DIGITAL RADIOGRAPHY ARTIFACTS

WM TOD DROST, DAVID J. REESE, WILLIAM J. HORNOF

Radiographic artifacts may mimic a clinical feature, impair image quality, or obscure abnormalities. With the development of digital radiography (DR), a new set of artifacts is introduced. Regardless of the technology, the classic technical errors that occur with film screen radiography still occur using DR. Artifacts created using computed radiography, DR, and incorrect image processing are discussed. Methods for correction of the artifacts are presented. Veterinary Radiology & Ultrasound, Vol. 49, No. 1, Supp. 1, 2008, pp S48–S56.

Key words: computed radiography, digital radiography, image processing, radiographic image enhancement, veterinary.

Introduction

Radiographic artifacts are portions of the image that may mimic a clinical feature, impair image quality, or obscure abnormalities.1,2 With the development of digital radiography (DR), a new set of artifacts is introduced. In this article, we will discuss some of the more common artifacts encountered with the two general categories of digital radiographic systems, computed radiography (CR), which uses a photosensitive phosphor sheet to record the latent image, and DR, which produces a digital radiograph without the need for a manual processing step. DR systems can be further divided into a charge-coupled device (CCD), which uses a scintillating sheet to produce light photons in response to radiation exposure, and a camera and lens system to record the image, and a flat panel DR, which either converts radiation exposure into electric charge which is then digitized (Direct DR) or uses a scintillating layer to generate light photons and then digitizes the emitted light (Indirect DR).3 For more information about DR equipment, see the article in this Supplement.4 Regardless of the technology, the classic technical errors that occur with film screen radiography still occur when using DR.5,6 Appropriate radiographic techniques must be used. Malpositioning, patient motion, incorrect patient identification, and double exposures can all still occur.1,2,5

One of the biggest image quality advantages of DR is the linear response to radiation exposure, resulting in a wider dynamic range compared with film/screen radiography. Using a film/screen system, the response of the film to radiation exposure is sigmoid shaped with a relatively narrow range of X-ray exposure, creating a quality radiograph. At the low end of the sigmoid curve, film/screen systems do not record low levels of radiation exposure and the resultant film is white or clear. At the high end of the sigmoid curve, the resultant film is black and overexposed. Increasing the amount of radiation exposure to a film/screen system at the high end of the sigmoid curve will not result in a blacker radiograph. DR systems are much more forgiving of exposure errors than film/screen systems (Fig. 1).6,7

Look-Up Table (LUT) Errors

Radiographs are typically viewed by backlighting on a viewbox. Chemical processes make film blacker as exposure increases. Film/screen systems typically respond over about a 20-fold change in X-ray exposure. In other words, the minimum amount of exposure it takes to make the film change is about 1/20 the amount it takes to make the film totally black and unresponsive to further increases in exposure. Thus, it is all but impossible to adequately expose a lateral view of a large dog pelvis positioned with the legs separated and still visualize the soft tissues surrounding one of the stifles. Conversely, a proper exposure of the lateral stifle will underexpose the pelvis. With film/screen systems, two separate radiographs must be made at different exposures to evaluate both the stifle and the pelvis. The dynamic range of film/screen is just too narrow to accommodate such a wide range of exposures.

Digital systems (both CR and DR) have a much wider dynamic range and remain linear up to a 10,000-fold change in exposure. CCD systems usually have a slightly narrower dynamic range than CR or DR because of veiling glare in the lens system, but still exceed the dynamic range of film/screen. Thus, a digital detector used to acquire a
single lateral radiograph of the above-mentioned patient will have accurately recorded both the pelvis and the stifle. The problem that arises now is how to display such a wide range of exposure for viewing.

Radiographs are displayed by backlighting rather than printing them on paper and viewing with reflected light, because a backlit radiograph has a much wider dynamic range of brightness than printed paper (or a computer monitor). However, as stated, even the relatively wide display range of blackness on a backlit radiograph is incapable of showing us both the stifle and the pelvis on a single view. So, how then can we take advantage of the wide dynamic range of digital systems? With the radiograph (film), we use a bright light on the stifle to enhance visualization of the stifle. With digital images, we use the LUT. The LUT determines how bright individual pixel values will be displayed. The LUT is basically a curve that maps pixel values to monitor brightness. If that curve matches the response of a film/screen system to X-ray exposure, it will look exactly like a radiograph. Thus, a digital radiograph that is too light or too dark needs an adjustment in the LUT but not in the radiographic technique.

