Over the past 20 years, fluoroscopy has revolutionized the medical treatment of pain and is now the cornerstone of the new medical specialty of interventional pain management. Recent understanding and improvements in fluoroscopic imaging, along with an improved understanding of the anatomy and pathophysiology of pain, have combined to allow the interventional pain specialist to diagnose and treat chronic pain more effectively than ever before.

On November 8, 1895, physics professor Wilhelm Roentgen (Fig. 1) was working alone at night in his laboratory. He was conducting an experiment using a cathode ray tube in which he created a potential difference between the cathode and an anode he had placed several inches away. He knew from previous experiments that a stream of charged particles would be created in the cathode and move toward the anode. Since he was working at night, his laboratory was dark. The cathode-anode apparatus was encased inside a cardboard housing and, by chance, a screen of fluorescent material lay on a table not far away. As the experiment progressed, Professor Roentgen noticed a mysterious light appearing on the table top fluorescent screen. He repeated the experiment and each time he generated the potential difference he observed the glowing light. He realized this light could not be caused by the cathode rays themselves since they were unable to penetrate the tube. Furthermore, visible light could not be the source of the mysterious illumination since the tube apparatus was covered by opaque material. He postulated that he must have generated some previously unknown type of radiation which he called “x-rays.”

Roentgen spent the next 8 months eating and sleeping in his laboratory while he repeated his experiment in various forms. He soon discovered that objects placed between the tube and the fluorescent screen produced shadows on the screen which could be captured on photographic film. He employed
his wife to place her hand on a photographic plate while he projected the mysterious rays at it for 15 minutes. The first x-ray image was thus created (Fig. 2). Roentgen ushered in a new era of x-ray imaging and in 1901 received the Nobel Prize in physics for his discovery.

Early, unprocessed fluoroscopic images were quite dim and with early techniques, in order to simply see the image the fluoroscopist needed to sit in a darkened room until vision was dark-adapted. With typical x-ray imaging at the beginning of the 20th century, the radiologist would sit or stand in front of the patient with the x-ray tube placed behind the patient, with a fluorescent screen in front of the patient. Images were routinely dim and of poor quality until the advent of the image intensifier in 1953.

By the 1940s the use of fluoroscopy had become widespread in medical practice and also became popular for various nonmedical uses. The fluoroscope has evolved steadily over the past century to become a powerful and flexible tool for viewing of both static and real-time x-ray images of the body. Continuing improvements in fluoroscopic imaging, combined with increasing knowledge of the mechanisms and anatomical sources for chronic pain, make it possible for the interventional pain specialist to provide increasingly safe and effective pain management.

**Fig. 2. Early fluoroscopic and x-ray imaging equipment.**
A,B,C: Reproduced from www.mayoclinic.com
D: Reproduced from www.mtn.org/quack/devices/shoexray.html
Scientific Aspects

- When high velocity electrons collide with metal, the kinetic energy contained within the electrons is converted to electromagnetic energy released in the form of x-rays.
- Kinetic energy is the energy of motion and is a property of all moving projectiles.
- The amount of kinetic energy contained within a projectile is a function of the projectile’s mass and velocity as determined by the following equation: KE = 1/2 mv^2 where KE is the kinetic energy in joules, m is the mass, and v is the velocity.
- It follows from the above relationship that, with regard to kinetic energy, velocity is exponentially more important than mass.
- Therefore low mass particles, like electrons traveling at high speed, can have high kinetic energy.
- The function of the fluoroscope, like any x-ray machine, is to provide a steady stream of high velocity electrons (projectiles) to bombard a metal target in order to produce a continuous, controllable stream of x-ray radiation.
- The x-ray tube of the fluoroscope serves to focus high energy electrons contained within an electrical current onto a small point within a metal target.
- As the kinetic energy of the electrons within the electric current is increased, the number and energy of x-rays produced from the collision with the metal target is increased.
- The fluoroscope allows for precise control of the number of x-rays generated (measured in milliamps) and the energy of the generated x-rays (measured in kilovolts).
- The x-ray tube housing directs the x-rays through tissue and onto an internal fluorescent screen within the fluoroscope.
- The imaging chain within the fluoroscope then amplifies and processes the fluoroscopic image with the ultimate creation of visible x-ray images on the monitor.

Fluorescence

- The term fluorescence describes a property of certain materials that emit visible light when exposed to stimulation by chemicals, electricity, or ionizing radiation.
- X-rays are a form of ionizing radiation powerful enough to cause the phosphorous material within a fluorescent screen to glow.
- Early fluoroscopic systems used barium platinocyanide as the fluorescent material.
- This was subsequently replaced by cadmium tung-
- The fluoroscopic picture that is produced is essentially composed of shadows created as x-rays that are absorbed preferentially by body tissues of various densities.
- Air allows most of the x-rays to penetrate through to the imaging medium, thus exposing the medium to unblocked x-rays.
- Bone and metal are denser and absorb x-rays, allowing less of them to penetrate through to the underlying plate.
- With plain x-rays, a photographic plate is used as the imaging media.
- The plate starts out as a white background and becomes dark in various areas as these areas absorb x-rays.
- The plate therefore shows “shadows” of dense tissue structures as white areas on the picture.
- With fluoroscopy, the density of the viewed image is reversed, with the higher density tissues casting shadows that appear to be darker on the displayed image.
- Higher density tissue appears as a darker area on the image screen in fluoroscopy because as penetrating x-rays hit the phosphor screen they stimulate a fluorescent reaction within the screen, causing that portion of the screen to become bright (Fig. 3).
Interventional Techniques in Chronic Spinal Pain

