



Breakthroughs in Radiography: Computed Radiography

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ABSTRACT:

Computed radiography (CR) is a digital imaging technology and digital x-ray image management system that has been used in human and veterinary medicine since the 1980s. CR helps eliminate many of the disadvantages of traditional radiography. A storage phosphor plate collects the pattern of x-ray attenuation that is extracted by a reader, which converts the data into a digital signal. The image is stored like any computer file and can be viewed on a computer screen, transmitted electronically, or printed out on paper or transparent film, similar to x-ray film. Computer software allows manipulation of the digital image to enhance viewing.

Conventional film-intensifying screen radiography has been used for decades and has served the medical profession well. In an age of computers and digital data, it is no surprise that digital diagnostic imaging has become the standard in human medicine. Introduced in the 1980s by Fujifilm Medical Systems, computed radiography (CR) was initially limited to a few select veterinary colleges and specialty private veterinary practices because of high cost. As technology has evolved, more and more veterinary practices have replaced conventional film-screen systems with CR. Further development has led to veterinary-specific CR systems, making digital radiography more accessible than ever before. This article considers the basic principles of CR and how it may be used in modern veterinary imaging.

LIMITATIONS OF TRADITIONAL RADIOGRAPHY

Silver halide film has several limitations. It has a limited linear response to radiation,

which means that it cannot tolerate a wide range in radiation exposure without risking saturation. In some studies, that latitude limitation means some areas will be overexposed and some underexposed in the same film. In general, users must choose between good contrast and good latitude with traditional radiography^{1,2} (Figure 1).

Another disadvantage with traditional radiography is that the image cannot be adjusted once taken. Although some errors, such as positioning problems or patient movement, reduce image quality regardless of the technology, other errors have different remedies depending on the procedure used. With traditional radiography, the film is exposed and then processed and viewed. At that time, any errors in the exposure cannot be remedied. Therefore, the image must be retaken, which increases radiation exposure to the technician and patient, increases the cost of the examination, inconveniences the animal's owner, and uses additional technician and veterinarian time.

In addition, traditional radiography requires handling of film for viewing, archiving, and

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Figure 1. Comparison of a conventional film-screen radiograph and a CR film. (Courtesy of Dr. Kip Berry, Maitland, FL)

Conventional pelvic radiograph of a dog with a total right-hip prosthesis.



CR film of the same patient. Increased resolution of the fine bony trabeculae and increased edge sharpness of the bony and soft tissue structures are apparent. Note the resolution of the wire mesh of the acetabular prosthesis compared with the image at the left.

transmission to others. If a pet owner, horse owner, or another veterinarian wishes to view an image from a remote location, the image must be either copied and sent via courier or scanned before electronic transmission. Films must be stored in a physical space that is large enough to access and sort films. This is usually a separate area from the patient's other records.^{2,3}

HISTORY OF DIGITAL RADIOGRAPHY

CR is a digital imaging technology introduced in human medicine in the 1980s by Fujifilm Medical Systems. CR is a process, not a single product. It is an entire digital x-ray image management system. Its use in veterinary medicine has increased over the last decade as smaller, more affordable systems have become available. Mobile equine practitioners have been the leaders in the use of CR technology because of its advantages for mobile farm calls.^{1,2}

Digital radiography is used for both small and large animal imaging, in veterinary teaching hospitals, by spe-

cialists (including veterinary dentistry), and in large private practices. As its use increases and prices drop, more practices will use digital radiography.

TECHNOLOGY OF COMPUTED RADIOGRAPHY

CR is an indirect capture digital imaging technology, which means that plates are used to capture the image before it is transferred to a computer. CR systems for veterinary medicine use a hospital's current radiographic generator. The image is created on reusable storage phosphor imaging plates rather than film.

