

# Xeroradiography in Veterinary Radiography: A Preliminary Study

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## INTRODUCTION

The imaging technic of xerography was developed by Chester F. Carlson in 1937 as a method of duplicating manuscripts (5, 9). He discovered that an electrostatic image of an object could be formed on a sensitive photoconductor surface when exposed to light. A uniform cloud of discrete particles (powder) could then be applied to the electrostatic image and the resulting "powder" image transferred to paper for a permanent image print. Experimentation with various wavelengths of light revealed that the photoconductor material was also sensitive to conventional x-rays. Hence, in xeroradiography an electrostatic latent image of an object can be formed during x-ray exposure. The latent image is comprised of varying charge densities determined by the differential absorption of the x-ray photons by the various structures in the beam path. An electrostatic charge is applied initially to a photoconductor plate of selenium. These photoconductor plates are placed in plastic cassettes which prevent light exposure. For exposure the object is placed between the plate and the anode of the x-ray tube. Once the plates are exposed to x-rays, the radiographic (xeroradiographic) print of the object can be produced in the development process. In developing the electrostatic image, the plate receives multiple bursts of colored powder (finely dispersed particles) and the resulting powder images (distribution of particles) are then transferred to paper. The final print, therefore, consists of a powder image fixed to paper by heating and subsequent hardening of a plastic based emulsion.

Xeroradiography provides good resolution, a wide range of perceptible densities, and prints in which the different densities are so well delineated that they are readily identified. Small tumor microcalcifications can be demonstrated as well as the subtle internal anatomy of adjacent soft tissue structures with very small absorptive differences (7, 8). This latter circumstance is difficult to demonstrate by conventional radiographic technics. Images of the extremities reveal exquisite soft tissue detail with en-

hancement of muscle planes, subcutaneous vasculature, individual lymph nodes and connective tissue structures (6). Each boundary of density difference in the radiographed subject is graphically demonstrated due to "edge enhancement" which will be explained subsequently. The more abrupt the change in density, the more distinct the images become. Xeroradiographs of osseous structures render remarkable detail, especially the trabecular pattern. Sharp differences in density are easily recorded as would be present with hairline fractures of bone. Subtle trauma to the soft tissues and cortical margins of bone have also been demonstrated with this technic (3). Xeroradiography has been employed in diagnosing metabolic bone disease such as the subperiosteal bone resorption in hyperparathyroidism (2). Foreign body localization is facilitated as these objects are well circumscribed in contrast to the surrounding soft tissues (4).

Xeroradiography has been applied to human radiography by other investigators (5). The process did not become practical until the late 1960's due to unreliable operation of the existing units and the higher dosage requirements required for xeroradiography compared to conventional radiography using image intensification screens. It was at this time that the xeroradiographic process was successfully utilized in the detection of breast cancer in mammography. The usefulness of xeroradiography in bone and soft tissue imaging of the extremities has also been demonstrated (6).

We felt that this imaging modality could be applied successfully in veterinary practice and our current investigative efforts have focused on its uses for diagnostic study of exotic animals.

## TECHNIC AND BASIC PRINCIPLES OF XERORADIOGRAPHY

The photoconductor material used for xeroradiography is selenium which is coated on an aluminum base plate for stability. The layer of vitreous seleni-

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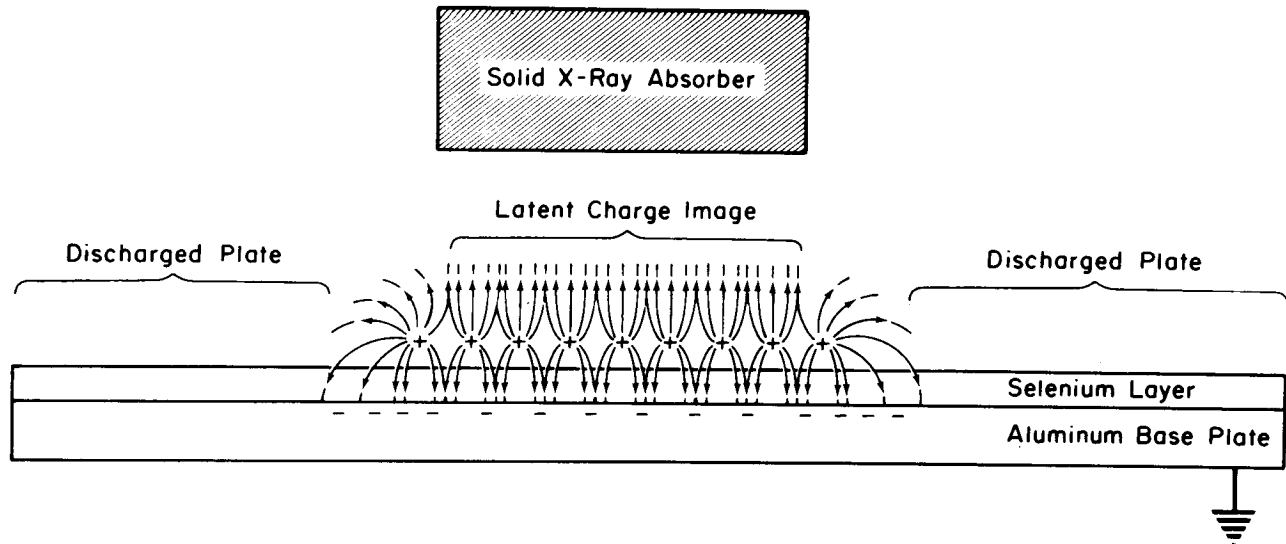


