a 24-bit color system will have one-third of that for each color or 8 bits (256 shades) of each color that can be combined to produce millions of colors. To produce a shade of gray the intensity of each of the three colors must be exactly equal, which means a 24-bit color camera can only produce 256 shades (8 bits) of gray.[19] Pixels are arranged in a **matrix**, a rectangular or square table of numbers that represents the pixel intensity to be displayed on the monitor.[1] Examples are 2048×1536 and 2048×2560, the most common matrices for image viewing by a veterinary radiologist. **Dot pitch** is the measurement of how close the dots are located to one another within a pixel. The number of pixels on a monitor's display is known as its **resolution**. As the dot pitch of a display becomes smaller, resolution improves.[1] The greater the number of pixels in an image, the higher the resolution, which means more information can be displayed. Brightness or luminance refers to how bright the image appears on a display.[19] The brighter the display, the greater dynamic range produced in the image. A greater dynamic range will allow you to resolve more shades of gray in the image and is necessary to provide a full 8-bit grayscale image or 256 distinct shades of gray. If the maximum brightness of a display is inadequate, adjacent shades of gray will not be distinguishable and subtle lesions may be missed. A monitor used for primary diagnosis should be at least 400–500 cd/m^2 brightness.[19] **Contrast ratio** describes the difference between the blacks and the whites that a monitor can display. Any monitor used for primary diagnosis should have a contrast ratio of at least 1000:1, which means the black on the display is 1,000 times darker than the white on the display.[19] Another important measurement to use in choosing a monitor is its **refresh rate**. The refresh rate is the number of times an image is rewritten on the monitor each second. The refresh rate controls the flicker seen by the viewer so a high refresh rate is preferable when selecting a monitor. The most common refresh rates set on computer monitors are between 60 and 75 Hz, which means the image is refreshed 60–75 times per second. When searching for a monitor, **aspect ratio** and **viewable area** are two other terms you need to know. The aspect ratio is simply the ratio of the width to the height of the monitor. The viewable area of a monitor is determined by measuring the front of the display diagonally from one corner to the other.[1]

Viewing digital images in a proper reading environment is as important as choosing the display monitor. Digital images should be viewed in a room with a low level of ambient light. As ambient light increases, the contrast ratio decreases, which means the ability of the eye to distinguish between gray levels is best when the ambient light level of the room is close to the amount of light coming from the screen. Also, the viewer should be viewing the monitor at eye level and not looking down or up at the monitor to avoid image degradation.[19]

Monitor stability should also be considered when choosing whether to purchase a consumer grade color monitor or a medical grade grayscale display monitor. Stabilizing the luminance of the backlight(s) is essential in the monitor's ability to be calibrated and to hold the calibration. The LCD backlight will vary in luminance over time and temperature. It takes time for an LCD monitor to warm up and stabilize after being turned on. A consumer grade monitor can take over an hour to reach maximum luminance versus the medical grade monitor, which is designed to bring the backlight to its calibrated luminance very quickly, often less than a minute. A medical grade monitor set to deliver 400 cd/m^2 will reliably do so for approximately 5 years. The high brightness consumer monitors will generally have an output of 450 cd/m^2, initially, but will gradually decay to about 375

cd/m^2 in about 18 months.[19] What does this mean? The consumer grade monitor, due to its lack of stability, will only be diagnostically useful for about a third of the time of a medical grade display. But the consumer grade monitor only costs a fraction of the cost of a medical grade monitor. So if a high-quality consumer grade color display will suit the needs of the practice, it may be the best choice from an economic perspective, understanding the monitor will need to be replaced on a more frequent basis.