The raw data of a digital acquisition is typically 12–14 bits, but after the LUT is applied during preprocessing, most systems discard those bits beyond the display range and save only 10–12 bits for viewing and storage. Thus, application of the LUT in the preprocessing phase is potentially destructive and information can be lost. This loss is typically manifest as clipping. Digital display programs also provide the user tools to interactively adjust the LUT once it is received from the modality. These are usually

![Fig. 1. Three digital radiographs of a frozen cadaver equine carpus taken at 80 kVp and 0.3 mAs (A), 1.5 mAs (B), and 10.0 mAs (C). At this display resolution the three radiographs are identical. (Images courtesy of Dr. Sarah Puchalski)](image1)

![Fig. 2. Lateral radiograph of a dog's tibia with look-up table applied during the acquisition that caused clipping. (A) The image as presented to the viewing software. (B) After the radiograph is rewindowed using the display software. It is obvious the soft tissues were clipped and are no longer available.](image2)
called window and level or contrast and brightness, respectively. Window/contrast determines the range of pixel values that will be displayed and level/brightness determines where that range is centered over the entire range of recoded exposures. However, if the image has been clipped in the preprocessing step, no amount of adjustment by the display software can retrieve it (Fig. 2).

**Image Processing Errors**

Digital image processing is described in more detail in this supplement, but some of the common artifacts caused by image processing are discussed here. As stated previously, the wide dynamic range attainable with digital X-ray detectors far exceeds that attainable with film/screen. Un-
fortunately, the relatively narrow dynamic range of both film and computer monitors does not allow us to perceive such a wide range of exposures in a diagnostically useful manner. With film/screen, it is typical that a properly exposed radiograph of the pelvis cannot be used effectively to evaluate the stifle, often even with a bright light.

Using a digital system, to solve the dilemma of seeing both the stifle and the pelvis on a single exposure, we would need to use two different LUTs, one for the stifle that would leave the pelvis white, and one for the pelvis that would leave the stifle black. We do not need to repeat the radiograph because we can adjust the LUT (Fig. 3). But, it would be nice to view all the anatomic areas in the image at once. This can be done, but it requires image processing.

Image processing involves mathematical manipulation of the image to minimize the overall range of displayed pixel values, while maintaining high contrast. In its simplest form this involves a process called unsharp masking. This is accomplished by making a copy of the original radiograph, blurring it, and then subtracting it from the original. Using the example of the lateral view of the pelvis described above, in the blurred image, the bones will not be visible because of the blurring, but we now have an image that is black over the area of the stifle (high pixel values) (Fig. 3B) and white over the area of the pelvis (low pixel values) (Fig. 3C). When these two are subtracted, the stifle and pelvis now have pixel values that are much closer to each other, while the bones (edges) have been preserved. This accomplishes the goal of making all structures visible with a single LUT (Fig. 3D). What we are attempting to accomplish is to
remove the overall exposure differences between the stifle and the pelvis, but we do not want to alter anatomic detail. By blurring the image we only approximate this. When we approach edges like a bone/soft-tissue interface, the blurring function averages pixel values. Thus, the values along edges in the blurred image are not real. When the images are subtracted, they cause edge enhancement and the halo or the Uberschwinger artifact. Edge enhancement makes radiographs look pretty, with high contrast and edge definition, but it also destroys fine detail along sharp edges like metal implants, and accentuates noise. These negative effects are generally not visible from far, but during close inspection, as you would do in a diagnostic situation, one can reveal the halo or the Uberschwinger artifact around implants that can be mistaken for bone loss, and the objectionable effects of noise (Fig. 4).

Uberschwinger or a rebound effect appears as a radiolucent halo around metal or areas where there is a large density difference between adjacent objects (Fig. 4).\(^5,9,10\) It results from the frequency processing induced by the unsharp masking that determines the degree of edge enhancement in the final image.\(^7,10\) Uberschwinger may simulate loosening of orthopedic devices or mimic pneumothorax. To suppress the Uberschwinger artifact algorithms have been developed that effectively allow control of the entire frequency spectrum of the image. Without a lengthy or mathematical explanation, this process essentially decomposes the image into frequency bands including the higher frequency components (sharp edges and noise) and lower frequency components (overall density). The low-frequency components can then be removed and the image reassembled with minimal Uberschwinger artifact or noise enhancement.