- The area that is not stimulated by penetrating x-rays is darker since x-rays that are absorbed by various tissues do not penetrate to the screen to cause phosphorescence.
- The denser the tissues, the less x-rays penetrate through to cause fluorescence on the underlying screen.
- The fluoroscopic image is analogous to the photographic negative, whereas the developed x-ray film is analogous to the photographic picture.
- The principle of increasing absorption of x-rays by increasingly dense tissue gives rise to the 5 basic observed radiological densities: air, fat, water (soft tissue), bone, and metal.

The Fluoroscopic Imaging Chain

- The fluoroscopic imaging chain consists of various components including an x-ray tube with cathode and anode, an image intensifier, and a fluorescent phosphor screen to capture the image created (Fig. 4).7

The X-ray Generator

- As with any x-ray machine, the fluoroscope converts electrical energy to x-rays.
- Alternating electrical current from the power source is transformed into high voltage direct current by the electrical transformer and rectifiers within the fluoroscopic x-ray generator.
- The x-ray generator allows for selection of the amount of electrical current (measured in terms of amperage) and voltage of the current (measured in terms of kilovolt peak) that is delivered to the x-ray tube for subsequent x-ray production.
- The milliampere (mA) of the current determines the number of electrons released to the x-ray tube and the intensity of the generated x-rays.
- The milliamperage of the current is proportional to the density of x-rays produced.
- The voltage (kVp) of the current applied across the anode and cathode of the x-ray tube determines the

Fig. 4. Fluoroscopic equipment. Reproduced from Boswell et al7 with permission from the authors and the American Society of Interventional Pain Physicians.
wavelength and thus the energy and penetrating ability of the x-rays.

- The milliamperes and kilovoltage of the current determine the quality of the image produced on the monitor by determining the quantity and energy respectively of the x-rays directed into the patient.
- The x-ray generator assembly includes an automatic brightness control (ABC) system that allows automatic adjustment of kVp and mA to optimize the image brightness on the monitor as the fluoroscope moves across areas of varying tissue density.
- Optimal mA and kVp settings can be set automatically by the modern fluoroscope or can be manually set by the operator.

The X-ray Tube

- During an x-ray exposure, direct current from the x-ray generator is transmitted into the x-ray tube.
- The high voltage current heats the filament within the x-ray tube, causing electrons to be accelerated from the cathode of the tube to the positively charged tungsten anode.
- These accelerated electrons strike the anode with enough kinetic energy to cause the electrons within the heavy atoms of tungsten to be displaced to lower energy levels, thus releasing energy from the tungsten atom in the form of high-energy (x-ray) photons.
- The moving electrical current creates thermal energy (heat) and radiant energy in the form of x-rays.
- Radiant energy generated in this fashion is called characteristic radiation.
- Additional x-ray photons are produced from bremsstrahlung radiation which creates energy from the collisions of the projectile electrons with the tungsten nucleus independent of any orbital drops of the tungsten electrons.
- “Bremsstrahlung” is the German word for braking and this type of radiation produces x-ray photons from the energy released by the projectile electrons as they collide with, and are slowed down by, the tungsten nucleus.
- The x-ray tube is inherently inefficient with 99% of energy converting to heat and only about 1% to x-rays.
- The entire x-ray tube apparatus is housed in a shielded vacuum tube within the fluoroscope (Fig. 5).
- The electrons released from the x-ray tube are high-energy x-ray photons capable of penetrating tissue.
- The x-rays that are directed through the patient may be absorbed or scattered by the tissues of the patient or may pass through the patient to be captured by the fluorescent imaging screen.

Fig. 5. Components of the x-ray tube.
Reproduced from Boswell et al7 with permission from the authors and the American Society of Interventional Pain Physicians.
Image Intensifier

