PICTURE THIS
Fluoroscopy produces real-time images that appear as an "x-ray movie," providing a helpful view for dynamic processes.

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Donna earned her degree in radiological sciences from Butler University. She worked in radiology in human medicine for 20 years before transitioning to veterinary medicine. Sixteen years ago, she began her career at Purdue University to bring advanced technologies to the veterinary school. In her spare time, she enjoys coaching, sports, boating, and spending time with her family.

RADIOLOGY/IMAGING

Fluoroscopy: Don't Miss the Show!

Fluoroscopy is an advanced diagnostic tool that helps the veterinary team refine a diagnosis by compiling a series of radiographic images into a movie. The result is similar to a child's cartoon flipbook in which multiple single images on separate pages, each with a tiny change, become a short animated clip when stapled together and flipped through quickly.

Fluoroscopy is used in research and primary care facilities to visualize dynamic processes, such as gastrointestinal motility, cardiovascular function, blood and urine flow, collapsing trachea, and swallowing, in real time. Fluoroscopic guidance is helpful in contrast procedures and in the placement of medical devices and surgical hardware. This article provides an overview of the history, technology, safety, and use of fluoroscopy in the veterinary hospital.

HISTORY OF FLUOROSCOPY

In 1896, one year after Wilhelm Conrad Roentgen discovered x-rays, Thomas Edison invented the fluoroscope.[1] This first fluoroscope was handheld, could not record images for later viewing, and had to be used in the dark, making it impractical for medical use. Fluoroscopy was used for entertainment purposes for many years until the dangers of radiation were recognized.

In 1940, John Coltman's invention of the electronic image-intensifying tube allowed doctors to use a

GLOSSARY

Anode Positively charged part of the x-ray tube head

Applied dose Amount of radiation absorbed by the patient

Cathode Negatively charged part of the x-ray tube head; contains the filament from which electrons are released

Collimation Process that helps reduce the beam size and thereby decrease scatter radiation

Kilovoltage peak Force/power of x-rays

Milliamperage Quantity of x-rays

Pulsed fluoroscopy Used to reduce radiation doses by using short bursts of x-rays instead of continuous fire

Scatter radiation Secondary radiation (not the primary beam) that has a slower wavelength and therefore is more dangerous

completely hands-free fluoroscopy machine in regular room lighting, and in 1953, Westinghouse commercialized the image intensifier.[1] These developments allowed for improved patient and personnel safety and improved diagnoses. The same basic design is still used in veterinary medicine today, with recording capabilities and digital advancements.

FLUOROSCOPIC EQUIPMENT

A fluoroscopic unit uses a standard x-ray tube head. In the tube head, excited electrons, emitted by a cathode, strike a tungsten target on an anode, releasing x-ray photons. The angle of the anode directs the x-rays downward, forming the primary beam. The beam exits the tube head through a beryllium window. The primary beam then passes through a collimator made of lead shutters, which helps limit it to just the area of interest.[2]

In fluoroscopic units, after the x-ray beam passes through the area of interest, it is intercepted on the other side by an input phosphor made of cesium iodide and is converted to light photons by the image intensifier. These photons are converted to photoelectrons that are then seen on a monitor.[2] Fluoroscopy units are usually equipped with multiple intensifier sizes, which allow the imager to vary the field of view on the screen, similar to magnifying an image.

The real-time image produced appears to be an "x-ray movie," displayed on a video monitor. This image appears as an inverted radiograph, flipping the bright (radiopaque) areas with the dark (radiolucent) areas. This inversion is helpful to improve the viewer's visualization of structures. Some units allow recordings of the study, known as a *cine loop*. Permanent or still images can also be acquired during fluoroscopy; these are typically referred to as *spot films*.

Imaging Units

There are 2 types of full-sized fluoroscopy units used in veterinary facilities: mobile C-arm units and R&F (radiography and fluoroscopy) rooms. Small handheld units, often used in large animal hospitals to image equine distal extremities, also exist. These units do not produce high-quality images and often overheat with prolonged use; therefore, they are not commonly used today in small animal practice.