Regardless of the display chosen, the monitor must be regularly calibrated. It is necessary to do so because LCD monitors degrade over time. The LCD screen is illuminated by a backlight that is constantly on at full intensity. As stated earlier, the luminance of this backlight will decrease over time, due to the phosphors in the lamp wearing out. Some monitor vendors may supply test patterns, software, and sensors to perform visual tests. External hardware and sensors can also be purchased. Information for the practitioner regarding medical display acceptance testing and quality control can be found on the American Association of Physicists in Medicine (**AAPM**), Task Group 18's website, http://deckard.mc.duke.edu/~samei/tg18. Task Group 18 consists of medical imaging experts and organizational affiliates who produced the document *Assessment of Display Performance for Medical Imaging Systems*. An excellent quick resource for information regarding DR systems for veterinary medicine, including monitor calibration, can also be found at www.animalinsides.com/htm.[19]

Cathode ray tube (**CRT**) and liquid crystal display (**LCD**) are the most common types of monitors currently used in a medical setting, though plasma monitors are increasing in popularity. LCD and plasma monitors should be familiar because most of the TVs on the market today are either LCD or plasma.

CRT monitors have a cathode and an anode located within a vacuum tube that works in a similar fashion to an x-ray tube. The advantages of the CRT monitor are they are less expensive, more durable than the LCD or plasma monitors, and have better color representation and superior resolution. The aspect ratio of a CRT monitor is 4:3. The disadvantages of the CRT monitors are they take up a lot of space, are heavy, are not easily adjustable for viewing at different heights and angles, and emit heat.[1]

LCD monitors are used more and more as they have decreased in cost and increased in quality in recent years. The advantages of the LCD monitor are they take up less space, use less power than a CRT monitor, are lighter weight, produce less heat, and the surface produces little glare. The aspect ratio of an LCD monitor is 16:9. The disadvantages are they cost more than a CRT monitor and have less of a viewing angle, the display is not as bright as the CRT, and each display is only capable of working with a single physical resolution.

Plasma displays contain many small fluorescent lights that are illuminated to form the color of the image. The plasma display varies the intensities of the various light combinations to produce a full range of color. The advantages are they require a smaller frame around the display, have a wide screen with thin depth, are brighter than the LCD, can be viewed at varying angles, and are light weight. The disadvantages are the high cost and low availability.[1]

Of the three monitors, LCD monitors are used more in the PACS display market due to their size, resolution, and lack of heat production. The workstation receives images from the archive and/or from the digital radiographic system. The workstation has PACS application software that allows the practitioner to view and manipulate the image. It would depend upon the type of small animal practice, caseload, and specialty to determine if more than one primary display workstation would be needed. One primary workstation

with either a 24 inch, 2K/2MP medical grade grayscale monitor or a high-quality consumer grade color monitor with a brightness of at least $450\,cd/m^2$ with a contrast ratio of 1,000:1 placed in a low-level ambient lit viewing area of the practice may suffice the needs of the practice. Monitors used for secondary viewing in surgery or in the exam room, after the diagnosis has been made, can be consumer grade 19 or 21 inch LCD panels of lesser quality than the primary. The larger dual panels may be helpful for surgery.[19]

Computed Radiography

Computed radiography was first introduced in the early 1980s by Fuji Medical Systems. CR is a cassette-based system containing an imaging plate instead of the conventional film-screen combination. Some advantages of CR are the cassette can be used in a similar fashion to the conventional x-ray film cassette and no major alteration to the existing x-ray system is required. The CR cassette can be placed on either the tabletop or in the cassette Bucky with a grid. When used tabletop, lead strips or strict collimation can allow two separate exposures to be made on the same cassette prior to processing. Whereas an x-ray film cassette is taken to a darkroom, the film is removed, stamped with the patient's name, and then sent through an x-ray film processor, the CR cassette is placed in a machine called a reader.

When the CR cassette is placed in a reader, the reader removes the imaging plate from the cassette and scans it with a red laser in a zigzag pattern called a **raster** to release the stored electrons. As the plate travels through the reader, the laser scans across the imaging plate multiple times in a process called **translation**. This scanning process produces lines of light intensity information that are detected by a photomultiplier/charge-coupled device (**CCD**) that connects the light to an electronic signal. The signal is digitized by an analog-to-digital converter (**ADC**). The ADC assigns each picture element or pixel a numerical value that corresponds to its level of brightness and position. The entire image is divided into a matrix of pixels based on the brightness of each pixel. As the number of pixels in a matrix increases for the same field of view, the smaller the pixels have to fit into the area. The smaller the pixels are in size the greater the spatial resolution.[1,3]

