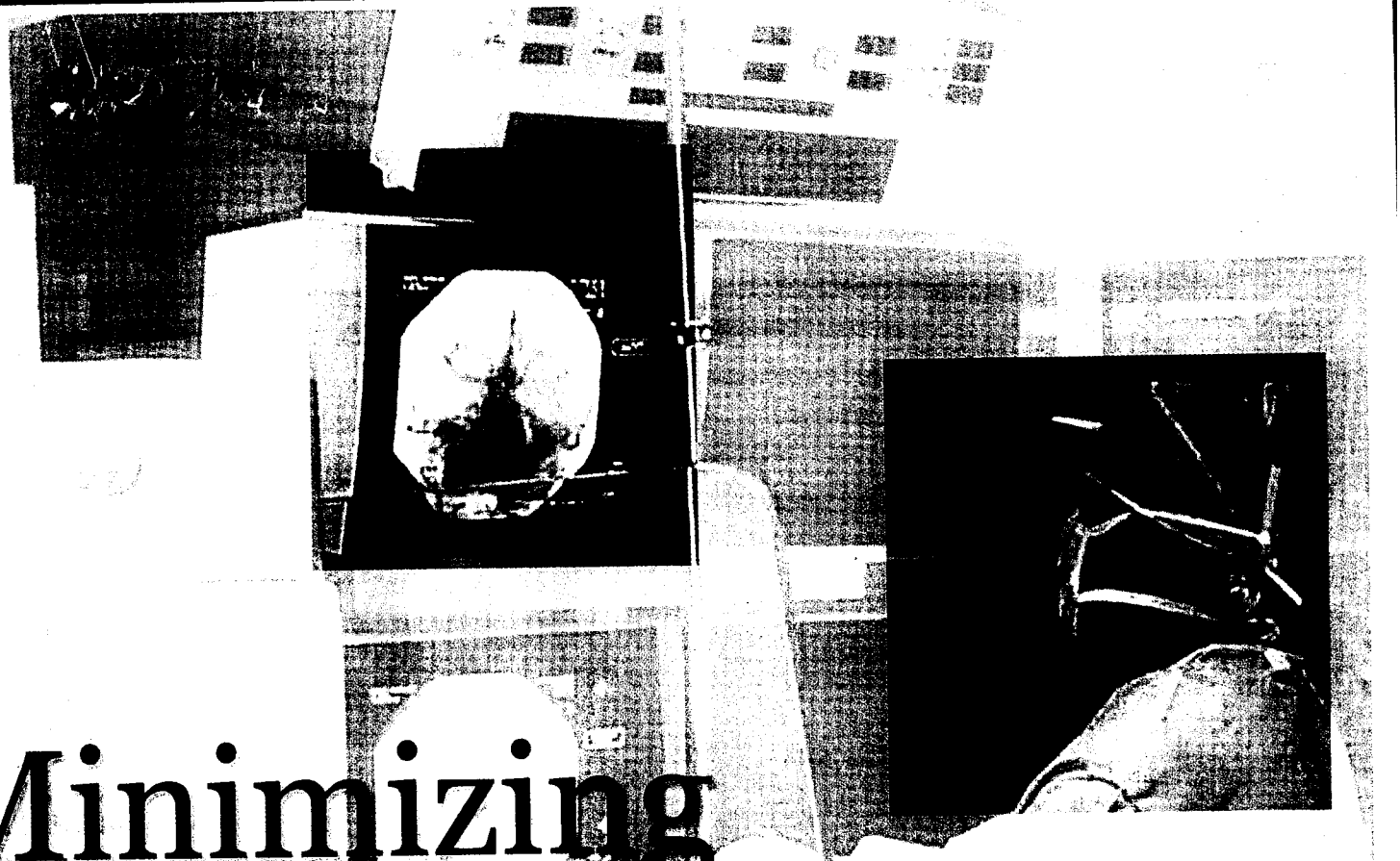

Minimizing Risks from Fluoroscopic X Rays

Third Edition

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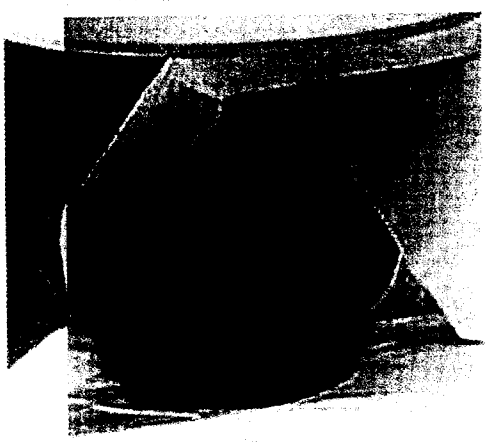