C-arm units are more compact than R&F systems, and unlike table units, they are portable, making them useful in both large and small animal practice, as well as research facilities. These units have the fluoroscopy head and the image intensifier on opposite ends of the C-arm, which can be positioned to present anatomy in

FIGURE 1. A typical surgical view of a hip pin verifying placement.

different angles and directions while the patient lies on a radiolucent surface within the C shape. C-arm units are used during surgery to help evaluate orthopedic fracture repair and reduction (**FIGURE 1**), identify catheter placement, and guide placement of stents and medical devices. They can also be used for contrast procedures that do not require the patient to be standing, such as cystography and angiography.

R&F units contain an advanced stationary radiography table with an integrated fluoroscope. The 2 separate tube heads, one for radiography and one for fluoroscopy, allow the machine to be used for both radiography and fluoroscopic imaging, but not simultaneously. The operator must know how to initiate the correct tube for the desired study. The fluoroscopy tube is mounted beneath the table, which can be moved into a vertical orientation for standing views (**FIGURES 2 AND 3**). During use, the image intensifier is positioned over the patient, and the under-table tube and intensifier can be manually moved simultaneously to cover the area of interest. R&F units can be used for procedures similar to C-arm units, as well as standing procedures such as collapsing trachea and swallow studies.

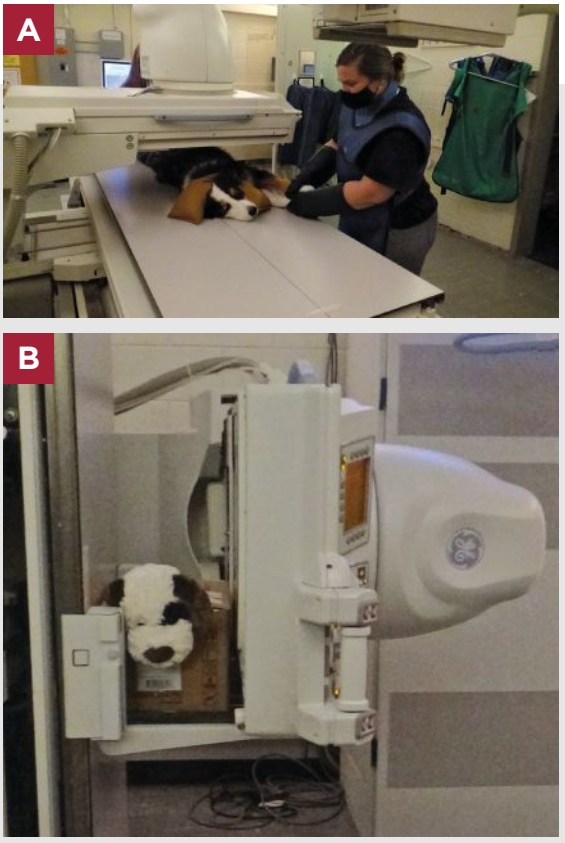


FIGURE 2. An R&F room. The fluoroscopy tube is located under the table and the image intensifier moved over the patient. **(A)** Patients can be imaged in a recumbent position for cystography or when sedation is needed to perform the examination. **(B)** To image a patient in a natural, upright position, the table can be turned vertically and a footboard placed. Typical examinations performed with the patient standing include tracheal studies, esophagrams, and upper gastrointestinal studies.

Contrast Agents

A contrast agent is often given during a fluoroscopic examination to enhance the area of interest and help highlight its function or delineate it from the surrounding area. Contrast agents can be negative or positive. Negative contrast agents are radiolucent; that is, they have a low density and allow almost all x-rays to pass to the recording surface. They appear white on fluoroscopic images (black on radiographs). Positive contrast agents have a high atomic number and high density and are radiopaque; that is, they absorb most x-rays and allow very few to pass to the recording surface. They appear black on fluoroscopic images (white on radiographs).