The storage phosphor plates are similar to intensifying screens. When exposed to x-rays, intensifying screens emit light immediately, exposing the radiographic film. In contrast, when phosphor plates are exposed to x-rays, part of the radiation energy is absorbed by electrons, which store the image temporarily. The latent image is read by scanning the imaging

Digital Imaging and Communications in Medicine

The American College of Radiology and the National Electrical Manufacturer's Association formed a joint committee to develop a global standard for Digital Imaging and Communications in Medicine (DICOM). DICOM was intended to realize the interoperability between multiple devices manufactured by different vendors (e.g., transmission of images or information, displaying of an image). DICOM's scope is diagnostic imaging.¹⁸



Figure 2. The two sizes of imaging plates available for the compact system are 8 × 10 inches and 8 × 12 inches.

plate with laser light. The electrons then return to their ground state by releasing visible light, which is detected and converted to a digital image.^{1,2}

Exposure to a bright light (including sunlight) fully de-excites the trapped electrons, erasing the stored image. The imaging plates are reusable thousands of times but are subject to physical wear and tear.²

This article focuses on CR, which is the most tested digital radiographic technology to date. Direct digital radiography (DDR; also called *direct capture digital radiography*) uses a single unit, without a separate plate and scanner. Both CR and DDR are used in human and veterinary medicine.⁴

COMPONENTS OF COMPUTED RADIOGRAPHY SYSTEMS

CR systems include hardware and software that fill several needs: radiation detection, radiographic display, and storage or archiving. A complete CR hardware system includes imaging plates, a laser light scanner (plate reader), computer, and printer. Veterinarians may use the same radiographic generator that is used for traditional radiography and the printer they normally use with their computer.⁵ There are studies from human medicine that suggest “soft copy” diagnoses (on the monitor) are equal to or better than hard copy diagnoses, although this depends on the quality of the monitor. Paper images from laser or inkjet printers are primarily client communication pieces in small animal medicine; in equine medicine, when annotated appropriately using the on-screen measurements, paper images can be used as a communication tool with veterinarians.

Several vendors offer high-quality film printers to use with CR systems. These printers produce diagnostic-quality films for on-site storage or to send to a referring

hospital or specialist. Many telemedicine services do not require hard-copy films and can support images in multiple formats.

Currently available CR systems offer a range of imaging plate sizes, although the portable systems offer only a limited number of plate sizes (Figure 2). Plate maintenance includes regular cleaning by wiping with ethanol-soaked gauze. The plates must be erased after each exposure/read cycle to eliminate the residual energy within the phosphors, which may produce ghost images. The laser scanning process deactivates only about 50% of the stored energy, so the residual must be erased before the plates are re-exposed. This can be done in conjunction with image reading in some systems. In addition, plates should be exposed to bright light at least once a week to remove any residual energy captured as they sit unused.⁶

A CR system often has its own dedicated computer. Radiographs typically require one to 10 or more megabytes of space, which can be stored on the system hard drive or a network server and on portable media such as CDs or DVDs (DVDs are now popular because of their increased storage capacity). An ideal CR system would have the computer networked to other practice computers for data transfer to other applications, such as practice management software. Veterinarians can use their own printer, in most cases, to print out hard copy (paper) images (Figure 3).

Mobile units are available that can be easily carried to a farm or on a house call. One currently available compact reader weighs 35 lb (16 kg). A laptop computer and portable printer are part of the mobile system⁵ (Figure 4).

Veterinary dentists may also use digital radiography, often with human dental equipment.⁷

Several veterinary teaching hospitals, specialist practices, and large equine practices now use Fuji CR systems. Although those systems are beyond the budget of a typical private practice, other manufacturers are now providing CR and DDR technology. Because the technology is



Figure 3. Computer hardware: monitor, keyboard, and printer.

new to veterinary medicine, there will likely be many new suppliers in the future. Some of them display their equipment in exhibit halls at major veterinary meetings.

IMAGE MANAGEMENT SOFTWARE AND IMAGE PROCESSING

The term *picture archiving and communication system* (PACS) applies to the combined hardware and software used for digital imaging. In addition to PACS created for human medical use, veterinary-specific PACS software has been developed. A PACS allows communication between computers. Some users of CR do not use PACS but instead simply use the image software provided by the manufacturer to manipulate and view the data.