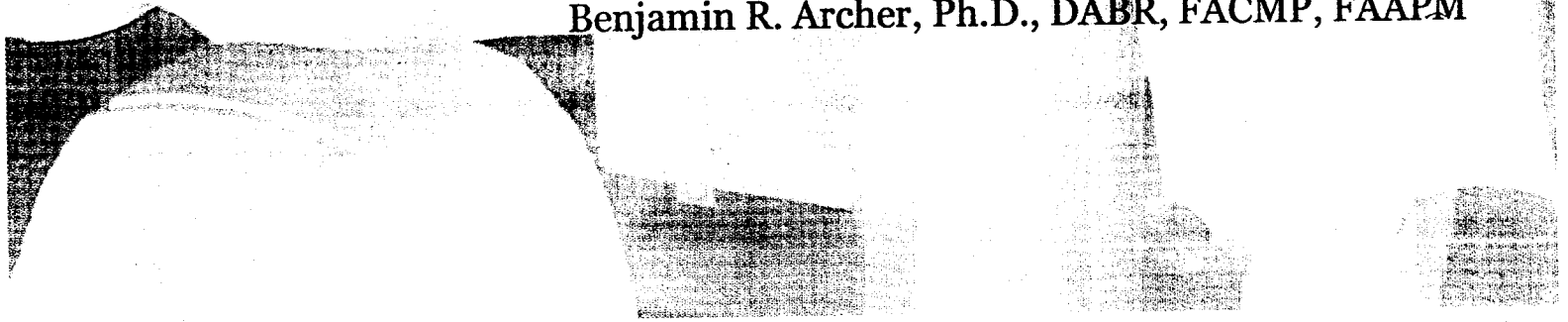

Instruction Manual

The following section contains the instruction manual on fluoroscopy. This section is copyrighted material and may not be reproduced in any form without the written permission of R. M. Partnership.

The instruction manual is a comprehensive review of radiation management for numerous types of fluoroscopic procedures. Few physicians will use every type of fluoroscopic device. For example, orthopedic surgeons will not likely need to employ cine fluorography, since cine is almost exclusive to cardiology. However, high-dose-rate fluoroscopy may be a feature of c-arm fluoroscopes that they do use. It is necessary that they be aware of high-dose-rate modes of operation and the precautions to be enforced in their use. We therefore recognize that some physicians may wish to skip over sections that deal with technologies with which they have no involvement. However, we caution that some discussions, while seeming to be irrelevant to an individual's practice, may in fact be very relevant. The reader is left to his/her own discretion in these matters.

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Ten Commandments
for
Minimizing Risks from Fluoroscopic X Rays

#1: Remember, dose rates will be greater and dose will accumulate faster in larger patients.

#2: Keep the tube current as low as possible.

#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.

#4: Keep the patient at maximum distance from the x-ray tube.

#5: Keep the image intensifier as close to the patient as possible.

#6: Don't overuse geometric or electronic magnification.

#7: If image quality is not compromised, remove the grid during procedures on small patients or when the image intensifier cannot be placed close to the patient.

#8: Always collimate down to the area of interest.

#9: Personnel must wear protective aprons, use shielding, monitor their doses, and know how to position themselves and the machines for minimum dose.

#10: Keep beam-on time to an absolute minimum!

—The Golden Rule

Introduction

The benefits and potential dangers of medical applications of fluoroscopy have been known for over 100 years. In the early decades of the 20th century numerous physicians and patients were severely injured by exposure to fluoroscopic radiation. Many physicians died of radiation-induced cancer. Prompted by the growing evidence of radiation-induced cancers and severe skin reactions, governmental agencies instituted regulations on the design and use of fluoroscopic equipment in medicine. With better controls on equipment design and heightened awareness on the part of practitioners, the number of adverse events declined. Unfortunately, this has lured generations of practitioners into the false sense of security that regulations and new technologies have rendered fluoroscopic injuries a thing of the past. *In fact, some modern instrumentation and medical advances have actually increased the potential for injury to patients and to personnel.* Since about 1990, a growing number of cases of fluoroscopically-induced **epilation, dermatitis and dermal necrosis have been reported in patients and physicians** (1-21). The United States Food and Drug Administration (FDA) has documented at least 40 cases of **radiation-induced skin injury in patients** from fluoroscopically guided procedures (13). Some have required skin grafts or myocutaneous flaps. We are aware of many additional injuries and have personally observed **serious radiation injuries in physicians** who have recently (since 1994) started using fluoroscopy in their practice. Vañó (22) has reported on **radiation-induced cataracts in physicians and assistants**. This increase in injuries is directly related to the burgeoning growth of interventional medical procedures that rely heavily on fluoroscopy for the proper placement of medical devices.