FIGURE 3. A C-arm fluoroscopy unit. This unit is mobile and can be manipulated around the patient to view anatomy in different angles. Surgery, cystoscopy, and cardiology are common settings in which C-arm units are used. The table the patient lies on must be radiolucent.

BOX 1

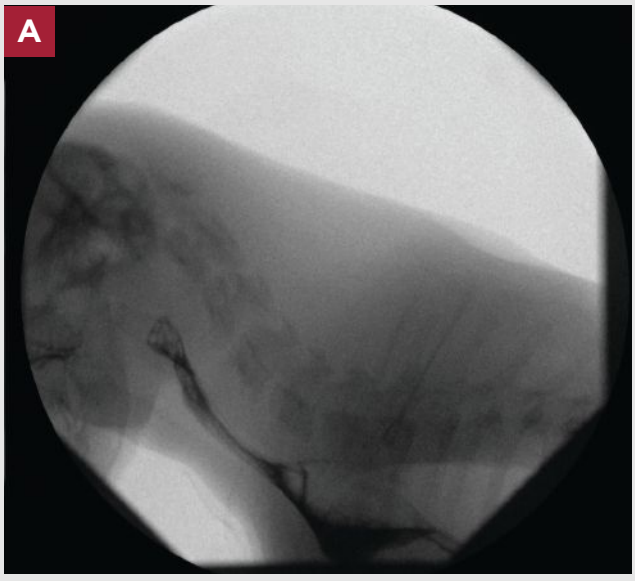
Fluoroscopic Esophagography

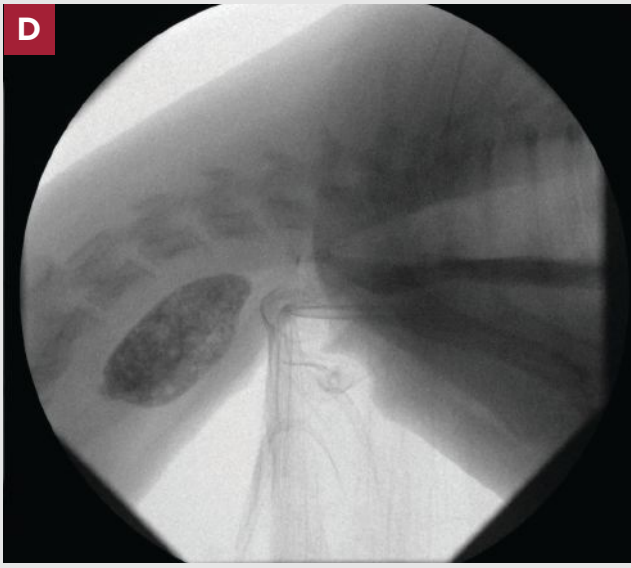
Purpose: To evaluate esophageal foreign bodies, strictures, masses, perforations, and motility disorders.

Contrast agent: Barium sulfate suspension is commonly used. However, if an esophageal perforation is suspected, or if endoscopy is to be performed immediately afterward, an iodinated contrast agent should be used.

Notes:
- Thoracic radiographs are required beforehand to assess for aspiration pneumonia (as well as any other comorbidities that may affect the differential diagnosis or treatment planning).
- The patient should not be sedated. If sedation must be used, only acepromazine is permitted, as it does not affect gastrointestinal motility.
- The patient should be imaged while standing to avoid the effect of recumbency on gastrointestinal transit.

Procedure:
- The pharynx, entire esophagus, and stomach should be surveyed.
- Assess both liquid and solid (soft food and/or kibble) phases, using "medium-size" boluses; depending on patient size, liquid boluses are generally 5–10 mL and food boluses are 8 g.