Spatial resolution is defined as the amount of detail in any image. Just as the crystal size and thickness of the phosphor layer determine the resolution in film-screen radiography, the phosphor layer and pixel size determine the resolution in a CR image. The thinner the phosphor layer, the higher the resolution. The unit of measuring spatial resolution is line pairs per millimeter (**lp/mm**). An x-ray test pattern, which consists of a series of lead strips separated by equal-size interspaces, is imaged. The higher the number of line pairs visualized, the greater the spatial resolution, and the smaller the detail that can be detected in an image. Film-screen images have excellent spatial resolution, measuring 10 lp/mm.[3] CR typically has 2.55–5 lp/mm resolution, which results in less detail than a film-screen image. The loss of spatial resolution is compensated for by the increase in **contrast resolution,** which refers to the proficiency of an imaging system to distinguish between small objects or tissues having similar tissue density, like liver and spleen. Many more densities or shades of gray are recorded in CR images, which increases the contrast resolution.[1,3]

After the reading process is complete, most of the electrons return to a lower energy state, which basically removes the image from the plate. The imaging plate still should be cleared at least every 48 hours by the CR reader erasure mode to prevent a buildup of background signal. CR plates are very sensitive to background and scatter radiation. After

the CR plate has been read, the signal is sent to the computer, where it is preprocessed. The data appears on the monitor for review and is then sent to a PACS.

Direct and Indirect Conversion Radiography

Digital radiography can be a confusing term because it includes both computed and direct and indirect methods of digital image capture. The more accurate term is direct digital radiography (DDR), which is now commonly abbreviated as DR.[5] The DR panel is typically hard-wired to the image processing system and cassetteless, though very recently Carestream Health and Fuji Medical Systems have each released to market a wireless DR panel that can be used in conventional film-screen x-ray systems.

In hard-wired DR detectors, the materials used for detecting the x-ray signal and the sensors are permanently enclosed in a protective housing and referred to as a **flat-panel detector**. The flat-panel detector is comprised of a photoconductor such as amorphous selenium (**a-Se**), which changes the x-ray photons directly into an electronic signal. Silicon and CCD detectors are also included in this category, though they are older technology[1,4] (Fig. 1.2).

With the direct conversion process x-ray photons are absorbed by a photo-conducting material, such as a-SE, and converted to electrons, which are stored in thin-film transistor (**TFT**) detectors. The TFT detector is an array or grouping of small pixels with each pixel containing a photodiode. A **photodiode** is a photoelectric semiconductor device that absorbs the electrons and generates electrical charges.[5] A field-effect transistor (**FET**), which is a nonrectifying transistor, or silicon TFT, isolates each pixel element and works like a switch to send the electrical charges to the image processor.[1] The information is sent onto the data columns and read out with dedicated electronics. Silicon integrated circuits are connected to the edges of the detector matrix. Integrated circuits control the line scanning sequence on one side and low noise, high sensitivity amplifiers carry out the readout, amplification, and analog to digital conversion function on the opposite side.[1]

Indirect conversion detectors are comparable to direct detectors in that they use TFT detectors but dissimilar to direct conversion because they require a two-step process to convert to electrons and send to the image processor. With both direct and indirect

Figure 1.2. Canon DR panel tethered to be used tabletop or under table.

conversion over one million pixels can be read and converted to a composite digital image in less than 1 second.[1]

It is recommended to avoid purchasing DR systems utilizing older technology. This older technology information is being included to assist the practitioner in identifying older systems that may still be offered by some vendors. The older indirect conversion DR system is based on CCDs. A charge-coupled device is basically a semiconductor device used as an optical sensor that stores a charge and then sequentially transfers it. In this case, the x-ray photons strike a scintillation material, such as a photostimulable phosphor or a CsI scintillator, and this signal is coupled by lenses that work like cameras. These cameras reduce the size of the projected visible light image and transfer the image to one or more small CCDs that convert the light into an electrical charge. The charge is stored in a sequential pattern and released line by line and sent to an analog-to-digital converter).[1,3]