Fig. 1. Schematic Representation of Electrostatic Field. The positive charge along the surface of the selenium plate and the negative electrons in the aluminum base plate set up an electrostatic field. At the margins of the field the lines of force are not perpendicular. The fringing electrostatic fields at the margins causes attraction of additional toner particles at these interfaces. This results in enhancement of the edges and increased delineation of the margins of differences in x-ray absorption (tissue interfaces for example).

um is approximately  $130 \mu$  in depth and, as with all photoconductors, when an appropriate electrical potential is generated between its surface and an electrical ground, a positive charge will accumulate along its surface. Negative charges (electrons) accumulate in equal numbers in the metal base plate. With exposure to an outside energy source such as light or x-rays, the selenium becomes a conductor and the potential is discharged by the free flow of electrons in the selenium with loss of the positive surface charge. The latent image which is formed on the selenium surface is comprised of varying residual charge densities depending on the differential absorption of x-rays by the various structures in the radiographed specimen. Hence, the selenium surface below areas of high density, such as bone, retain proportionately greater charge potential than the surface below surrounding soft tissues (1).

The electrostatic latent image on the selenium plate is developed by dusting the plate with charged plastic toner particles which are blue in color. By controlling the charge polarity of the toner particles, a positive or negative radiographic print (xeroradiographic image) can be obtained. During the dusting process a build-up of toner particles occurs at each interface of charge density difference on the latent image due to electrostatic field effects (1).

By definition there is no flow of electrons in the electrostatic condition. The positive charge along the surface of the selenium is separated from the corresponding negatively charged electrons in the aluminum base plate by the selenium layer. Therefore, an electric field is established between the positive charge layer on the selenium surface and the elec-

trons in the aluminum plate; the lines of force are illustrated in Fig. 1. The lines of force are perpendicular to the metal plate except at the margin of the positive charge layer along the selenium surface. These fringing electric fields at the margin of the positive surface charge account for the additional attraction of negatively charged toner particles (1). Hence, extra toner powder accumulates at each margin of charge discontinuity on the selenium surface caused by the x-ray exposure. In the final radiographic image (print) each interface of density difference of the radiographed specimen is enhanced by an excess deposition of toner particles at that edge. This inherent physical property commonly referred to as "edge enhancement" accounts for the high resolution of density differences by the xeroradiographic image. Most of the information in the xeroradiographic (XR) print is derived from edge enhancement which is dependent on the abruptness of change in density of the radiographed specimen. Optical contrast of the XR print is less important in the perception of density variation than in a conventional radiograph, thus, permitting greater delineation.

Both positive and negative charged toner particles are available for development. A sorting electrode grid retards the positive or negative toner particle cloud depending on the mode setting on the control panel. In the positive mode of development, negatively charged toner particles are attracted to the electrostatic image on the selenium plate. The dense structures such as bone are dark blue while the soft tissues appear in lighter shades of blue. The negative mode of development is accomplished by allowing only positively charged particles of toner material

to reach the selenium plate. These particles are repelled by the positive surface charge and are attracted to discharged areas of the plate with the assistance of the negatively biased back plate. Therefore, areas which retain a high residual surface charge receive very little toner powder and in the final image the bones appear white while less dense structures are blue.

## MATERIALS AND METHODS

The subjects to be radiographed were selected from the population of the National Zoological Park and the Department of Animal Medicine. A number of studies were obtained in response to a definite clinical problem. Others were chosen because of some anatomical feature or arrangement which we wished to delineate.

The animals studied during clinical and experimental trial included several species of snakes and other reptiles; the radiographs were used for sexing purposes. Radiographs were made of canine hind legs following tendon and muscle injury. Angiograms were performed on domestic pigs to determine resolution of small muscular branch vessels less than 1 mm in diameter. In most instances the studies were compared with routine radiographs. These animals were exposed to radiation by a tungsten target system with a 1 mm focal spot, 40 in. focal film distance. Two methods of recording the images were utilized: (1) low intensity, high contrast technic using conventional non-screen radiographic film, and (2) xeroradiography with a Xerox 125 System.<sup>3</sup>

Our system contains two units, a conditioner and the processor. These units are separate, mobile, and do not require development chemicals since development is a dry process. The conditioner stores the selenium plates and removes the residual latent charge image from previous x-ray exposures by momentary heating of the selenium plate. When a plate is required for an x-ray exposure, a plastic cassette is placed in the conditioner and the selenium plate is automatically loaded in the cassette. Just prior to loading, the surface charge is applied to the selenium plate by an air-ion generating device. The amount of charge applied to the selenium surface can be controlled by a "thumbwheel" switch on the control panel of the conditioner. The greater the charge potential on the selenium plate the greater the contrast on the final radiographic print.