- Assess pharyngeal function with a narrow fluoroscopic aperture and frame rate of 30 fps. Make sure the patient's head remains as straight as possible so that specific pharyngeal structures (epiglottis, upper esophageal sphincter) can be assessed accurately.
- Assess esophageal function using a wider aperture and (generally) a lower frame rate (e.g., 15 fps). A brief loop focused on the gastroesophageal sphincter should be performed at the end of the swallow to assess for reflux or an "achalasia-like" syndrome.

Case example: A 4-month-old, 1.5-kg, female American Eskimo dog presented with a diagnosis of megaesophagus and suspected persistent right aortic arch based on barium study. The patient had multiple episodes of regurgitation daily despite a gruel diet. Imaging was recommended to confirm megaesophagus. A fluoroscopic esophageal swallow study was conducted using 60% wt/vol barium sulfate suspension alone and meatballs coated with barium suspension.

(A and B) Liquid bolus in mid-cervical area. Barium coats the ventral margin of the esophagus, accumulates in the caudal portion of the thoracic esophagus, and forms a "bird-beak" shape as contrast and fluid pool at the lower esophageal sphincter. This was seen with administration of 2 liquid barium swallows. Hypermotile waves of peristalsis were also seen coursing along the ventral aspect of the esophagus, propagating toward the lower esophageal sphincter.

(C) Meatball image—soft food mixed with barium. The food bolus passes through the upper esophageal sphincter normally, then stays within the cervical esophagus for a delayed period of time before being propelled caudally.

(D) Lower esophagus view of barium entering the stomach. A large food bolus was propelled through the esophagus, then stayed within the mid-thoracic esophagus before a large wave of peristalsis propelled it into the stomach. However, a small amount of this bolus remained within the caudal esophagus and did not completely empty into the stomach. A small volume of barium is seen coursing from the stomach and into the dilated caudal esophagus.

The diagnosis was diffuse esophageal dilation with fluid and food pooling and abnormal peristalsis (primary and secondary dysfunction) due to possible lower esophageal sphincter achalasia-like syndrome, lower esophageal sphincter dysmotility/asynchrony, or other cause of diffuse esophageal dysfunction with probable secondary esophagitis.

Fluoroscopic examinations mostly rely on positive contrast agents to obtain maximum enhancement of the area of interest. The first contrast agent, lead subacetate, was used to view the stomach of a guinea pig in 1896.[3] Lead subacetate was chosen because of its high density.

Today's positive contrast agents fall into 2 categories: barium sulfate and iodinated contrast agents. Barium sulfate is insoluble, meaning the body cannot absorb it. Barium sulfate is very useful for gastrointestinal studies (**BOX 1**); however, it is suggested that iodinated contrast media is used in place of barium when a perforation is suspected.

Water-soluble iodinated contrast agents may be ionic or nonionic. Ionic iodinated contrast media are hypertonic solutions, meaning they have high concentration of solutes that will cause surrounding cells to dehydrate. Nonionic contrast agents have a low osmolality and do not separate in solutions, making them up to 6 times safer than ionic contrast media (**BOX 2**); however, they are very expensive and do not have a long shelf life.[4] Nonionic contrast agents are useful for vascular and urinary studies. These agents are absorbed into the bloodstream and excreted by the kidneys, and they can be administered intravenously, orally, or intrathecally.

SAFETY PRECAUTIONS

Unlike in the early days of fluoroscopy, the diagnostic use of x-rays must now be justified and the radiation dose kept "as low as reasonably achievable" (ALARA). Fluoroscopic procedures can expose both patient and personnel to a high dose of radiation; therefore, fluoroscopy should never replace standard radiography. The veterinary team must remember that the radiation exposure during a fluoroscopic examination is higher than that associated with a single radiograph.

During a fluoroscopic examination, the greatest occupational hazard to the veterinary team performing the examination is scatter radiation (i.e., secondary radiation), owing to the long exposure time and increased kilovoltage peak (kVp). Because the configuration of a fluoroscopy unit differs from standard radiography, the veterinary team needs to understand where the radiation is coming from and where potential scatter radiation is highest. Table units, with the tube head below the table, project most scatter upward.