- Native fluoroscopic images are dim and difficult to view.
- The image intensifier was developed to brighten the viewable image.
- Early image intensifiers consisted of a system of lenses and mirrors.
- Later versions added a video camera and monitor for viewing of intensified images on the monitor screen.
- The intensifier system takes the incoming x-rays and converts them to electrons in a series of steps that take place within the input layer.
  - The x-rays enter the input window of the image intensifier which is made of a thin layer of glass or metal.
  - The x-rays are then directed to an input phosphor layer made of cesium iodide where they are converted to light photons.
  - There is an initial weak multiplying effect at this level as a single x-ray photon can yield several hundred visible light photons.
  - The input phosphor produces the instantaneous dim fluoroscopic image (first viewed by Roentgen) and these light photons are absorbed by the photocathode and converted to electrons.
  - The energy from this fluorescence is magnified (intensified) several thousand fold as those electrons converted from the light photons are accelerated from the photocathode through a vacuum to an anode within the output layer where they are available for viewing.
- Intensification comes from the fact that these energized, accelerated electrons now have enough energy to yield several thousand visible photons when they interact with the atoms of the output phosphor layer.
- The image is further intensified via an output phosphor window that is much smaller than the input surface of the intensifier, in a process known as minification.
- The intensification process produces a much brighter, more discernible image for viewing. Brightness is amplified by the image intensifier on the order of 5,000- to 20,000-fold.7
- Modern image intensifiers are of varying sizes depending on the field of view necessary for the clinical application.
  - Small, portable C-arm systems used for visualizing extremities may only require a 9-inch diameter input window for adequate imaging, while systems used for visualizing the abdomen or trunk may use input windows as large as 20 inches.
  - Typically, fluoroscopes used for interventional pain management have image intensifiers with 12-inch diameter input windows (Fig. 6).

Fig. 6. Typical fluoroscopic unit.
Collimation

- The modern fluoroscope provides for internal collimation to optimally define the size and shape of the x-ray beam in order to better conform to the field of view.
- Unattenuated x-rays may cause glare on the image screen at the edges of the patient’s body, resulting in poor image quality.
- Collimation reduces the amount of unattenuated radiation at the edges of the viewing area, thus reducing glare as well as overall patient radiation exposure by minimizing both direct and scatter radiation.
- Reduced scatter also means less radiation exposure to the operator.
- Optimizing the size and shape of the x-ray beam through collimation reduces the volume of tissue exposed to x-rays, thereby reducing scatter, and improves image quality by reducing image degradation.
- The collimator consists of radiopaque shutters that move into the x-ray path, attenuating areas of the x-ray beam.
- Collimator blades are typically circular (iris) or rectangular in configuration and many fluoroscopes allow for both circular and rectangular collimation.
- The collimator automatically adjusts the x-ray beam to conform to the field of view as the fluoroscope moves across areas of varying body tissue density. The operator can manually adjust the collimation window to conform to a particular region of clinical interest (Fig. 7A).

Optical Coupling

- Modern fluoroscopic systems incorporate optical coupling chains in order to process the images for optimum viewing capabilities.
- Once the light leaves the image intensifier output window, it is available for viewing as an x-ray image.
- In C-arm systems, the image signal is typically routed to a video camera which converts the x-ray image to a voltage signal that is viewable by closed-circuit television.
- This television monitor displays the real-time video image during continuous fluoroscopy.
- A typical mobile C-arm fluoroscope can simultaneously display a static image by using a second television monitor for viewing of the last image in the video sequence (Fig. 7B).
- This “last image hold” capability allows the interventionalist to minimize radiation exposure by performing procedures utilizing a series of static images to follow needle placement.
- The typical modern fluoroscope incorporates 2 monitors mounted on a mobile video display unit in order to allow several people to view real-time and static images side by side at the same time.

Analogue to Digital Converter

- Newer fluoroscopic imaging systems incorporate digital image conversion technology in order to utilize digital image enhancement techniques for improved image quality, and to facilitate computer processing, storage, and distribution of images.
- With digital conversion, the analogue video signal is digitized and stored in computer memory.
- Subsequent computer enhancement of the fluoroscopic image may achieve image clarity approaching that of x-ray film but with the use of less radiation.
- Digital images can also be quickly and conveniently distributed via computer networks and stored on computer workstations or archived into various digital storage media for later retrieval.

![Fig. 7. Illustration of optical coupling and collimation.](image-url)
**Fluoroscopy Table and Pad**

- Materials placed between the x-ray tube and the image intensifier will tend to absorb x-rays.
- Differential absorption of x-rays by differing densities of patient tissues creates meaningful shadows that convey clinically useful information.
- Table and pad materials that have inconsistent density or produce high attenuation of x-rays will create loss of image contrast, may cast artifactual shadows on the imaging screen, and can ultimately result in increased patient radiation dose.
- The x-ray tables and pads used with the fluoroscope are designed to optimize fluoroscopic imaging.
- Newer composite materials, such as carbon fiber, used in fluoroscopy tables provide adequate strength to support large patients while minimizing x-ray attenuation and distortion.
- Thin foam pads overlying the table have a minimal effect on x-rays, whereas large gel supports or irregularly folded pillows may create significant x-ray attenuation and/or distortion and artifact.
- Diving board configuration of the table will allow for easier imaging of upper body structures during interventional pain procedures.

**Configuration of Fluoroscopic Systems**

- Fluoroscopic systems can be configured to meet the specific needs of the clinical application.
- The fluoroscopic components described above can be configured into fixed or mobile units.
- For interventional pain management, mobile C-arm fluoroscopes are most commonly used since the compact design is both economical and flexible and the configuration is capable of producing high quality images, especially when used with a carbon fiber table (Fig. 8).
- The C-arm configuration allows angulation of the imaging chain into various orientations about the patient’s body axis which improves visualization and access to anatomic structures during interventional pain procedures.