Once charged and loaded into the cassette, the plate is ready for exposure. Decay of the surface charge on the selenium plate will occur with notice-

able loss of resolution in the final image in 15–20 min if the x-ray exposure has not been completed. Hence, the subject to be radiographed must be in close proximity to the conditioner to allow adequate time for transport of the charged plates and positioning of the subject. When the exposure has been made, the cassette is placed in the processor and the selenium plate is removed automatically. The time interval between exposure and development is one half hour before the charge on the selenium plate decays in contrast to the shorter pre-exposure time intervals of 15–20 min. This may be due to a change in the physical properties of the selenium after exposure to x-rays. The charge image is developed in the processor by dusting the selenium plate with plastic toner particles. Overall density of the final radiographic print may be increased by controlling the number of toner powder bursts applied to the selenium plate. The density control is located on the processor control panel and can only be used in the negative development mode. The number of toner bursts are preset in the positive development mode regardless of the density setting on the control panel.

Once the powder image is formed on the selenium plate it is then transferred to plastic coated paper by direct contact. The residual powder on the plate is removed and the plate is moved to a storage bin. The powder image which is now on the paper is fused with the plastic coating by heating. The final print is cooled for permanent fixation and is now suitable for interpretation and storage. Malfunctions of the machine do sometimes occur; the most common include paper misdirection and obstruction during image transfer and nonuniform and inappropriate density distribution during the period of powder dispensation.

Image defects (artifacts) may occur, such as sporadic white spots throughout the radiographic print, and are referred to as powder deficient spots (PDS). They usually appear in underexposed areas out of the field of interest, but when excessive may be due to selenium plate aging and deterioration. Light prints, poor resolution, and non-uniform density of the images may also occur with aging of the selenium. Plate "fatigue" is variable depending on use, but most plates will give good service and provide diagnostically acceptable images for about six months. The selenium layer is very sensitive to any form of mechanical abrasion and should not be handled unless the plate is covered. Permanent artifacts may occur due to fingerprint marks on the selenium plates. The plastic cassettes contain a ground electrode which, when in close proximity to the charged selenium layer, may cause a discharge. This occurs when too much pressure is applied to the plastic cassette during positioning. The discharge artifact is a

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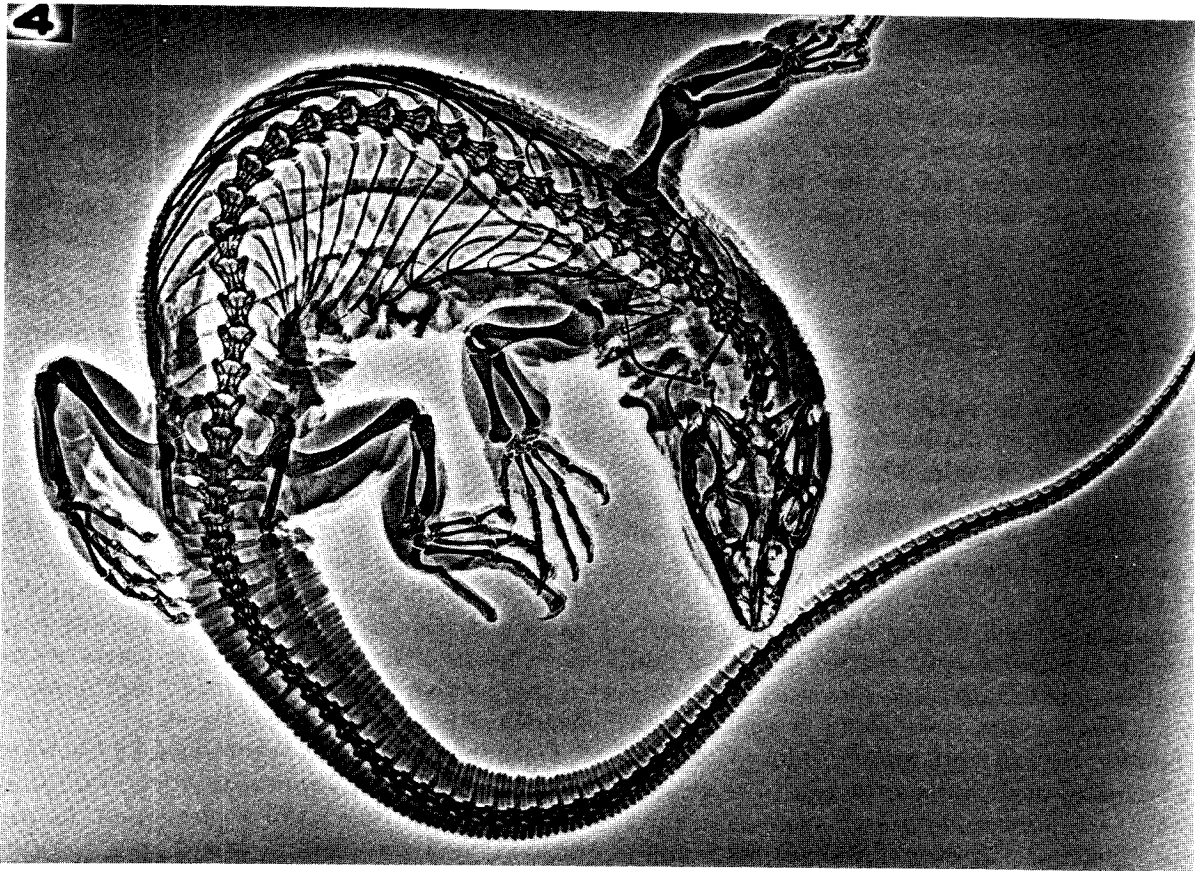