Images are obtained using an available x-ray generator and the digital imaging plates.⁸ Veterinarians must develop new technique charts for their new CR system based on the manufacturer's guidelines. Because digital and screen-film have different characteristics, it cannot be assumed that the exposure techniques that work best for screen-film will be optimal for digital imaging.³

After the plate's image is transferred to the scanner, the digital images are communicated electronically to a computer. The images can be displayed on a computer screen, sent to others via email, or printed on transparent film or photo-quality or plain paper. Because of the high exposure latitude, an unprocessed digital image usually does not look the same as a film/screen radiograph. Most CR systems have built-in image processing software to enhance the diagnostic information (e.g., bone detail) in the displayed image. In the best systems, these image-processing algorithms are preset by species and view and optimized for veterinary radiography. Other systems offer the user a "tool kit" of algorithms to adjust the displayed image to pull out different degrees of detail.

Human medical CR software helps optimize the



Figure 4. Mobile CR system: laptop and printer.

image for each radiographic view. Animal and human radiographic parameters differ sufficiently enough that software parameters developed for human medical use are not immediately adaptable for veterinary use. Veterinarians should ensure that their software is customized for their specific use, whether equine or small animal imaging.

Image software should ideally allow a user to include information about the animal and client. Highlighting suspect areas and noting comments on the image can make future readings easier. Image manipulation tools include brightness, contrast, magnification, inverting black and white, edge enhancement, and cropping. Using the image-management software, images that are too light or dark can be adjusted and marginal images can be optimized. The long latitude allows brightening or darkening of an image and potentially reveals areas that would not appear on the standard radiograph (Figure 5).

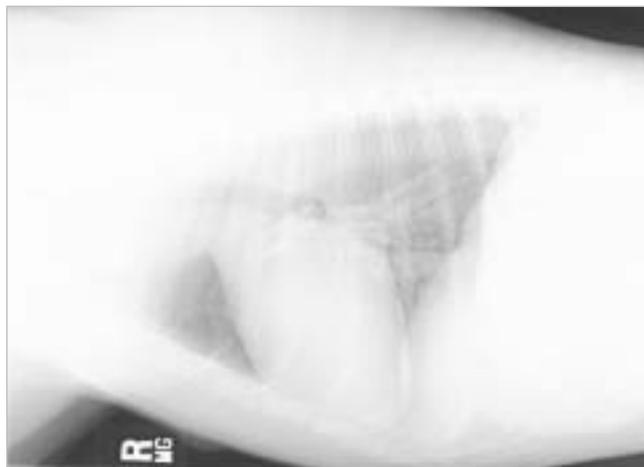
Ideally, the PACS software would interplay with a practice's medical records system. Including digital images in patient records is one step closer to an integrated medical record system.⁹

ADVANTAGES

The Images

Assuming a perfectly obtained exposure, on balance, a CR digital image is similar to that obtained with conventional radiography, with each having advantages and disadvantages.^{1,10-13} When using film, the veterinarian must choose between good contrast and good latitude. This choice is not required when using CR. There is a linear relationship in digital radiography that does not exist with film. The number of electrons trapped by x-ray exposure is linearly related to the x-ray intensity. Images from the storage phosphor plates have more exposure latitude (more shades of gray) than film images. High gray-scale resolution is desirable because it allows detection of very slight differences in radiation attenuation

Figure 5. CR thoracic images of a medium-size dog.
(Courtesy of Dr. Kip Berry, Maitland, FL)



Underexposure.



Overexposure.



Properly exposed image of the same dog after computer manipulation.

that may not be visible with film.¹ Because x-ray film has a limited linear response, a relatively small under- or overexposure may result in an unacceptable image.¹⁴

The higher contrast resolution (or exposure latitude) of CR has two consequences:

- The need for retakes resulting from over- and underexposure is reduced. Images that are too light or dark that would be discarded on film can be contrast-adjusted with the image management software. Marginal images, which would normally be read or forwarded to a specialist for a consultation, can now be optimized, increasing their diagnostic utility.
- It is possible to see both soft tissue and bone detail in a single image, reducing the total number of images that have to be taken. Although both can be seen in some standard radiographs, CR offers an advantage in larger patients. Some software packages offer special “energy subtraction” tools, which make it possible to view bone-only and soft tissue-only images from a single exposure.¹⁵

In digital radiography, the x-ray beam is converted into an electronic form that is digitized and numerically encoded into discrete picture elements (pixels). The number of pixels per unit area determines the theoretical spatial resolution of the digital image. Actual spatial resolution of the digital image is determined by the efficiency of the imaging plate and the design of the plate reader.