Personal Protective Equipment

All staff who remain in the room during the examination must wear proper personal protective equipment (PPE). The suggested PPE to wear during fluoroscopy is a lead apron and a thyroid shield with a 0.5-mm lead equivalent, and, optimally, lead glasses or goggles.[5,6] Any personnel handling the patient or whose hands are positioned close to the primary beam should

BOX 2

Fluoroscopic Cystography

Purpose: To evaluate for bladder leakage/rupture, anatomic abnormality, or urinary tract disease (e.g., prostatic neoplasia, ruptured bladder, urachal remnant, pelvic bladder, bladder tumor).

Contrast agent: Nonionic iodinated contrast medium

Notes:
- Heavy sedation or light anesthesia is required.
- Survey abdominal radiographs are required beforehand to assess bladder visualization and position (as well as any other abnormalities that may affect the differential diagnosis or treatment planning).
- Enemas may be required, based on the survey radiographs.
- The patient should be fasted for 12 hours before the imaging study, and the enema (if needed) given 1 hour before the study.
- The patient should arrive with an aseptic urinary catheter placed in the bladder.

Procedure:
- Obtain survey spot film.
- Remove as much urine as possible from the bladder.
- Give contrast medium while fluoroscopy is recording.
- Additional contrast medium may need to be given to distend the bladder or to keep the bladder distended (if contrast is leaking).

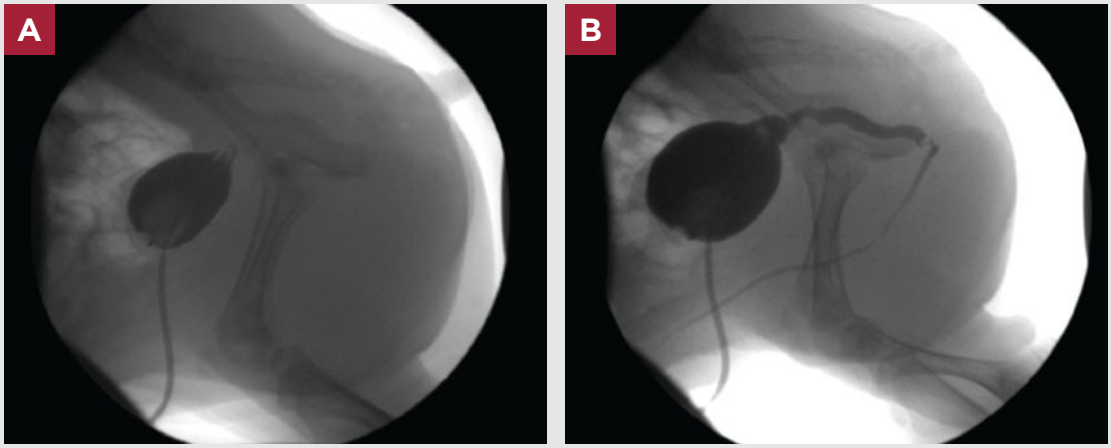
Case example: A 6-month-old, 17-kg, male castrated pig presented with a diagnosis of obstructed urethra. Radiographs showed peritoneal effusion, and ultrasonograhy showed an empty bladder. Uroperitoneum was diagnosed, and surgery was performed. The bladder was ruptured in the cranial aspect. A Foley catheter was passed; saline pushed through the catheter kept coming back. A cystotomy was performed.

Positive-contrast normograde cystography was performed via a cystostomy tube, using 50% diluted iodinated contrast media, 70 mL total. Several cine loops were acquired.

(A) After injection of 40 mL contrast media administered via cystotomy tube, the urinary bladder is full and progression of the contrast into the pelvic urethra can be observed. There is a well-defined depression of the cranioventral wall of the urinary bladder, just cranial to the insertion of the cystotomy tube. The pelvic urethra is dilated, with an abrupt filling defect caudal to the ischiatic tuberosity.

