

Computed Radiography in Perspective

E. David Stearns, RVT, IDEXX Laboratories, Inc., Westbrook, Maine

Introduction

Imagine the excitement accompanying the first realization that noninvasive visualization of bones was possible. German physicist Wilhelm Conrad Roentgen was working in a darkened room on November 8, 1895, experimenting with electrical charges flowing through a vacuum tube, when a piece of paper coated with barium platinum cyanide glowed. Coincidentally, it had been left near a cardboard covered tube. Experimentation with the fluorescent paper and the charged tube followed. He discovered that if he held his hand between the tube and the paper, he could see the silhouette of hand bones on the paper.

Roentgen took full advantage of the glowing paper and on December 22, 1895, produced the oldest existing radiographic record. It shows the bones of his wife's hand with a large signet ring on one finger. Medical professionals quickly embraced this new technology. Since then many technological advances have improved radiologic diagnostic capability.

Keeping up with advancements can be difficult. A technician who stays abreast of the technology is a valuable clinic asset. This article will review film-screen radiography (FSR), discuss computed radiography (CR) in depth, introduce direct digital radiography (DDR), and contrast and compare the different systems. CR systems were introduced to the medical market in

1981. Although CR equipment acquisition cost has been relatively steady, more economically feasible systems are now available through veterinary vendors. The cost of DDR is financially impractical for most practices.



X-ray Generator

All three systems use an x-ray generator. The amount of radiation produced by this machine is regulated by adjusting controls for milliamperage (mA), exposure time in seconds (s), and kilovolt peak (kVp). Single-phase (SP) 300-mA stationary and 100-mA mobile generators have been considered standard in veterinary practice. High frequency (HF) generators are becoming more popular primarily because they produce a more constant, concentrated, and consistent source of radiation than SP units. The HF unit offers shorter exposure times and decreased potential for motion blur.

Ideally, generators should produce x-rays traveling parallel to one another and striking the film plane at right angles. But x-ray production always results in some

radiation scattering off in other directions. Filters (typically equivalent to 2.5 mm aluminum) positioned close to the x-ray source reduce this scatter and decrease patient and operator exposure. A lighted adjustable collimator is essential as it decreases scatter radiation even further.

Conventional Film Screen Radiography (FSR)

Conventional FSR relies on the use of film to record radiation after x-rays pass through the patient. Adjusting mA and exposure time influences the number of x-rays produced and the density (blackness) of the dark part of the image, but has no effect on the power or penetrating ability of the beam, hence no effect on contrast.

However, adjusting kVp influences the density and contrast of the resultant image on the film. When making technique adjustments to change contrast, while keeping the same density, it is important to maintain mAs-kVp balance. As kVp is increased, mAs must be decreased and vice versa.

Many strategies have been developed to keep radiation "as low as readily achievable" (ALARA). Radiographic film has an emulsion layer of gelatin and crystals of light-sensitive silver halide bound to plastic. Exposure to light or radiation sensitizes the silver halide crystals, forming a latent image. Large crystals have a better chance of being struck by an x-ray than small crystals and require less exposure, but because of crystal size, the image is grainy when compared to images produced on slower films with smaller crystals.

Continues

tals. Using the fastest film that will provide a diagnostic image not only decreases radiation, but also allows for faster exposures, resulting in less motion blur.

Intensifying screens further decrease the amount of radiation needed. These screens have phosphor crystals that light up when struck by x-rays. This light triggers the silver halide crystals. Screens come in a variety of types (rare earth and calcium tungstate) and speeds (ultra-speed, high-speed and the relatively slower high-detail screens). There is a trade-off though, and the highest speed screens have the least resolution. It is important to match the film spectrum with the screen and use manufacturer-provided technique charts to determine exposure.

A grid, which is a flat plate with lead foil strips separated by transparent spacers, can be positioned between the patient and the film to reduce the scatter radiation caused when the parallel traveling x-rays strike the patient's body and deflect off at odd angles. Grids are classified by the ratio of lead strip height to distance between strips and by the number of lines per inch. A typical grid used in veterinary practice is 8:1 with 103 lines per inch. More expensive grids normally have higher ratio and more lines per inch, and absorb more scatter. As an example, a 12:1 grid with 200 lines per inch which would be used to create a crisper image of higher quality, but also requires a higher dose of radiation. The use of a bucky, which is a moving grid, will prevent the appearance of grid lines. A grid is needed if the radiographed body part measures greater than 10 cm.