Fig. 8. Carbon fiber diving board style table with pad and C-arm focused.
Radiation Safety

- Soon after the discoveries of x-rays in 1895 and of radium in 1897, it became apparent that radiation had the capacity to cause injury.\textsuperscript{1-3,8}
- Reports of skin irritation from radiation exposure soon began to appear in the scientific and lay literature.
- By 1900, it was well-accepted in the scientific community that prolonged exposure to x-rays could produce skin burns.
- By 1905 medical malpractice suits for x-ray injuries were being settled in favor of patients.
- There were early recommendations to limit time and frequency of x-ray exposure and to collimate the x-ray beam to protect patients as well as suggestions to increase the distance from the x-ray apparatus for operator protection.
- Although the focus during the first quarter of the 20th century was primarily on discovery of new x-ray applications, there was increasing concern regarding the potential danger of x-ray exposure.
- Radiation safety became a major concern by the mid-20th century and modern standards of x-ray protection have evolved steadily since 1950.
- The National Council on Radiation Protection & Measurements (NCRP) was established in 1929 and continues to be the primary source of radiation safety recommendations in the United States.\textsuperscript{8}
- Health hazards from x-rays (and all forms of ionizing radiation) stem from the fact that energy imparted to the body from radiation has the capacity to cause cellular injury and cell death.
- When ionizing radiation makes contact with atoms of matter, an orbital electron of the matter molecule is converted to an ion.
- When ions are created within living cells they behave as free radicals and cause other atoms within the cell molecules to ionize, resulting in damage to the cell structure.
- Sometimes damage is slight and can be repaired by the cell, but higher levels of radiation may cause irreversible cell injury.
- Radiation may cause direct cell injury with alterations to the structure of DNA (somatic mutations) and other chemical changes within cellular matter.
- Somatic mutation may cause pathology that is initially silent but is manifested in subsequent generations.
- Cell injury may also be indirect as radiation triggers chemical chain reactions that result in cell membrane permeability changes that ultimately translate into cellular dysfunction.
- Fluoroscopic guidance is frequently utilized in performing many interventional techniques, including precision diagnostic and therapeutic injection procedures.
- It has been estimated that approximately 4 to 10 million interventional procedures are performed annually in the United States, with at least 50% of them being performed under fluoroscopy.\textsuperscript{9-24}
- The major purpose of fluoroscopy in interventional pain management is to verify correct needle placement to ensure target specificity and accurate delivery of the injectate.\textsuperscript{9-22,25-31} Incorrect needle placement has been described for multiple procedures without fluoroscopy.
- The most commonly used fluoroscopy in interventional techniques in managing chronic pain is with C-arm fluoroscopes with image intensification.
- Radiation exposure may be associated with risks to the physician, patient, and personnel.\textsuperscript{1-3,8,12,32-34}
- Most interventional procedures in the management of chronic pain require fluoroscopic exposure only for short periods of time.
- In 1994, the Center for Devices and Radiological Health of the Food and Drug Administration (FDA) issued an advisory, warning health care facilities of the potential for radiation-induced burns to patients from prolonged fluoroscopic procedures.\textsuperscript{8}
- The same warning also applies to physicians and other staff members of the team.
- Physicians are more likely to have side effects and significant radiation exposure due to the cumulative effect of radiation exposure.
- A number of interventional procedures, including radiofrequency cardiac catheter ablation, percutaneous transluminal angioplasty, vascular embolization, stent and filter placement, thrombolytic and fibrinolytic procedures, percutaneous transhepatic cholangiography, endoscopic retrograde cholangiopancreatography, transjugular intrahepatic portosystemic shunt placement, percutaneous nephrostomy, and biliary drainage or urinary or biliary stone removal are high risk procedures.\textsuperscript{32}
  - However, none of the procedures listed by the Center for Devices and Radiological Health included interventional pain techniques.
- Biologic effects of radiation can be broadly grouped as stochastic or nonstochastic effects.\textsuperscript{32}
- A stochastic effect is one in which the probability of the effect, rather than its severity, increases with dose.
  - The probability of radiation-induced leukemia is substantially greater after exposure to 1 Gy (100 rad) than after exposure to 1cGy (1 rad), but there will be no difference in the severity of the disease if it occurs.
  - Stochastic effects are believed to lack a threshold dose because injury to few cells or even a single cell could theoretically result in production of the effect.
Nonstochastic effects are other effects for which the probability of causing certain types of harm will be zero at small radiation doses.

- Above a threshold level, damage will become apparent, with severity increasing as dose rises above the threshold.
- Cataracts, erythema, epilation, and even death are examples of the deterministic effects that can result from high radiation exposures.

The goals of radiation protection standards are to limit the incidence of radiation-induced illness and disease in patients and workers, and to reduce the risk of genetic injuries in their progeny.