Fig. 2. Xeroradiograph of a Monitor lizard. With a single exposure the integument, internal organs, and osseous structures are well delineated yet represent a large range of density differences.

large irregular, white area in the positive mode and blue in the negative mode.

## RESULTS

Xeroradiographs in general provide exceptional resolution of the anatomical structures in the radiographed specimens. The high quality line rendition of the body structures also makes perception of small density differences possible and are aesthetically pleasing. Figure 2 is a xeroradiograph of a lizard. The integument as well as epidermal scales are easily recognized. The appendicular musculature is readily discernible and individual muscle groups can be outlined. Tendons can be visualized even to their insertions and the periarticular connective tissue is also delineated. The axial and appendicular skeleton is demonstrated in graphic detail with remarkable visualization of the trabecular pattern, bony protuberances, and joints. Subcutaneous structures were not well delineated in the smaller specimens, but the subcutaneous connective tissue supports and small vessels are seen in the larger animal subjects such as the dog (*Canis familiaris*). Hair, feathers, and other skin

derivatives were also demonstrated in other animal specimens.

In contrast to the xeroradiographic images, conventional radiographs lack the high quality resolution of soft tissue interfaces. Although skin and subcutaneous structures can be delineated with proper conventional radiographic technique, the denser muscle bundles and osseous structures tend to be underexposed if the technical factors are oriented to the soft tissues. While very good bony detail can be obtained using non-screen film, the proper exposure technique for osseous radiology precludes adequate visualization of the skin and subcutaneous layers. The muscle groups, however, appear less well delineated regardless of conventional technique when compared to the xeroradiographs. The angiogram (Fig. 3) demonstrates remarkable small vessel detail and high order branching of the muscular vessels. Images of the snakes for sexing purposes show the male hemipenis in such detail as to leave no doubt about properly matching snakes for mating purposes (Figs. 4A, B). The muscle and tendon injuries to the hind leg of the dog are also easily detectable, especially the subtle achilles tendon disruption near its insertion (Figs. 5A, B, C). Again, the major virtues of this technic

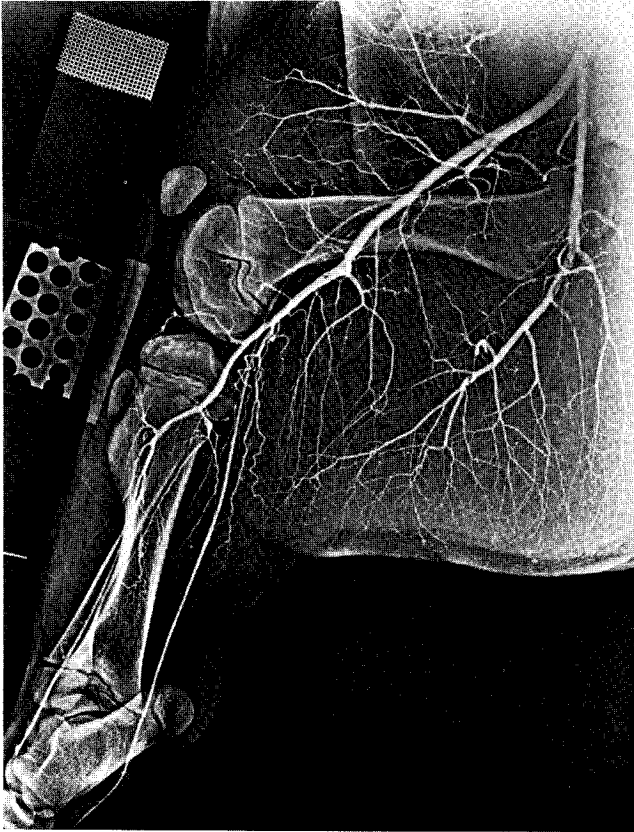


Fig. 3. Angiogram of the hind limb of pig. Contrast medium fills small arterial branches which are well delineated by this technic.

are the improved inherent contrast and delineation of soft tissue differences in density.

## DISCUSSION

The physical properties of xeroradiography provide very unique imaging qualities. Edge enhancement of tissue interfaces accounts for the high quality resolution of the xeroradiographic images. The technical latitude is remarkably wide in xeroradiography and adequate images are obtained even when the exposure factors are far from optimal. In high contrast, low intensity conventional radiography, small errors in exposure lead to radiographs that do not contain enough structural information to be diagnostically acceptable.