After exposure, the film must be developed. The sensitized silver halide crystals are reduced to black particles of metallic silver while the film is in contact with developer solution. The unaltered silver halide is removed from the film by the fixer solution. Extensive rinsing of the

fixed film is needed because remaining fixer solution will discolor the film. The development process can be carried out either manually with the chemical solutions in tubs or baths, or automatically with a processor applying the solutions and producing a ready-to-read film.

Common Causes of Image Problems

The production of diagnostic images is hampered by technical errors resulting in image problem. They can be broken down into these categories, a) detail, b) film density and c) other artifacts. Poor detail can be associated with too much or too little film density; motion of patient, machine head, or cassette; poor film-screen contact; or inappropriate film-screen combination. General causes of unacceptable film density include over and underexposure, over and underdevelopment, and film-based fogging. Common causes of exposure problems include inadequate measuring of patient, improper use of technique chart, improper focal-film distance, incorrect machine settings, and inconsistent line voltage.

Contaminated developer can cause an overall film fog. Light fogging can occur from a light leak into the film bin, cassette, or darkroom. Safelight filter cracks can also be a source of light fogging. Scatter radiation can cause fogging if the loaded cassette is left in the x-ray room while other films are exposed. Film can get fogged during storage if it becomes outdated or is exposed to scatter radiation, high temperature or high humidity.

Damaged or dirty cassettes often generate artifacts. Some common causes of nondiagnostic manually processed FSR images include air bubbles on the film, two films getting stuck together, fingerprints, rough film handling, static electric-

Definitions and Abbreviations

ACR—American College of Radiology

ALARA—as low as readily achievable

CR—computed radiography

DDR—direct digital radiography

FSR—film-screen radiography

IP—imaging plate

mR—milliroentgen

PACS—picture archiving and communication system

ity, inadequate stirring or rinsing of chemicals, incomplete fixation, and evaporated developer. Causes of nondiagnostic automatically processed FSR images include dirty or damaged processor guide shoe, improper processor venting, developer rack problems, and inadequate developer recirculation.

Computed Radiography (CR)

The term computed radiography (CR) refers to the process of creating a diagnostic digital image from data acquired with an imaging plate (IP) and reader. The CR process includes image acquisition, processing, and display. Commercial CR has been widely used in human medicine during the past decade. Recent introduction of reasonably priced CR have systems resulted in more veterinary interest. Equine practitioners led the way, taking advantage of mobile systems with the ability to acquire and view diagnostic radiographic images in the field.

CR Equipment

Essential CR equipment includes an imaging plate (IP), reader, and computer. (Figure 1) The IP is used instead of film to acquire a latent image. The reader processes the latent image and turns the resultant analog data into a digital signal. Image software provided by the manufacturer is used to manipulate data and view the image. Software programs called picture



Figure 1 Computed Radiography equipment includes an imaging plate, reader, and computer.

archiving and communication systems (PACS) are provided with some veterinary systems. PACS not only manage image processing and display, but also control data storage, retrieval and transfer. PACS are most useful when they interface with existing practice management software, allowing attachment of the image to the patient record.

The IP, which looks like a conventional intensifying screen, has a layer of crystals that can store x-ray energy. This plate is placed in a cassette, similar to the conventional FSR cassette. The acquisition of the image requires about the same amount of radiation energy as 200-speed film. Radiation energy moves electrons into a high-energy state, forming a latent image on the plate. The exposed IP is placed into the reader, which uses red laser light to scan the plate and cause latent image electrons, trapped in a high-energy state during exposure, to be released into a lower energy state and stimulate phosphorescence. Light is produced when the IP is read. In this way, the IP is similar to an intensifying screen, except that the light is produced in response to laser stimulation after exposure rather than during exposure in response to x-ray bombardment. The reader photomultiplier tube gathers the light energy, which is converted into a digital signal and sent to a computer where the image is displayed on a monitor.