Multiple dose reduction techniques include intermittent fluoroscopy, removal of grid, last image holding, electronic collimation, dose spreading, adjustment of beam quality, image magnification, dose level settings, pulsed fluoroscopy, and appropriate training of fluoroscopy operators.

Radiation risks to the physician and assisting personnel are evaluated using the maximum safe allowable exposure limits, which have been established by the National Council on Radiation Protection & Measurements.33

The current estimation of risk from radiographic exposure to a specific body part is based on the biologic effects of whole body exposure converted by weight factors, specific for individual organs and tissues.

In 1991, the International Commission on Radiologic Protections adapted specific organ risks.34

Current standards are designed to prevent any radiation exposure in situations where there is no potential benefit and to reduce unavoidable exposure to “as low as is reasonably achievable” (ALARA) in situations where there is some potential benefit from the exposure.

Occupational exposure standards are set limits based on the “effective dose equivalent” which takes into consideration the mathematical summation of partial and whole body exposures.

Cumulative dose can be measured by dosimetry badges worn by workers and analyzed periodically by a contracted, independent third party.

Dosimetry badges typically consist of a solid state radiation detection device encased inside a plastic holder outfitted with various filters.

The x-rays entering the badge alter the solid state radiation detector.

Subsequent light output of the detection device is proportional to the radiation absorbed, and therefore periodic reading of the detector can determine the amount of x-ray exposure for the individual.

For optimal monitoring, 2 badges are worn, 1 outside and 1 inside the lead apron in order to determine the total external exposure as well as the efficacy of the lead apron protection.

Badges are analyzed on a monthly basis and allow for monitoring of cumulative radiation exposure over time.

Current occupational exposure recommendations set the upper effective dose equivalent of 50 mSv/year (5 rem/year) and a cumulative dose not to exceed 10 mSv (1 rem) times the age of the worker. Thus lifetime exposure for a 50-year-old radiation worker would be 500 mSv (50 rem).

In the early days of radiology, an x-ray image of a body part typically required 10 to 15 minutes of direct x-ray exposure and radiation injuries were commonplace.

Modern x-rays are now completed within milliseconds and typical radiation exposure is a small fraction of what it was 100 years ago.

However, with modern fluoroscopes there is again the possibility of delivering high energy x-rays to the patient for prolonged periods of time as increasingly complex procedures are performed using continuous fluoroscopy with high-powered fluoroscopes.

In 1994 alone there were more than 50 reports of patient injury from prolonged exposure to x-rays during fluoroscopic procedures, leading the FDA to issue a health advisory in that year.8

Since 1994 a number of case reports of serious patient injuries from radiation during fluoroscopy have been published.35-42

These injuries are often delayed since the effects of excessive radiation exposure are usually not immediately apparent.

Injuries have included skin burns serious enough to require skin grafting.

Since mandatory reporting of fluoroscopy injury is not required, the actual extent of this problem is unknown.

Occupational radiation exposure can be reduced to as low as is reasonably achievable through adherence to 3 basic principles:

- Reduce time of exposure
- Increase distance from the radiation source (x-ray tube, scatter from patient)
- Shield yourself and your patient from direct and scatter radiation.

Additional safety principles include:

- Pulsed fluoroscopy
- Image magnification
- Dose level settings
- Dose spreading
- Electronic collimation
- Adjustment of beam quality
- Appropriate training of operators.
• The longer the time one is exposed to a radiation field, the greater the total exposure.
• Limiting time of exposure is a simple, common sense method for reducing risk.
• With modern fluoroscopic systems, a short burst of radiation used with “last image hold” capability allows the operator to identify needle position with minimal x-ray time.
• With this technique (last image hold), the interventionalist takes a fluoroscopic “snapshot” of the field, holds the static image on the monitor, moves the needle a small distance toward the target, and then obtains another brief fluoroscopic image to determine the new needle position.
• This type of technique will reduce total fluoroscopy time, as compared to continuous fluoroscopy, to track needle progress.

The inverse square law states that the amount of radiation exposure is proportional to the inverse square of the distance from the source.
• The amount of radiation exposure declines exponentially as the operator moves away from the source.
• With fluoroscopy, distances of 6 feet or more from the x-ray tube and the patient result in minimal radiation exposure as long as the operator is not in the direct path of the x-ray beam.
• However, direct exposure to the x-ray beam, such as when the operator’s hand is visible on the fluoroscopic screen, or close exposure to scatter from the patient, results in significantly higher risk.