**Exposure Artifacts**

When the receiver does not get enough X-ray input the resultant image is grainy, noisy, mottled, and pixilated.\(^2,5,11\) but because the LUT can be adjusted, the radiograph appears properly exposed. Because DR systems are more sensitive to radiation and have a wide dynamic range, severe underexposure using a DR system can result in an image, whereas using the same patient and radiographic technique on a film/screen system, an image of the patient would not even be visible. In Fig. 5, images are seen (when rewindowed) outside the collimated portion of the radiograph. In this case a breach in radiation safety was uncovered. It is tempting to interpret the underexposed portion of the radiograph because rewindowing makes that portion of the image more obvious. However, subtle radiographic findings may not be apparent in underexposed digital radiographs.\(^7\) The graininess or pixilation (Fig. 6) observed in underexposed digital radiographs comes from statistical uncertainty in adjacent pixels. This is analogous to scintigraphy where, the more counts per pixel, the better the image quality.\(^12,13\) Display size affects the appearance of a radiograph. If the display size of an underexposed radiograph is minimized, the result is several of the pixels in the original radiograph are now averaged in a single-display pixel. When the uncertainty of adjacent pixels is minimized by making the displayed size smaller, the radiograph appears much sharper. Conversely, if a slightly underexposed digital radiograph is zoomed to view individual pixels and compared with a properly exposed radiograph, the underexposed radiograph is objectionably noisy (Fig. 6). With a given film/screen system, there is a relationship between dose and detail. In general, high-detail systems require more dose than high-speed systems, and a system must be chosen for the study at hand. A high-speed system would typically be used for surveying abdomens, whereas a high-detail system would be used for surveying the spine of the same patient. With digital systems the same principle applies. Lower radiation exposure can be used for survey radiographs, but when more anatomic detail is needed, a higher dose is required.

---

**Fig. 7.** Two radiographs of a canine lumbar spine acquired from a flat panel detector system. (A) This radiograph is overexposed to the point of saturation of the detector. The midabdominal organs are not seen and the soft tissues dorsal to the spine are completely black. With this degree of overexposure, the calibration mask is visible, revealing the plank-like arrangement of the flat panel detector system. (B) A properly exposed lateral radiograph of the lumbar spine of the same dog in A.
On the opposite end of the spectrum, the wide dynamic range of digital systems permits using more photons than the minimum necessary to acquire an acceptable radiograph for a given study. However, even with the wide dynamic range of digital systems, eventually, the detector system will saturate or reach a state where it can no longer respond to additional dose. When this happens, each pixel in the overexposed area has been set to its maximum value, and the margins of structures, especially thin structures, are no longer viewable, even when one tries to rewindow the images (Fig. 7A). With CR systems, the saturated areas appear uniform, but some DR systems use a calibration mask to correct for nonuniformity in the detector, and with all pixels set to the same maximum value, the mask becomes visible. Each DR system that uses a calibration mask will typically have a characteristic pattern in the mask depending upon the construction of the panel. In some DR systems, planking or linear striations can appear in the background (Fig. 7A). To correct this artifact, the animal must be reradiographed using a lower exposure (Fig. 7B).

**Calibration Mask Errors**

If a uniform X-ray source is applied to a digital detector, the response of each pixel should be identical. However, an X-ray field is not uniform because of the heel effect and inverse square law. By acquiring a flood field with a DR detector and creating a calibration mask, the sensitivity of each pixel can be set identically. This is similar to calibration masks created to correct for camera uniformity and linearity. Using DR, the display pixel is precisely matched with the detector. The DR detector is typically mounted in the table such that the orientation of the panel is fixed relative to the tube. This process creates an excep-
tionally uniform image that compensates for heel effect and inverse square law. Using CR, this approach cannot be used because the imaging plate is separate from the detector. Each pixel of the display does not map exactly to a pixel-sized area of the CR phosphor sheet. Thus, CR systems must be designed with incredible precision to make travel of the detector through the scanning process as uniform and reproducible as possible. If one of the phosphor sheets is scratched or damaged there is no way to correct for it. Because the orientation of the CR cassette relative to the X-ray beam cannot be assured, this cannot be corrected by creating a correction matrix. CCD systems are fixed in the table and have a close match between the detector and display pixels, but because of the distance between the scintillator and the camera, slight changes in temperature can result in shifting.