Good contrast is maintained as long as the exposure remains within the slope of the H and D curve, an expression of the response characteristics of these two imaging modalities. The H and D curve is simply a plot of the density variations of radiographic film or a xeroradiographic print *versus* the log relative exposure required to produce it. The slope of the H and D curve for radiographic film is very steep using conventional high contrast technic; therefore, small errors in exposure places the density difference (contrast) on the "toe" or "shoulder" of the curve.

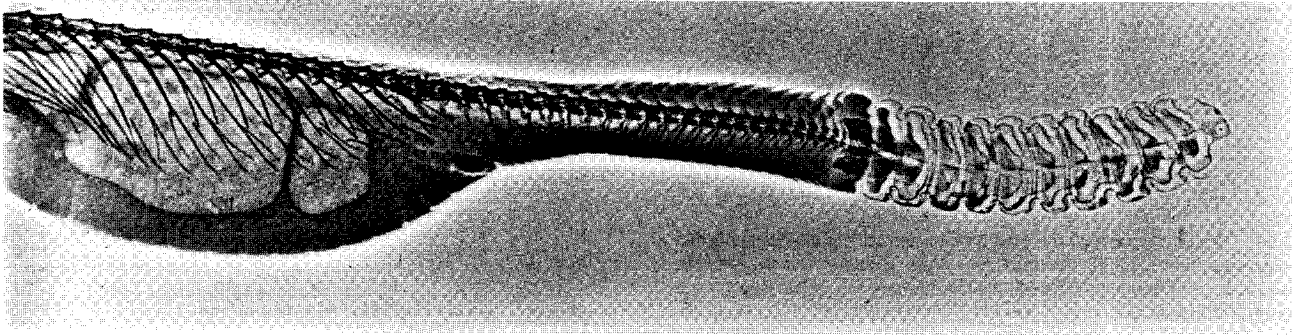


Fig. 4A. Xeroradiograph of female rattlesnake. Bowel is well seen. No definite calcifications or sexual organs are seen.

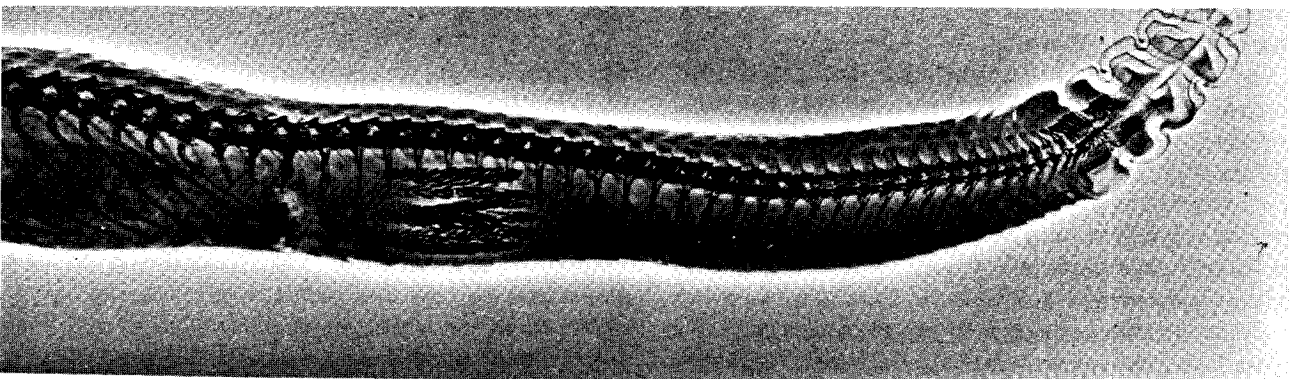


Fig. 4B. Xeroradiograph of male rattlesnake. Dense "brush-like" organs are seen in the ventral soft tissue. These structures lie just lateral to the hemipenis and assist in the act of copulation.