Lead aprons are mandatory, and thyroid shields are recommended as standard garb within the procedure room when fluoroscopy is used.
• Lead shielding can be tailored to body contours and rendered reasonably comfortable while providing an effective barrier to radiation exposure, especially to the thyroid and pelvis.
• In order to reduce direct and scatter radiation exposure respectively, a wide variety of lead glass screens are available for placement between the operator and the x-ray source and patient.
  • Lead glass screens can be configured to fit the particular procedure room space and can be attached to ceiling mounts or used with rolling frames on the floor.
  • Lead glass is an effective barrier to eye exposure and can be configured with optical correction although lead glass lenses may be heavy and uncomfortable.
  • Regular glass lenses also afford some protection, and other alternative materials for eye protection are becoming available. Eyeglasses that do not provide wrap-around capability do not provide protection and may increase the radiation dose to operators’ eyes.
• The use of leaded gloves has been advocated by some in order to reduce exposure of the interventionalist’s hands during procedures.
  • With lead protection worn on the hands there is less chance of direct exposure to the hands from both direct and scatter x-rays.
• The increased density of lead within the x-ray field will cause the fluoroscope to increase output as it tries to penetrate the increased density. Therefore, leaded gloves within the field of view (i.e., visible on the monitor) will cause an automatic increase in mA, kVp, and scatter radiation. Furthermore, lead gloves are expensive and may decrease the tactile sensation so important to needle placement. Keeping hands completely out of the beam (and therefore never visible on the monitor) is advisable with or without lead gloves.
• It has been described that risks can be minimized with a healthy respect for electromagnetic radiation, continued radiation safety education, radiation monitoring, and safe, common sense practices, along with keeping in mind basic principles of ALARA (as low as reasonably achievable), time, distances, and shielding.
• The top 10 measures for minimizing risks from fluoroscopic imaging in interventional pain management are listed in Table 1.43

<table>
<thead>
<tr>
<th>Table 1. Ten measures for minimizing risks from fluoroscopic imaging in interventional pain management.</th>
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<tbody>
<tr>
<td>1. Recognize that dose rates are greater and dose accumulates faster in larger patients.</td>
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<tr>
<td>2. Keep the tube current as low as possible.</td>
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<tr>
<td>3. Keep the kVp as high as possible and mA as low as possible, to achieve the appropriate compromise between image quality and low patient dose.</td>
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<td>4. Keep the patient at maximum distance from the x-ray tube.</td>
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<tr>
<td>5. Keep the image intensifier as close to the patient as possible.</td>
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<tr>
<td>6. Do not overuse geometric or electronic magnification.</td>
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<td>7. If the image quality is not compromised, remove the grid during procedures on small patients or when the image intensifier cannot be placed close to the patients.</td>
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<tr>
<td>8. Always collimate down to the area of interest.</td>
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<tr>
<td>9. Personnel must wear protective aprons, use shielding, monitor their doses, and know how to position themselves and the machines for minimum exposure.</td>
</tr>
<tr>
<td>10. Keep beam-on time to an absolute minimum.</td>
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</tbody>
</table>

Adapted and modified from Wagner and Archer BR.43
Clinical Applications

Approximately 4 to 10 million interventional pain procedures are performed annually in the United States, with at least 50% of them being performed under fluoroscopy.\textsuperscript{10,11,23-29,43-45} The major purpose of fluoroscopy is to ensure correct needle placement for accurate delivery of injectate and solutions to increase clinical efficacy, decrease possible side effects, and enhance patient safety. The importance of fluoroscopy in correct needle placement has been demonstrated repeatedly in multiple publications. Botwin et al\textsuperscript{15,16,28,29} and Manchikanti et al\textsuperscript{9,18,44} have prospectively evaluated the radiation exposure to physicians performing fluoroscopically-guided interventional procedures in private practice.

- These studies found low radiation exposure, leading the authors to conclude that interventional procedures could be performed safely under optimal conditions with appropriate safety precautions.
- Manchikanti et al\textsuperscript{18} evaluated a large number of patients in a private practice setting.
- In the first study in 2002, 1,000 consecutive patients with chronic pain, undergoing interventional procedures by a single physician, were evaluated. Table 2 illustrates radiation exposure in 1,000 patients.
- Manchikanti et al\textsuperscript{18} showed that mean radiation exposure time was higher per patient and per procedure in obese patients.
- Manchikanti et al\textsuperscript{9} evaluated radiation exposure to vari-

<table>
<thead>
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<th>Table 2. Illustration of radiation exposure in 1,000 patients.</th>
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<tr>
<td><strong>Number</strong></td>
</tr>
<tr>
<td>Per procedure</td>
</tr>
<tr>
<td>Per patient</td>
</tr>
<tr>
<td>Cervical facet joint nerve blocks</td>
</tr>
<tr>
<td>Caudal/interlaminar epidurals</td>
</tr>
<tr>
<td>Lumbar facet joint nerve blocks</td>
</tr>
<tr>
<td>Intercostal nerve blocks</td>
</tr>
<tr>
<td>Percutaneous adhesiolysis</td>
</tr>
<tr>
<td>Lumbar transforaminal epidurals</td>
</tr>
<tr>
<td>Thoracic facet joint nerve blocks</td>
</tr>
<tr>
<td>Joint injections</td>
</tr>
<tr>
<td>Cervical transforaminal epidurals</td>
</tr>
<tr>
<td>Stellate ganglion blocks</td>
</tr>
<tr>
<td>Lumbar sympathetic blocks</td>
</tr>
<tr>
<td>Medical branch neurotomy</td>
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<tr>
<td>Spinal endoscopy</td>
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</tbody>
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Reproduced from Manchikanti et al\textsuperscript{9} with permission from the authors and the American Society of Interventional Pain Physicians.
ous regions with physicians at various levels of training. Groups were based on experience of the physician with Group III undergoing procedures with a physician having the highest level of experience; Group II with an intermediately-experienced physician; and Group I with the least experienced physician.