(B) After injection of 70 mL of contrast solution, normograde contrast filling of the entire urethra is present (prostatic, membranous, and penile). The pelvic urethra remains dilated with an abrupt filling defect at the level of the ischiatic tuberosity. A thin tortuous contrast line is present within this filling defect, allowing mild normograde progression of the contrast distally into the membranous urethra.

The diagnosis was urethral partial obstruction likely secondary to a possible stricture or (less likely) urethral polyp. Depression at the cranial urinary bladder wall is likely secondary to repair of the bladder rupture.



also wear front- and back-sided, full-coverage, 0.5-mm lead gloves. As with standard radiography, anyone who remains in the room must wear a dosimetry badge to measure the dose of scatter radiation.

While most lead aprons are suitable for frontal coverage, it is suggested that two-sided lead aprons covering both front and back, often referred to as 360-degree coverage, be worn during fluoroscopic procedures. This is because of the amount of scatter radiation generated while the system is collecting images; personnel in the room should never turn their back to the table or unit. Table units have a lead curtain to further protect the personnel performing the examination and manipulating the image intensifier position from scatter radiation.

Radiation Dose Reduction

During fluoroscopy, x-rays are continuously being released and converted to produce the images being displayed on the video monitor. Depending on the specific system, frame rates of 1 to 30 fps (frames per second) may be available. To help keep the radiation dose ALARA, the lowest frame rate that provides the best diagnostic quality is the best choice. The veterinary nurse or clinician should always adjust the collimation to the area of interest to reduce radiation exposure to the patient and veterinary team.

Different technical factors can also help reduce radiation exposure. It is important for the veterinary nurse operating the unit to be familiar with the machine's capabilities. Using pulsed fluoroscopy with a lower pulse rate can reduce the patient's radiation exposure by almost half.[1] The pulse rate is directly proportional to the applied dose. If the image is fairly static, with not much movement, a lower pulse rate of 4 to 8 p/s (pulses per second) will lower the patient and operator dose significantly. If the situation warrants viewing a moving object, such as during a motility study, at least 8 to 12.5 p/s might be required.

Increasing or decreasing the magnification over the area of interest can also increase or decrease the amount of radiation the patient receives. Exposure, kVp, and milliamperage (mA) can also be adjusted to ensure the lowest diagnostic dose. Fluoroscopy units tend to use a low mA and higher kVp. Most units have an automatic and/or manual exposure rate or a set kVp and mA. Automatic exposure rates are preset tube voltage and current levels based on the object being imaged.

Contrast Agent Dose and Administration

Different contrast agents are used for specific studies, and not all agents are administered the same way. Contrast agents often vary in concentration based on the brand. Care should be taken in selecting and administering contrast agents, as many are nephrotoxic when given repeatedly or in large quantities. Ionic contrast agents can cause severe dehydration, bradycardia, congestive heart failure, nausea and vomiting, peripheral vasodilation, immune-mediated responses, and allergic reactions.[3] Contrast studies should be at least 24 hours apart. Caution should be used when administering barium because peritonitis can occur when barium leaks out of the gastrointestinal tract or is accidentally aspirated. Peritonitis can cause permanent adhesions and granulomas.

All contrast agents and doses must be prescribed by the veterinarian. It is the veterinary nurse's role to ensure the specific details for each procedure and to make sure the correct contrast dose is administered via the route intended.

Veterinary Team Education

Each practice should develop specific protocols for fluoroscopic examinations. These should include examination-specific details and principles to be followed by the veterinary team to help eliminate errors. Fluoroscopy units should be operated under the direction of educated personnel who are familiar with the technical and safety requirements and operational guidelines of the specific system. All personnel involved in an examination should be aware of the appropriate radiation factors to ensure that radiation exposure is kept to a minimum. TVN

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