Interesting artifacts occur if there is anything in the X-ray beam during the calibration process. To our knowledge, systematic characterization of calibration mask artifacts for DR systems is not reported. What are presented here are our own observations.

The calibration procedure typically requires a set of radiographs to be acquired, with the detector entirely flooded with the X-ray beam. If any object is in the X-ray beam during the calibration process, or if the X-ray beam does not reach the outside margins of the detector, it will be burned into the mask. If during the calibration procedure there is an object in the beam that is not fixed in position relative to the panel, when the object is moved, a pair of artifacts will appear (Fig. 8). One will be a negative image of the object from the mask and appears dark, whereas the other will be a radiograph of the object itself and appears lighter than the background. To illustrate this principle, a flat-panel DR system was calibrated with a piece of electrical tape stuck on the X-ray table (Fig. 8A). A flood-field radiograph was made without moving the X-ray table after calibration (Fig. 8B). No artifact was present, because the calibration mask successfully compensated for the tape. A second radiograph was made after moving the X-ray table slightly and it produced a paired black and white image of the tape (Fig. 8C). The contrast resolution of digital systems far exceeds that of film/screen systems, and in clinical situations artifacts from such things as the paint used for the crosshairs on the collimator window may show up with radiographs of small patients.

Inhomogeneous tabletops may produce stipple that was not visible using film/screen. In this situation if the tabletop cannot be replaced, the calibration procedure should either be performed with the detector on top of the table, or the table should be moved between each of the calibration exposures. If the panel is calibrated without moving the table between exposures, the pattern in the table will be burned into the mask and subsequent radiographs acquired after moving the table will have the additive effect of the negative mask image of the tabletop stipple added to the radiograph of the stipple in the new location.

Occasionally, the cause of calibration mask artifacts can be difficult to locate, but the key is recognizing the artifact as a paired black and white structure. Particularly frustrating are intermittent artifacts, like something loose inside the collimator. Virtually invisible iodinated contrast medium splashed on the collimator window can be difficult to detect, but the key to recognizing collimator contamination is that the artifacts are blurry because of penumbra (Fig. 9) whereas tabletop or debris on the panel itself are sharp.

DR systems are susceptible to radiofrequency (RF) interference. Generally, the detectors are shielded against RF interference, but if the detector is placed in close proximity to an RF source, like some automatic exposure control detectors, or if there is a break in the shielding of the detector of cables, artifacts can result (Fig. 10). In general, RF-interference artifacts have a periodic pattern, which is characteristic for the cause. RF interference can be problematic as it may be intermittent, and with portable units, may only occur in certain locations or with the detector in certain positions.

**Ghost Images**

DR systems can produce ghost images. Ghost images are analogous to the ghost images produced by certain film/screen systems because of afterglow in the scintillating screen. Once the fluorescent screen is stimulated, light is...
emitted, but the intensity of light emission decreases with
time. If the cassette is immediately processed and reloaded
with fresh film, the afterglow from the previous exposure
can be burned into the film before the next exposure.
Effectively, this same thing can happen with DR systems,
particularly those with photodiodes. Typically, the light
emitted by the scintillating layer is digitized by the photo-
diodes and a radiograph is created. However, stimulated
photodiodes trap charge, and release of that charge can
persist after the readout. This occurrence is illustrated in
an equine stifle examination, where high exposure is used
and a lead marker is placed on the detector outside the
contour of the patient. The photodiodes around the marker
receive a very high radiation exposure, whereas the pho-
todiodes beneath the marker receive little exposure. For a
short period of time after the exposure, the level of charge
retained by the photodiodes differs between the two
areas. If a subsequent exposure is made quickly, it will
then show a negative image of the lead marker (Fig. 11).

CR Artifacts

Double exposures occur when two exposures are made
using the same cassette without erasing the plate in be-
tween. The wide dynamic range of CR allows two similar-
density images to be viewed at the same time. Compared
with film/screen systems, a double exposure is not darker
than a single exposure. Double exposures are created if a
CR plate is not completely erased by the automatic plate
reader. Ghost or memory artifacts (a.k.a., selenium
memory artifacts) occur when effective saturation of the
image receptor is present. Radiation can be trapped for
several minutes in the plate. One must ensure that the cor-
rect erasure setting is employed. If the cassette has not been
used for a while, it should be erased before use. This
generally leads to fogging artifacts vs. ghost artifacts. Correcting double-exposure artifacts requires reradio-
graphing the patient.