Table 3 shows the procedural characteristics and radiation exposure in seconds.

<table>
<thead>
<tr>
<th>Procedure</th>
<th>Group I</th>
<th>Group II</th>
<th>Group III</th>
</tr>
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<tbody>
<tr>
<td>Per procedure</td>
<td>12.0* ± 0.49 (330)</td>
<td>9.0* ± 0.37 (662)</td>
<td>7.5 ± 0.27 (827)</td>
</tr>
<tr>
<td>Lumbar facet joint nerve blocks</td>
<td>11.7* ± 0.56 (143)</td>
<td>7.0* ± 0.32 (208)</td>
<td>5.7 ± 0.17 (180)</td>
</tr>
<tr>
<td>Cervical facet joint nerve blocks</td>
<td>10.4* ± 0.65 (73)</td>
<td>5.5 ± 0.23 (131)</td>
<td>5.9 ± 0.14 (265)</td>
</tr>
<tr>
<td>Caudal/interlaminar epidurals</td>
<td>11.7* ± 1.41 (56)</td>
<td>8.7* ± 0.96 (95)</td>
<td>3.7 ± 0.29 (141)</td>
</tr>
<tr>
<td>Lumbar/cervical transforaminal epidurals</td>
<td>14.0 ± 1.77 (26)</td>
<td>15.0* ± 1.23 (80)</td>
<td>10.6 ± 0.60 (92)</td>
</tr>
<tr>
<td>Percutaneous adhesiolysis</td>
<td>20.8 ± 5.65 (5)</td>
<td>14.5 ± 1.69 (28)</td>
<td>18.9 ± 1.72 (50)</td>
</tr>
<tr>
<td>Thoracic facet joint nerve blocks</td>
<td>11.5* ± 2.17 (13)</td>
<td>7.9 ± 1.14 (29)</td>
<td>5.6 ± 0.65 (29)</td>
</tr>
<tr>
<td>Sacroiliac joint injection</td>
<td>15.0* ± 4.89 (5)</td>
<td>3.7 ± 0.28 (50)</td>
<td>7.5 ± 3.20 (4)</td>
</tr>
<tr>
<td>Intercostal/paravertebral/lumbar sympathetic nerve blocks</td>
<td>10.0 (1)</td>
<td>12.5 ± 3.40 (13)</td>
<td>7.4 ± 1.09 (27)</td>
</tr>
</tbody>
</table>

( ) Indicates number of procedures
* Indicates significant difference: Group III vs. Groups I & II
# Indicates significant difference: Group II vs. Group I

Procedures performed less than 25 times were not listed in this table; however, they were utilized in calculating the exposure and per procedure.

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- Manchikanti et al° also evaluated scatter radiation inside and outside the apron.
- Table 4 shows scatter radiation exposure outside and inside apron to various physicians.

Table 4. Illustration of scatter radiation exposure in mREM outside and inside lead apron.

<table>
<thead>
<tr>
<th>Location of Dosimetry Badge</th>
<th>Group I (330)</th>
<th>Group II (662)</th>
<th>Group III (827)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chest [outside]</td>
<td>510</td>
<td>535</td>
<td>690</td>
</tr>
<tr>
<td>Neck [inside]</td>
<td>68</td>
<td>25</td>
<td>0</td>
</tr>
<tr>
<td>Groin [inside]</td>
<td>0</td>
<td>0</td>
<td>15</td>
</tr>
<tr>
<td>Groin [outside]</td>
<td>1,260</td>
<td>400</td>
<td>1,152</td>
</tr>
</tbody>
</table>

( ) Indicates number of procedures

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Manchikanti et al\textsuperscript{44} have shown the effectiveness of protective measures in interventional pain management as illustrated in Tables 5 and 6.

Botwin et al\textsuperscript{15,16,28,29} evaluated radiation exposure to a physician performing fluoroscopically-guided caudal epidural steroids injections, lumbar transforaminal epidural steroid injections, and lumbar discography.