The spatial resolution of CR images is lower than a high-quality film image. However, much of the increased film resolution is beyond the range detectable by the human eye, and as technology advances, this difference is becoming negligible. Many studies conducted in human medicine show that CR images are equal to or better than traditional film for evaluating most body parts. Perceived image quality and the ability to visualize abnormalities depend more on software manipulation and processing of the image after it is taken than on spatial resolution. CR has been clinically validated in human medicine for over 18 years in a variety of applications, including mammography, suggesting that its minimally lower spatial resolution is not a clinical limitation.^{1,2,16,17}

The ability of the viewer to appreciate the image quality obtained with CR partially depends on the quality of the computer monitor. Likewise, the quality of paper used to print out CR images affects the quality of the image that is visualized on paper.

CR software allows an image to be not only manipulated but also measured and drawn on. For instance, heart dimensions or hip angles in a dog or hoof angles in a horse can be measured. These measurements and comments can be printed directly onto the image, and the original (clean) image can be retained as a separate file.

Time Savings

Use of CR can reduce the time it takes to see the image. A veterinarian can obtain the image—and potentially make the diagnosis—sooner, and a veterinarian and client can discuss the findings and proceed to the next step without delay.³ This is especially true for clinics with manual processing or in mobile practices. In busy practices in which images are not processed until the client has departed, obtaining an image quickly is preferable to the veterinarian calling the client on the phone and trying to convey the findings or to the client returning to the clinic to view the image. Clients may also be more willing to proceed to the next step if they do not have to reschedule and pay for an additional consultation.

often be remedied through manipulation of the image on the computer.

Image Storage and Transport

Backup copies are easier to create and store. The user can also usually export the image files in other formats (e.g., jpg, bmp, tiff) depending on the image management software. Like other computer files, these should be backed up on removable media to avoid loss or corruption of patient data.

Digital storage allows quick access and viewing. With today's demand for fast information, having access to a digital file offers veterinarians a distinct advantage over retrieving and viewing a specific film.

Digital storage allows easy transferability of images via email and easy reproduction. Veterinarians can simply print out a copy of the images for clients to take home. Equine veterinarians may want to provide copies for both the client and farrier when corrective shoeing may be necessary.

An image can be sent electronically to a specialist for further evaluation. In emergency situations, this instant consultation with a specialist could be lifesaving for the patient.

CR images can be manipulated with computer software to enhance visualization.

Practices that currently use an automatic processor may not realize the same time savings as those who are using manual development. Additionally, practices that have inefficient workflow patterns may still have those inefficiencies when they use CR.

Fewer Retakes

Retaking radiographs is common in veterinary medicine. Patient motion, improper exposure, and positioning problems all contribute to the need to retake a radiograph. At the least, these retakes require additional use of veterinarian and technician time. Other disadvantages include additional client trips to the clinic, farm visits, or house calls. The patient may have to be sedated again, and the veterinary team is exposed to additional radiation and developing chemicals.^{1,3}

Retakes are significantly reduced with digital radiography. Some, but not all, problems that cause retakes can be remedied. Specifically, problems with exposure can

Large images may need to be sent off site via file transfer protocol (FTP) or custom teleradiology systems or be converted to compressed formats (e.g., jpg) for efficient transmission. Network PACS that allow access to the database are found in larger practices or universities and can solve some problems (e.g., veterinarians can access the larger system from a remote location and view the radiographs without downloading them onto their own computer).

A digital image can be emailed to allow the veterinarian and client to view the image in follow-up calls. Likewise, images can be emailed to specialists, without the extra work of making copies.