Improper LUT assignment often leads to artifacts. The
goal of LUT assignment is to maximize the contrast in the
specific part of the image that is of interest. LUT-assign-
ment errors can lead to alterations in image contrast and
density. If the wrong region of interest is selected, the
whole image will be incorrectly displayed. Understanding
how a CR plate reader works is important for understand-
ing alterations in image contrast and density. Using an
automatic setting, a high speed, low-intensity laser initially
scans the entire plate. From this initial scan, a histogram
is generated to characterize how the energy is displayed
across this plate. Based on the histogram, density and
contrast parameters are automatically set and these pa-
rameters are then used in the final (second) reading of the
image plate. Using a semi-automatic method for scanning
a plate, the user selects a region of interest that the plate
reader will then scan and use for histogram analysis. With
the semi-automatic mode, if a person selects the
wrong region of interest, the histogram generated will not
represent the proper region. In the automatic mode, the
degree of collimation and the type of material in the image
(such as metal) may affect the histogram that is initially
generated. For instance, on a thoracic radiograph, if one
chooses a region of interest over the heart vs. a region of
interest over the lungs, two different images will be pro-
duced. Alternatively, if the user selects the wrong body area
or incorrect diagnostic specifier (e.g., thorax vs. musculo-
skeletal) before the image is made, then the plate reader
will set up a different type of histogram. For example, if
an abdomen algorithm is initially chosen, the thorax is

Fig. 12. Lateral radiograph of a canine stifle with degenerative joint
disease made using a computed radiography (CR) system. A linear
white artifact is superimposed over the head of the fibula (white arrow). A
hair, that prevented light emitted by the photosensitive phosphor plate dur-
during the reading process from reaching the detector, was found in the CR
cassette.

Fig. 13. Close-up of the cranial dorsal thorax of a dog made using a
computed radiography (CR) system. Dust or debris was present on the light
guide as the CR plate was fed through the CR reader. The resultant artifact
is a thin white line (white arrows) that spans the length of the radiograph.
imaged. Postprocessing of the thorax based on abdominal algorithm will lead to an improperly presented image. Fortunately, these artifacts can be corrected by readjusting the LUT instead of reexposing the patient to radiation.2

Too much or too little collimation may affect image quality.6 Without collimation, the image plate reader thinks the images are overexposed and selects the wrong histogram, making the image too light. With too little collimation, the plate reader thinks the image is underexposed, and makes the image dark and grainy. In the automatic mode, the plate reader usually finds the edge of the collimated view and then creates a histogram within the collimated area by defining the maximum and minimum signal in that region.1 If the collimation is not parallel to the edges of the film, the true collimated edge of the image may not be recognized, and the histogram will set incorrect sensitivity levels. This may be corrected using a semi-automated mode that sets the sensitivity based on the center of the image, assuming that the center of the image was exposed.1 Scatter radiation in the noncollimated area of the image may prevent the software from properly detecting the collimated borders.1

A light-bulb artifact is present when the outer portions of the film are darker than the remainder of the image.7 This occurs when backscatter radiation enters the periphery of photosensitive phosphor imaging plate. This artifact is seen more frequently in obese patients and when the images are not collimated. Decreasing kVp, using more precise collimation, and using lead backing on the cassette help eliminate this artifact.7

CR imaging plates have a higher sensitivity to radiation compared with X-ray films and are more susceptible to fogging.6,7 Backscatter is more frequent in CR plates because of this increase in sensitivity to radiation.16 To help avoid fogging, one should avoid extraneous radiation and/or use lead foil backing to decrease the amount of backscatter.7,16 Imaging plates must bend as they move through the CR plate reader.1,16 With repeated use, cracking can occur. These cracks usually show on the edges of the image first and do not interfere with the image. Cracks appear as linear, white artifacts.1,11,16

Foreign bodies in the cassettes occur when using CR, but not DR, because DR does not have a cassette. Any foreign body blocks light and/or radiation from reaching the photosensitive plate and creates a white artifact on the image (Fig. 12).1,6,7 If the foreign material is a liquid, it may stick to the rollers in the plate reader, and then will cause a repeating artifact. These liquids can damage the plate reader.6 Dust or debris on the light guide will lead to a white line on the image (Fig. 13).6 These artifacts can be corrected by cleaning the plate and the light guide, respectively.

Disclosure of Conflicts of Interest: The authors have declared no conflicts of interest.

REFERENCES