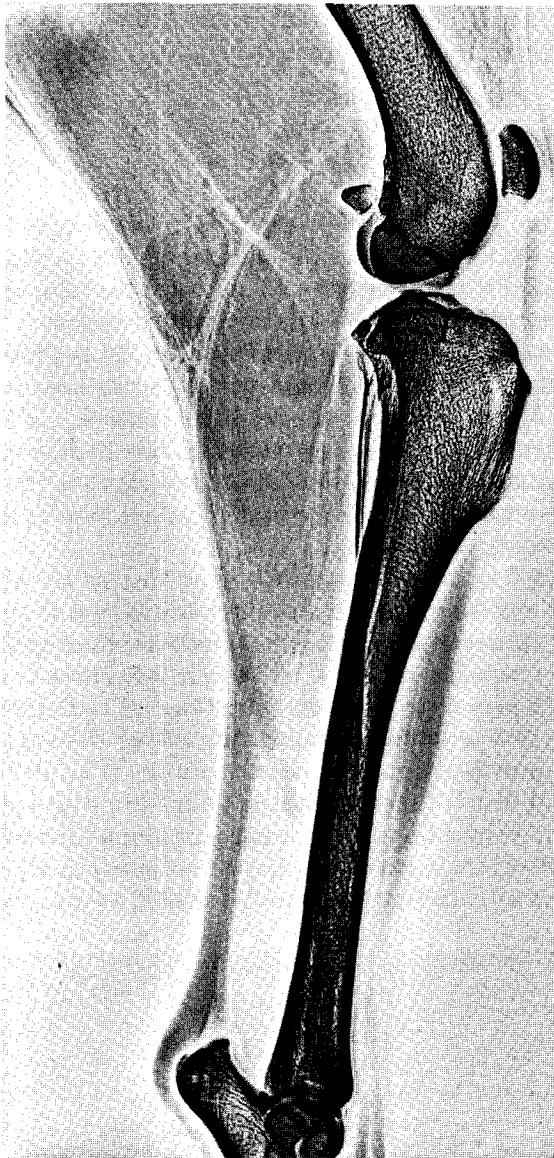


Fig. 5A. Xeroradiograph of the hind limb of normal dog (*Canis familiaris*). The achilles tendon is well delineated as a linear structure inserting into the calcaneus. The interface between the tendon and the underlying fat is a smooth well defined line.

Since the exposure latitude is very wide in xeroradiography, large variations in exposure often do not alter contrast significantly.

The high contrast conventional radiograph provides a very narrow range of perceptible densities; therefore, when relatively radiopaque structures are well imaged, the surrounding relatively radiolucent structures are overexposed and not well depicted. In xeroradiography a long scale of contrast exists, and the images provide detail of both radiodense and radiolucent structures on the same radiographic print. To illustrate this point, a step wedge comparison of a xeroradiographic and a conventional radiograph with identical exposure settings shows that more density variations are perceived on the xeroradiograph (Fig.

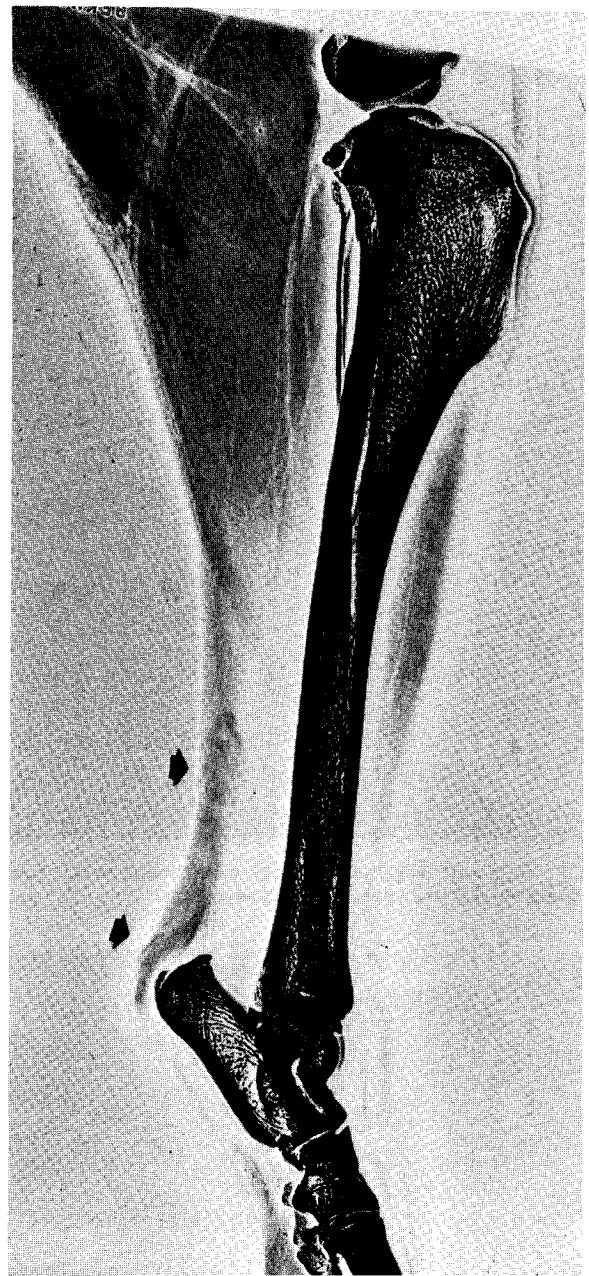


Fig. 5B. Xeroradiograph following trauma to the achilles tendon. The tendon is thickened (arrows) and the interface between the fat and tendon is irregular and indistinct.

6). In addition, the present system for processing and developing the selenium plates is simple, flexible, and does not include the problems of wet processing.