Cost Savings

Although the overall cost of purchasing a CR system is higher than that of a film developer, there are some cost savings associated with CR, including fewer retakes. Redoing images entails the cost of equipment, supplies, time, and labor. In cases in which two tradi-

tional images would be taken to visualize bone and then soft tissue (especially in large patients or body parts), one image may suffice with CR. Savings include less labor and time of the veterinarian and technician as well as less film, developing, and storage of multiple images. For high-volume practices, the monthly cost of film, developer maintenance, and chemicals may be higher than the monthly lease of a new CR system.

Monitoring Changes

Animals with chronic or progressive disease often have sequential radiographs taken over time. Comparison of these images, including disease progression or response to treatment, is easier with CR than with traditional radiography. The images can be manipulated to have the same contrast. Although differences associated with patient mobility, phase of respiration, or poor positioning may still occur, the veterinarian can equalize the contrast and monitor differences in the sequential images that may reflect actual changes in the patient and not in the exposure technique. Mobile veterinarians in the field can easily access prior images rather than waiting to return to the clinic to make comparisons.

DISADVANTAGES

Disadvantages of using CR include making the change to a new system, the need for training, and cost. Because veterinary staff have to learn to use the new

CR system must be weighed against the benefits of using less film and chemicals and the significant benefit of increased efficiency. The cost savings of using a CR system grows over time as the number of retakes is reduced.

Some veterinarians charge more per image for CR than for traditional film radiographs. This reflects the improved service, the reduced number of films that must be taken, and client appreciation of the new technology. Both the initial costs and maintenance costs affect the purchase analysis. Cost comparisons of conventional and CR include initial capital and setup, training, and operating.

The cost of consumables in conventional radiography includes film, film jackets, fixer, developer, and disposal of toxic chemicals. CR technology eliminates those costs, although the initial cost of the CR plates is more than that of standard film cassettes.

Digital images must be backed up just like other computer files. If veterinarians want printed copies of each image, their hard-copy storage space will not be reduced.

Digital manipulation cannot make all images useful. Very poor exposure or patient movement cannot be overcome with image enhancement. Veterinarians must also be careful not to overprocess an image and create artifacts (e.g., apparent lesions) through software manipulation. Comparing the unprocessed image with the manipulated one is a way of detecting processing artifacts.

Optimal viewing of CR images requires a high-quality

The cost savings of using a CR system grow over time as the number of retakes is reduced.

software, ease of use should be an important purchase criterion. Manipulation of images takes practice and can be time-consuming at first, depending on a user's computer skills.² Because CR systems allow use of the existing radiographic generator and cassette-based methodology, staff will be comfortable with that familiar aspect of the new technology.

CR systems are costly, although their prices are falling consistently and they are affordable and economical for some high-volume practices. Direct costs include the computer hardware, software, and optional higher-quality paper for printing (images may be viewed on the monitor for reading fine detail). The initial cost of the

ity monitor and, if detailed print images are desired, a high-quality printer and laser film. Veterinarians must become accustomed to viewing films in an area other than on a view box.

CR will not compensate for poor radiographic techniques or tools or poor staff training. For example, sloppy measurements caused by broken or bent calipers or not using a grid for images of anatomic regions greater than 15 cm will have the same effect on CR images as on film/screen images. In addition, improper labeling or misidentification of patients will undermine the image storage and retrieval functions. Investment in a new CR system should include a renewed commitment to main-

taining a high level of radiography practice for all staff.

THE FUTURE OF RADIOGRAPHY

Digital imaging provides many intangible benefits that are hard to quantify. Justifications for its use include increased veterinarian efficiency, better diagnostic analysis, and timely decisions about patient care. One major intangible benefit of CR is that it can help staff recognize that radiography is not a product but a service that provides diagnostic information, including the image and written report. Increasingly, veterinarians collect, store, and transmit medical information digitally, thus providing added convenience to veterinarians and clients.

Many practitioners will wait for costs to come down before investing in digital imaging equipment. However, the integration of this technology into private veterinary practice is certain. Veterinarians will need to learn about digital radiography so that they are ready to use it when it comes to their hospital.

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