Digital image quality is addressed in guidelines produced by the American

College of Radiology (ACR) (ACR Guidelines 2003). The ACR specifies that CR image capture should be digitized to at least 2.5 line pairs/mm and that images should be digitized to 10 bits/pixel or greater. Investing in a monitor with high resolution is important. The ACR recommends that display workstation gray-scale monitors have at least 50-foot lamberts for maximum luminance (ACR Guidelines 2003). The diagnosis is usually made on the monitor or the soft copy. (Figure 2) In fact, one study showed that with soft-tissue foreign bodies, detection is easier on the monitor when compared to FSR and CR hard copy (i.e. printed on film).

Copies printed on paper can benefit client education, but are not needed to make the diagnosis. There are many printer options to consider. Getting a high-

quality medical film printer may be necessary to send images to a referral veterinarian or to maintain a hard-copy record to store, but that is an expensive option. Many veterinarians are able to view digital images sent via e-mail, CD, or DVD. Most practices prefer not to maintain hard-copy records.

Although CR will not prevent all artifacts and poor image shots, it obviously prevents all film and development errors. But because CR uses a radiograph machine and its peripheral equipment (e.g., collimator, timer, bucky, and grid), artifacts associated with these tools will still occasionally occur. Grid lines that have a similar frequency (lines/inch) as the scanner may cause a wavy (moiré) pattern. Manufacturers should know which grid works best with their system. As an example, a 200-line/inch 8:1 grid works well with the IDEXX-CR™ System. Operator errors, such as using the grid technique, but forgetting to use the grid on a large-chested dog, and other operational errors can occur. Operational errors are not as critical with CR because the system is incredibly forgiving of exposure errors compared to FSR. This is because film has less exposure latitude. A 20%



Figure 2 Using CR, the diagnosis is usually made from the monitor.

Continues

underexposure of film results in a non-diagnostic image in most cases, whereas the same level of CR underexposure is easily managed by imaging software. CR latitude for overexposure is even greater.

With CR, errors made setting the machine have to be substantially out of range to require retake. A corrected overexposed image will have more detail than a normally exposed image. Correction of underexposed images boosts contrast, but causes decreased signal-to-noise ratio, resulting in decreased detail. Radiologists

and veterinarians are not as comfortable making a diagnosis from an image with less detail and may request a retake. This is especially common when they are in the early stages of making a switch from FSR to CR because film images have more detail than CR images. Studies have shown that the increased level of detail found in FSR is not necessary to make the diagnosis. Examples include FSR and CR direct comparison studies regarding production of diagnostic images of the hand and the equine stifle, in addition to detection of

soft-tissue foreign bodies and pulmonary edema. (Figure 3)

Even though it is common for retakes to be requested during the learning phase of the FSR-CR switch, it is important to keep ALARA concepts in mind. Granted, veterinary patients are not highly susceptible to the negative effects of diagnostic radiation, but technicians often restrain animals while exposures are being made and are thus prone to acquiring dangerous levels of radiation if the ALARA principle is not pursued. On the other hand, reducing exposure too far results in so much image noise and loss of detail that misdiagnosis can occur. Underexposure can decrease the detection of low-contrast objects such as lung nodules, emphasizing the need for a good technique chart. Be advised that some manufacturers use an optimum exposure index that is higher than necessary. Although time consuming, it is best to perform your own tests with the help of the CR manufacturer. Some vendors provide this service on-site with the purchase of their system, using a dosimeter to determine the radiation produced by the machine and to find the radiation necessary to get a diagnostic image of a standardized phantom. This can be compared to the ACR reference level FSR guidelines of 25 mR (milliroentgen) for a phantom PA chest film and 600 mR for an AP abdominal view. Establishment of a unique technique chart with a low-optimum exposure index is essential in the quest to find balance.

The theory that switching from FSR to CR will result in decreased retakes and hence decreased radiation exposure to staff was confirmed in a study that found the image rejection rate fell from 9.9% to 7.3% when CR and PACS systems were in place. Not only that, studies reveal certain instances in which CR use was associated with radiation dose reduction without loss of information. This reduction in dose is not always achieved in real-world



Figure 3 FSR image on the left, compared with CR image on the right. Studies have shown that the increased level of detail found on FSR is not necessary to make diagnosis.

situations, but to get radiation ALARA it is recommended to make dose measurements as part of an x-ray machine acceptance test and, if possible, to use a high frequency machine. Artifacts are more common during the initial stages of switching from FSR to CR and can be caused by operator error or malfunction of equipment (see **Table 1**).