Complementary metal oxide silicon (**CMOS**) systems use specialized pixel sensors. When these sensors are struck with x-ray photons, they convert the x-rays to light photons and store them in capacitors. Each pixel has its own amplifier, which is turned off and on by circuitry within the pixel converting the light photons into electrical charges. Voltage from the amplifier is converted by an analog-to-digital converter, also located within the pixel. The system was developed by NASA and is both extremely efficient and takes up less fill space than CCDs.[1,3]

When choosing a digital radiographic system it is important to ask about the detective quantum efficiency of the detector. **Detective quantum efficiency** (**DQE**) is basically how efficiently a system converts the x-ray input signal into a useful output image.[1] DQE looks at the effects of noise and contrast on the digital image. Electronic and quantum noise are always present in digital imaging. The effect of noise is usually referred to as **signal-to-noise ratio** (**SNR**). A higher-quality image consists of more signal and less noise. So high SNR captures the most useful image information and provides a higher-quality image.

In DR, contrast refers to the system's ability to accurately reproduce an object's actual contrast. Digital detectors have a wide dynamic range so they can capture a large range of intensities. Their ability to produce high contrast resolution means they can display thousands of shades of gray that can be enhanced with automatic contrast enhancement and window/leveling parameters. The ultimate goal of a system is to have a high DQE, which allows the ability to image small low contrast objects.[1,3,4]

Direct and indirect DR detectors have an increased DQE over CR systems. In comparing direct and indirect DR, direct DR typically has the higher DQE. Indirect DR systems using the newer CMOS instead of CCDs in their panels are more comparable to the direct DR systems. Keep in mind the DQE of detectors changes with kilovoltage peak (**kVp**), but normally the DQE of selenium and phosphor-based systems is higher than for CR, CCD, and CMOS systems. Another factor that increases the DQE is the size of the area of the TFT photodiode array. The greater the size of the TFT array the greater the DQE because the more radiation detected increases the amount of signal generated.[1,3,4]

Digital Image Processing

The basic digital imaging principles and equipment have been reviewed and the veterinarian has chosen and purchased the equipment. During installation, the vendor will set up the computer software to meet the needs of the veterinary practice (Fig. 1.3).

Figure 1.3.   DR system administrator setup window.

   The vendor will need to know which direction the patient is typically placed on the radiographic table so the orientation can be set up in the computer. This will allow the Right (R) and Left (L) anatomic notation to appear correctly on the image, if the patient is placed correctly on the table. The vendor will put the name of the practice on the image and the view taken (example: VD Thorax, Oblique Mandible, or CrCD Stifle). If the practice is a specialty practice, there may be specialized views that the vendor will need to set up in the menu or additional information to be added to each displayed image.

   It is important to provide an overview of the digital imaging process once the patient is positioned on the radiographic table. Digital imaging will greatly reduce the amount of time normally needed to image a patient. For the technician, learning to use the equipment efficiently is the next step. Utilizing a DICOM modality worklist (**DICOM MWL**) will decrease the errors frequently caused by entering patient information directly into the DR system at the time the patient is to be imaged. A DICOM MWL is a bridge to the practice management software that eliminates the need for technicians to enter patient information into the DR system. If not using a DICOM worklist, it starts with entering the patient's information into the computer and selecting the correct anatomic region of interest prior to taking the exposure. It is imperative to enter complete patient identification information correctly. When a large referral practice receives images on "Charley" with no last name associated, particularly jpeg or tiff files on a CD, sent to their PACS administrator to load images onto their PACS system, it is often difficult to trace the last name, which delays the specialists' ability to view the images on their workstations. The accession number assigned to the patient when the images were taken helps the original practice to find the patient but is not helpful for the referring practice unless complete information is present. If the practice uses a DICOM modality worklist and the images are sent via an email with a DICOM link or DICOM images are sent via CD, it greatly expedites the transfer of images to the specialty practice's PACS for viewing.