Our current project has dealt with the feasibility of xeroradiography in imaging anatomical structures of animals. The superior visual rendition of body structures by this new radiographic imaging system offers many areas of potential use such as soft tissue injury and neoplasms. Several ongoing projects which include study of fracture healing in avian species, specimen radiography, and microangiogra-

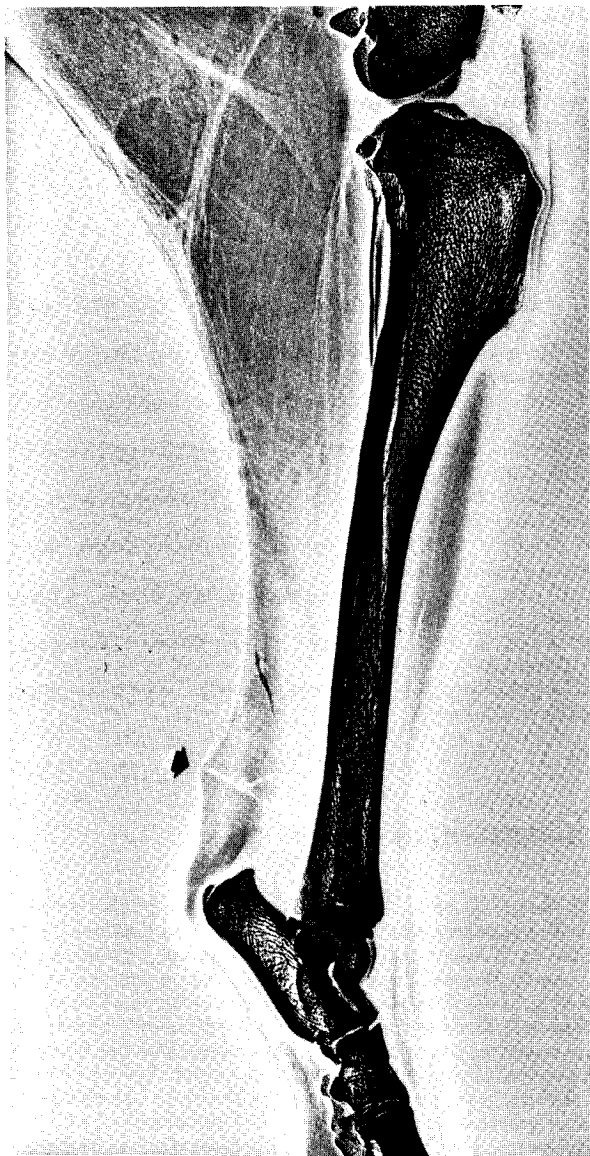


Fig. 5C. Xeroradiograph after rupture of the achilles tendon. In the area of greatest soft tissue swelling (arrow) a linear radiolucent branching line is seen.

phy may demonstrate the increased value of this diagnostic modality when compared with conventional radiography.

The mechanism of fracture healing is well documented in mammals both radiographically and histologically. The pneumatized bone in birds presents unique problems when it fractures. The detail provided by xeroradiography can greatly enhance the visualization of soft tissue components of the injury and skeletal changes that occur during repair. Standard imaging technics have been uniformly unsuccessful in demonstrating avian tuberculosis which is a slowly developing contagious disease. The use of high resolution xeroradiographs may allow early diagnosis which is of utmost importance in control of this disease. Other lung parenchymal problems may

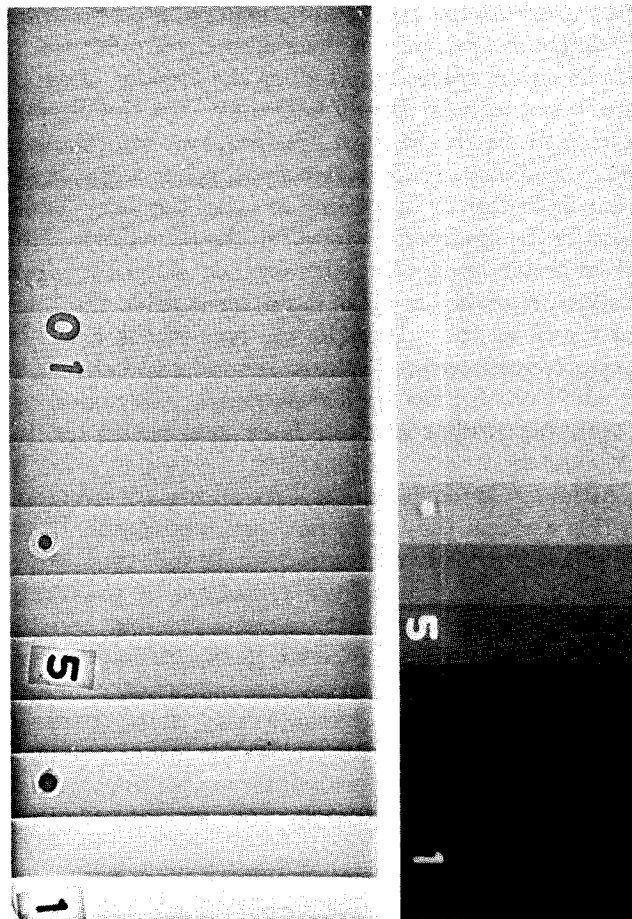


Fig. 6. Step wedge phantom imaged by conventional radiograph and xeroradiograph. In the xeroradiograph (left) a greater number of steps are seen showing greater latitude of density rendition than on the conventional radiograph (right).

be diagnosed early due to the delineation of the vessel wall-air interface.