Using PACS image processing software can clarify pathology that would be difficult or impossible to visualize using FSR. Production of more than one image from the same digital data can highlight different tissue densities and aid in diagnosis. As an example, processing a thoracic radiograph for optimal visualization of the lungs in one image and for optimal visualization of the heart in another image can be quite useful when compared side by side. (**Figure 4**) On the other hand, misuse of this software can produce artifacts that interfere with diagnosis or even contribute to misdiagnosis. Limiting the number of individuals manipulating images in post-processing and relying upon the default processing parameters set in the software will keep artifacts to a minimum. Some PACS software is programmed with unique postprocessing filters to accom-

Continues

Table 1 Artifacts

<i>Appearance</i>	<i>Cause(s)/Solution</i>
Thin white jagged wavy lines usually on the perimeter	Cracked imaging plate; Replace IP if cracks interfere with clinically important part of image
General fogging	a) Backscatter; Apply lead foil to back of cassette b) IP exposed to radiation after erasure; Repeat erasure just prior to exposure
Fogging with hint of previous image	Inadequate erasure; Increase erasure cycle time or expose IP to more intense light
Multiple images	IP double-loaded in cassette; If discovered, erase IP prior to reloading into another cassette
Fine white line(s) parallel to long dimension of film	Laser printer; Clean or replace
Fine white line(s) perpendicular to long dimension of film	Plate reader photomultiplier tube debris; Clean the light guide of the photomultiplier tube
Curvy fine white lines	Hair stuck to IP; Routine cleaning of IP
Image of back of cassette	Cassette loaded upside down; Load properly
Moiré pattern	a) Absence or malfunctioning bucky b) Use of grid with same frequency of lines as the reader's scan lines; If noted, change the grid line frequency—check with manufacturer c) Loading IP into reader with grid lines parallel to reader scan lines; Set up grid so the lines on the IP are perpendicular to the reader's scan lines



Figure 4 CR image adjusted for optimal visualization of the lungs on the left, the heart on the right.

modate for species and anatomical position using display algorithms that provide, from a single exposure, the multiple images needed to review different tissue densities.

Direct Digital Radiography (DDR)

DDR is similar to CR except that the image is acquired directly, rather than by using an IP and reader. As technology advances, these units may become feasible for veterinary practices. Although the quality has been shown to be comparable to that of CR in some studies, a recent realistic head-to-head comparison in a human hospital setting resulted in a unanimous decision by the staff to use CR as their main radiologic system.

Advantages of CR

The switch from FSR to CR requires a substantial investment, so is it worth it? There are many advantages to switching to CR that will not be fully realized until the switch has been made. High-volume practices may find that the ongoing cost of chemicals, film, processor, and other FSR maintenance is higher than the cost of the CR lease. Equine practitioners often use compact CR systems because of mobility. One currently available plate reader weighs only 35 pounds and runs on 110-volt power or can be operated from a power inverter. Combine this with a laptop and portable printer and the whole system can be taken on the road. A CR system can dramatically improve the service provided to clients. This is especially evident in mobile practices where the diagnosis and treatment can take place in one visit compared to two visits using FSR. The result is fewer telephone calls to track the client down, schedule the recheck, etc.

Elimination of darkroom and storage areas for film saves space and eliminates staff exposure to harmful chemicals. Since CR is associated with fewer artifacts and technical errors, fewer retakes are needed. As previously discussed, it is possible to evaluate multiple tissue types (e.g. soft tissue and bone or heart and lung), from one

exposure. The image can also be illustrated to identify distance or angles. CR fits with the move toward totally digital medical records. It is only a matter of time before this technology is incorporated into the majority of veterinary practices. The advances will probably mirror the computerization of clinics that has taken place in the past two to three decades as the benefits of computed radiography are realized. The bottom line is that veterinary medicine will fully embrace some form of computer digital radiography to produce diagnostic images. The investment of making this switch is significant, but once the equipment is available and the staff trained, there is potential for the system to reduce the radiation, cost and time it takes to provide diagnostic images. **TNJ**

Acknowledgment

The author thanks medical writer, Tad B. Coles, DVM, of Overland Park, Kansas for technical and writing assistance while preparing the manuscript. The author also appreciates the guidance of Jennifer Wasson, RVT and Fred Metzger, DVM, DBVP of Metzger Animal Hospital and thanks Robert Wrigley, BVSc, Dip. ACVR of Colorado State University for critical review during preparation of the manuscript.