The results showed that total fluoroscopic time was 15.6 seconds on average for transforaminal epidural steroid injections,\textsuperscript{15} 12.55 seconds for caudal epidural steroids injections,\textsuperscript{16} and 57.24 seconds for lumbar discography.\textsuperscript{29}

### Table 5. Illustration of procedural characteristics and radiation exposure in seconds.

<table>
<thead>
<tr>
<th></th>
<th>Group I (509)</th>
<th>Group II (500)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Per patient</td>
<td>12.5 ± 0.40</td>
<td>8.9* ± 0.40</td>
</tr>
<tr>
<td>Per procedure</td>
<td>7.5 ± 0.27</td>
<td>4.9* ± 0.11</td>
</tr>
<tr>
<td>Face joint nerve blocks (cervical/lumbar/thoracic)</td>
<td>5.8 ± 0.11 (474)</td>
<td>4.5* ± 0.07 (481)</td>
</tr>
<tr>
<td>Epidurals (caudal/interlaminar)</td>
<td>3.7 ± 0.29 (141)</td>
<td>2.7* ± 0.27 (160)</td>
</tr>
<tr>
<td>Transforaminal (cervical/lumbar)</td>
<td>10.6 ± 0.60 (92)</td>
<td>8.4* ± 0.50 (102)</td>
</tr>
<tr>
<td>Percutaneous adhesiolysis</td>
<td>18.9 ± 1.72 (50)</td>
<td>11.8* ± 2.39 (35)</td>
</tr>
<tr>
<td>Intercostal/sympathetic blocks (cervical or lumbar)</td>
<td>7.4 ± 1.09 (27)</td>
<td>4.0* ± 0.35 (35)</td>
</tr>
</tbody>
</table>

( ) Indicates number of procedures
* Indicates significant difference

Procedures performed less than 25 times were not listed in this table; however, they were utilized in calculating the exposure and per procedure.

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### Table 6. Illustration of scatter radiation exposure in mREM outside and inside lead apron.

<table>
<thead>
<tr>
<th>Location of Dosimetry Badge</th>
<th>Group I</th>
<th>Group II</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of patients</td>
<td>509</td>
<td>500</td>
</tr>
<tr>
<td>Number of procedures</td>
<td>827</td>
<td>865</td>
</tr>
<tr>
<td>Neck [inside]</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Chest [outside]</td>
<td>690</td>
<td>313</td>
</tr>
<tr>
<td>Chest [inside]</td>
<td>NA</td>
<td>0</td>
</tr>
<tr>
<td>Groin [outside]</td>
<td>1152</td>
<td>176</td>
</tr>
<tr>
<td>Groin [inside]</td>
<td>15</td>
<td>13</td>
</tr>
</tbody>
</table>

NA = Not available

Reproduced from Manchikanti et al\textsuperscript{44} with permission from the authors and the American Society of Interventional Pain Physicians.
Zhou et al evaluated fluoroscopic radiation safety for spine interventional pain procedures in university teaching hospitals. The results of their study showed that fluoroscopic exposure time for various interventional procedures performed in university settings was significantly higher than were the radiation exposures in private practice settings as shown in Fig. 9. This study also showed significant differences among physicians in the same university setting.

A. Mean fluoroscopic time for common pain procedures.

ESI = epidural steroid injection; FB = facet joint block; SB = sympathetic nerve block; SI = sacroiliac joint injection; DG = discography.

B. Mean fluoroscopic time for epidural steroid injection by physicians.

C. Mean radiation dose for epidural steroid injection by physicians.

Letter A to G represent 7 attending physicians unrelated to their first or last name. There is a significant difference on the radiation dose for Epidural Steroid Injection (ESI) among the physicians (F(6,92)=3.493; p=0.0037)

Fig. 9. Illustration of fluoroscopic exposure for interventional procedures in an academic setting. Reproduced from Zhou et al with permission from the authors and the American Society of Interventional Pain Physicians.
Key Points

1. Over the past 20 years, fluoroscopy has revolutionized the medical treatment of pain.

2. The history of the discovery of fluoroscopy dates back to November 8, 1985, when Professor Wilhelm Roentgen discovered x-rays.

3. When high velocity electrons collide with metal, the kinetic energy contained within the electrons is converted to electromagnetic energy released in the form of x-rays.

4. The function of the fluoroscope is to provide a steady stream of high velocity electrons in order to produce a continuous, controllable stream of x-ray radiation. The term fluorescent describes a property of certain materials that emit visible light when exposed to stimulation by chemicals, electricity, or ionizing radiation.

5. The fluoroscopic picture that is produced is composed of shadows created as x-rays or absorbed preferentially by body tissues of various densities. The fluoroscopic imaging chain consists of various components including an x-ray tube with cathode and anode, an image intensifier, and a fluorescent phosphor screen to capture the image created.

6. Direct current from the x-ray generator is transmitted into the x-ray tube during an x-ray exposure.

7. The image intensifier takes the incoming x-rays and converts them to electrons in a series of steps that take place within the input layer and brightens the viewable image.

8. The modern fluoroscopes provide facilities to collimation, and incorporate optical coupling.

9. Radiation exposure may be associated with risks to the physician, patient, and personnel.

10. Most interventional procedures in the management of chronic pain require fluoroscopic exposure only for short periods of time. Biologic effects of radiation are grouped as stochastic and nonstochastic and follow the principles of ALARA, “as low as is reasonably achievable,” all the time.
References


5. www.mayoclinic.com


8. FDA Public Health Advisory: avoidance of serious x-ray induced skin injuries to patients during fluoroscopically guided procedures. Food and Drug Administration: Rockville, MD; September 9, 1994.


Washington, DC; 1993.