   Each anatomic region has a processing algorithm specific to that region for reconstructing the image prior to it being displayed on the computer screen. A processing algorithm is simply a mathematical formula that makes adjustments to the image data so the resulting image has been properly reconstructed.[1] If doing abdominal imaging, with or without using contrast media, you must choose the abdominal algorithm and not the thorax algorithm or the image data will not be properly processed (Fig. 1.4).
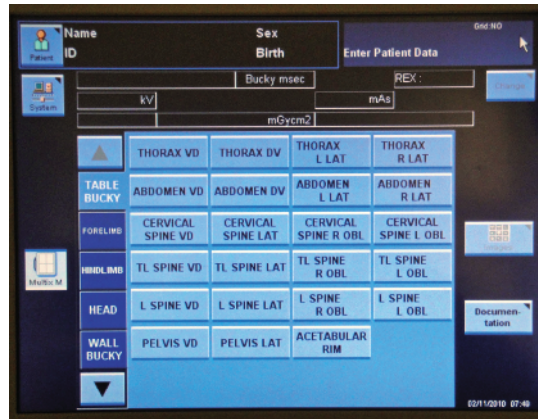
Figure 1.4. Example of anatomic region and patient data entry page in a DR system.
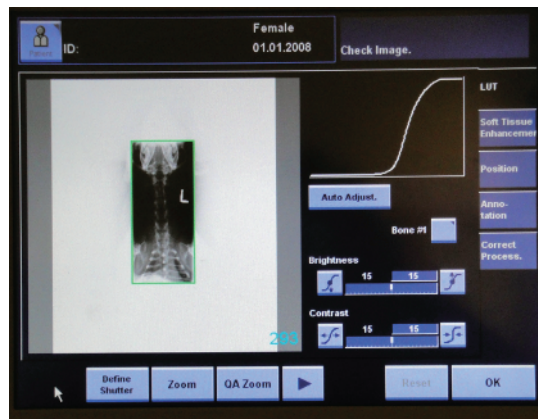

Figure 1.5. DR image review and QA adjustment page.

Prior to the image being displayed, a histogram or graph showing the distribution of pixel values for that particular image is constructed. If the histogram indicates a high or low exposure, the image brightness will automatically be adjusted to correct the error. After the histogram evaluation, a **lookup table** (**LUT**) can be used to further alter the digital image to change the image density and shades of gray to manipulate how the anatomic region of interest appears. Of course this will also alter the image's brightness and contrast. The lookup table, which is a graph, will appear as a straight line if the image is not changed. If it is changed, it will have a curve similar to that of a film-screen image. This feature is mentioned because the ability to use this function is available. Please remember any change to the digital image prior to accepting the image and sending it to the primary workstation may decrease the veterinarian's ability to manipulate the image once it goes to the workstation. It is very rare that the image should be altered in any way other than possibly changing the orientation of the image on the screen before transferring it to the primary workstation (Fig. 1.5).

Another feature is changing the orientation of the image. If the image is oriented incorrectly, it will be necessary to flip or rotate the image horizontally or vertically so it appears correctly before sending the image to the primary workstation for the veterinarian to review. There will be a function menu or tab named Position or Image Orientation on the Quality Assurance (QA) page or on a toolbar that will allow the patient orientation to be changed. Also under QA, there should also be a Zoom function to allow you to review the image prior to sending. There may be a Shuttering function that will allow post-exposure collimating. If the area of interest was not collimated well using the collimator on the x-ray tube, you will have the ability to correct this to a degree on the computer. To avoid excessive backscatter radiation and to improve the quality of the image, there is NO substitution for collimating to the area of interest with the collimator on the x-ray tube, but this feature in the QA function on the computer will help. A Region of Interest (ROI) tab is generally available, also. If on the small computer screen it appears that the anatomic part is not well visualized or too dark, using the ROI function will adjust the image to a viewable brightness level. Again this tends to happen when the milliampere seconds (mAs) and kVp are too high and the histogram could not adjust appropriately. Also using the ROI function will affect what the veterinarian can adjust once the image is sent to the primary workstation for review. Using a technique chart to choose the correct technical factors and collimating to the anatomic part appropriately should prevent the necessity of using the Shutter and ROI functions. Once all the changes are complete, send the image to the primary workstation.

CHAPTER 1