References

American College of Radiology. 2003 ACR Practice Guidelines and Technical Standards. 2003: 415-419, 655-663. Available at: http://www.acr.org/dyna/?doc=departments/stand_accred/standards/standards.html

Barthez PY, Manwaring N, Mitelmann PH, Benoit E. Comparison of single-phase and high-frequency generators for x-ray units. *Vet Radiol Ultrasound*. 2002. Mar-Apr;43(2):118-122.

Bernhardt TM, Otto D, Reichel G, Ludwig K, Seifert S, Kropf S, Rapp-Bernhardt U. Detection of simulated interstitial lung disease and catheters with selenium, storage phosphor, and film-based radiography. *Radiology*. 1999. 213(2):445-454.

Biller DS, Goggin JM. Radiographic and ultrasonographic techniques. In: Birchard SJ, Sherding RG eds. *Saunders Manual of Small Animal Practice*. 2nd ed. Philadelphia, Pa: WB Saunders Co; 2000. 17(1):37-63.

Bindeus T, Vrba S, Gabler C, Rand T, Stanek C. Comparison of computed radiography and conventional film-screen radiography of the equine stifle. *Vet Radiol Ultrasound*. 2002. Sep-Oct;43(5):455-60.

Cesar LJ. Computed radiography: its impact on radiographers. *Radiol Technol*. 1997 Jan-Feb;68(3):225-232.

Cesar LJ, Schueler BA, Zink FE, Daly TR, Taubel JP, Jorgenson LL. Artefacts found in computed radiography. *Br J Radiol*. 2001. Feb;74(878):195-202.

Don S, Hildebolt CE, Sharp TL, Shackelford GD, Lau DM, Herman TE, McAlister WH. Computed radiography versus screen-film radiography: detection of pulmonary edema in a rabbit model that simulates neonatal pulmonary infiltrates. *Radiology*. 1999. Nov;213(2):455-60.

Fawver SDA. A tale of two CRs: hospital conducts side-by-side test. *Radiol Manage*. 2003. Mar-Apr;25(2):30-31.

Kimme-Smith C, Aberle DR, Sayre JW, Hart EM, Greaves SM, Brown K, Young DA, Deseran MD, Johnson T, Johnson SL. Effects of reduced exposure on computed radiography: comparison of nodule detection accuracy with conventional and asymmetric screen-film radiographs of a chest phantom. *Am J Roentgenol*. 1995. Aug;165(2):269-273.

Ludwig K, Link TM, Fiebich M, Renger B, Diederich S, Oelerich M, Lenzen H, Heindel W. Selenium-based digital radiography in the detection of bone lesions: preliminary experience with experimentally created defects. *Radiology*. 2000. Jul;216(1):220-224.

Peters SE, Brennan PC. Digital radiography: are the manufacturers' settings too high? Optimisation of the Kodak digital radiography system with aid of the computed radiography dose index. *Eur Radiol*. 2002. 12(9):2381-2387.

Reiner B, Siegel E, McLaurin T, Pomerantz S, Allman R, Hebel JR, Fritz S, Protopapas Z. Evaluation of soft-tissue foreign bodies: comparing conventional plain film radiography, computed radiography printed on film, and computed radiography displayed on a computer workstation. *Am J Roentgenol*. 1996. Jul;167(1):141-144.

Roberts GD. Radiographic Technical Errors. American Association of Equine Practitioners Resort Symposium Feb 4-6, Puerto Vallarta, Mexico. American Association of Equine Practitioners 2000. 73-79.

Rhodes WJ, Biery DN. History of veterinary radiology in North America. *Vet Radiol Ultrasound*. 1995. 36:427.

Swee RG, Gray JE, Beabout JW, McLeod RA, Cooper KL, Bond JR, Wenger DE. Screen-film versus computed radiography imaging of the hand: a direct comparison. *Am J Roentgenol*. 1997. Feb;168(2):539-542.

Weatherburn GC, Bryan S, West M. A comparison of image reject rates when using film, hard copy computed radiography and soft copy images on picture archiving and communication systems (PACS) workstations. *Br J Radiol*. 1999. Jul;72(859):653-660.

Wolbarst AB. Looking within: how x-ray, CT, MRI, ultrasound, and other medical images are created. Berkeley: University of California Press; 1999.