Successful propagation programs in reptilian collections requires proper pairing of individuals. The use of high detail radiographs allows documentation of the hemipenis in many reptiles and lizards an area poorly demonstrated by conventional radiographs and difficult to impossible to demonstrate by routine physical examination. Soft tissue neoplasms may be difficult to diagnose and characterize by physical examination. Any form of high resolution imaging modality may offer improved detection, characterization of the internal structure and extent, as well as the diagnosis of these lesions. Many generalized collagen conditions, inflammatory diseases, and joint problems result in abnormalities of the synovial membrane resulting in enlargement of the synovium and joint effusion that should be easily detected by xeroradiography.

The x-ray dosage received by a subject when employing xeroradiography is slightly higher than

with conventional radiography using non-screen film. Anticipated advances in development of more sensitive selenium plates may reduce the amount of exposure necessary for xeroradiography. In the clinical setting in which the edge enhancement effect might prove most beneficial, radiation dosage is not as great a consideration as in chronic or serial studies. Additionally the extremities are often the structures of interest and dosage constraints are not as limiting as in studies involving or near more susceptible vital organs such as the gonads or the lens of the eye. In most circumstances single or several exposures will be sufficient for the clinical diagnosis. Repeated radiographic studies at some later date would not be anticipated.

Although some technical limitations are inherent in this method they were not insurmountable. The time factor prior to and immediately following exposure can be overcome by a minimum of pre-study planning. Problems with cassette loading usually only require minor adjustment, as did difficulties encountered with cloud density and uniformity. These difficulties tended to decrease with more frequent use of the equipment and greater facility on the part of the user. After this preliminary experience we believe that this imaging technic will have future utility in veterinary practice.

## SUMMARY

The technic of xeroradiography offers improved imaging of anatomical detail when compared with conventional radiography. Our current investigation with this new imaging modality has focused on its uses for diagnostic study of exotic animals. Xeroradiographs of animal subjects reveal improved anatomical delineation of soft tissues and osseous structures when compared with conventional high contrast radiography. This improved rendition of tissue interfaces of different density is due to the inherent properties of edge enhancement. Examples of animal xeroradiographic prints are presented with discussion of the xeroradiographic technic and its potential utility in veterinary medicine.

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## REFERENCES

1. Boag, J. W.: Xeroradiography. *Phys. Med. Biol.* 18: 3-37, 1973.
2. Detection of Hyperparathyroidism. *Xerox Medical Application Bulletin* 108, June 1973.
3. Extremity Trauma: *Xerox Medical Application Bulletin* 119, June 1974.
4. Foreign Body Detection. *Xerox Medical Application Bulletin* 106, June 1973.
5. Roach, J. F. and Hillabae, H. E.: Xeroradiography. *Am. J. Roentgenol.* 73: 5-9, 1955.
6. Wolfe, J. N.: Xeroradiography of Bones, Joints, and Soft Tissues. *Radiology* 93: 583-587, 1969.
7. Wolfe, J. N.: Xeroradiography of the Breast. Charles C Thomas, 1st Ed. 1974.
8. Wolfe, J. N.: Xerography of the Breast. *Radiology* 91: 231-240, 1968.
9. Xeroradiography Operators Manual. Xerox Corporation; Pasadena, California.

## ZUSAMMENFASSUNG

Im Vergleich zur herkömmlichen Röntgenographie bietet die Xero-Radiographie eine bessere Methode zu Aufnahmen von anatomischen Einzelheiten. Unsere gegenwärtige Untersuchung dieser neuen Röntgenbildmethode konzentrierte sich auf ihre Anwendung in diagnostischen Studien von exotischen Tieren. Verglichen mit den herkömmlichen Hochkontrastaufnahmen zeigen die Xeroröntgenaufnahmen eine bessere anatomische Wiedergabe von weichen Geweben und Knochenstrukturen. Diese verbesserte Darstellung von Gewebezweischenflächen von unterschiedlicher Dichte basiert auf der Fähigkeit dieser Methode, die Kontouren zu vergrößern. Der Bericht beschreibt Beispiele von Xeroröntgenaufnahmen von Tieren sowie Erläuterungen der Xero-Radiographie-methode und untersucht Möglichkeiten für ihre Nutzbar-machung in der Veterinärmedizin.

## RÉSUMÉ

En comparaison avec la radiographie classique, le procédé de xéroradiographie procure de meilleures représentations de détails anatomiques. Nos recherches récentes à l'aide de ce nouveau moyen de représentation se sont concentrées sur ses applications dans les travaux de diagnostics chez les animaux exotiques. En comparaison avec la radiographie classique à haut contraste, la xéroradiographie des animaux considérés a donné de meilleurs dessins anatomiques de tissus mous et de structures osseuses. Cette amélioration dans la résolution des surfaces de contacts entre tissus de densités variables provient des caractéristiques spécifiques de renforcement des zones marginales. On trouvera des échantillons de photographies de radio-xéroradiographie animale accompagnés de commentaires sur le procédé xéroradiographique et sur son potentiel d'avenir en médecine vétérinaire.