Key to the safe operation of fluoroscopy is the training of personnel responsible for its use. While adverse health effects from fluoroscopy are unlikely, they can be severe. *It is essential that radiation be properly managed to minimize risks to patients, to operators, and to personnel.* On September 9, 1994, the FDA (23) specifically addressed its concern about the "occasional but severe" radiation injuries in patients and advised facilities about the need for proper training of fluoroscopy personnel. Specific recommendations of this **1994 FDA Advisory** include the following:

- that facilities assure appropriate credentials and training for physicians performing fluoroscopy;
- that all operators be trained and understand system operation, including the implications for radiation exposure from each mode of operation;
- that facilities ensure that physicians performing fluoroscopic procedures have education so they may, on a case-by-case basis, assess risks and benefits for individual patients, considering variables such as age, beam location and direction, tissues in the beam and previous fluoroscopic procedures or radiation therapy;
- that patients be counseled regarding the symptoms and risks of large radiation exposures;
- that physicians justify and limit the use of high dose rate modes of operation;
- that information regarding absorbed dose to

the skin of the patient be recorded in the patient's medical record if it exceeds a selected dose threshold.

X rays are an indispensable medical tool that must be applied with a great deal of respect for their potential hazards. Moreover, diagnostic x rays are the principal source of exposure of the general public to potentially carcinogenic man-made ionizing radiations. The responsibilities and the liabilities of the fluoroscopist who uses diagnostic x rays on a patient are similar to those involved in dispensing a legally controlled substance. As with drugs, small quantities of x rays can be detrimental to health, but the risk is extremely low. When used in large quantities, the risks are greater and very serious injuries can occur. *For these reasons, only the medical profession is legally permitted to directly and intentionally expose an individual, as a patient, to x rays.* This fact places a serious responsibility on the medical profession to train physicians in the safe, efficient, and frugal use of diagnostic-type radiation. This monograph is designed as a concise educational program to help facilities and their physicians meet the goals and recommendations of the FDA and to establish a safe working environment for all.

Qualifications Necessary to Operate a Fluoroscope

-The Need for Training

When used under properly controlled conditions, radiation is a safe and indispensable tool in the diagnosis of disease, but its proper application requires training. A large population of physicians who use fluoroscopy have effectively no training in the safe uses of fluoroscopic equipment, the management of radiation, or the biological effects associated with its use. The FDA warning points out that training of physicians for modern-day use of the fluoroscope is probably insufficient and needs to be expanded.

-The Role of Regulation and Certification

Most states in the United States and most industrialized countries have numerous regulations regarding the operation of radiation producing equipment. Regulations in the absence of training specific to medicine are insufficient to prevent severe radiation effects. A few regulatory bodies (e.g., state regulatory agencies) have mandated specific educational requirements for physician operators of the equipment, but most do not.

Board certification is an important tool for maintaining minimum standards for competency in medical practice. However, few board examinations test for knowledge in the area of the safe uses of fluoroscopy. The certification examination of the American Board of Radiology requires that candidates have comprehensive knowledge in the physics of imaging, radiation effects, and radiation control. Other medical boards have not previously placed such an emphasis on these aspects of radiation in medicine, but they will be included in some board examinations in cardiology.

-The Role of Credentialing

The FDA has pointed out the need for health care facilities to ensure the proper training and credentialing of physicians who perform fluoroscopy in their institutions. Credentialing of a practitioner implies that a physician is qualified not only to perform the medical procedure, but also to perform it safely.

Medical boards at some facilities, in cooperation with radiation safety staff, have taken a proactive response to the FDA advisory by mandating training and credentialing of physicians before authorizing them to use fluoroscopy.

-Before Operating the Fluoroscope

Before you operate medical x-ray equipment, you should know the laws in your state and apply a few common-sense principles to optimize the safe delivery of radiation. As the operator of the equipment you must know:

- How to properly operate the x-ray machine and the features specific to that unit,
- How to properly position the patient and the x-ray system for the procedure,
- How to control image quality (by controlling kVp, mA, use of a grid, etc.),
- How to minimize radiation levels (by using collimation, special dose rate controls, etc.),
- How the radiation is distributed in the room,
- How to position personnel for minimum radiation exposure,
- How to properly use shielding devices and personnel-monitoring devices.

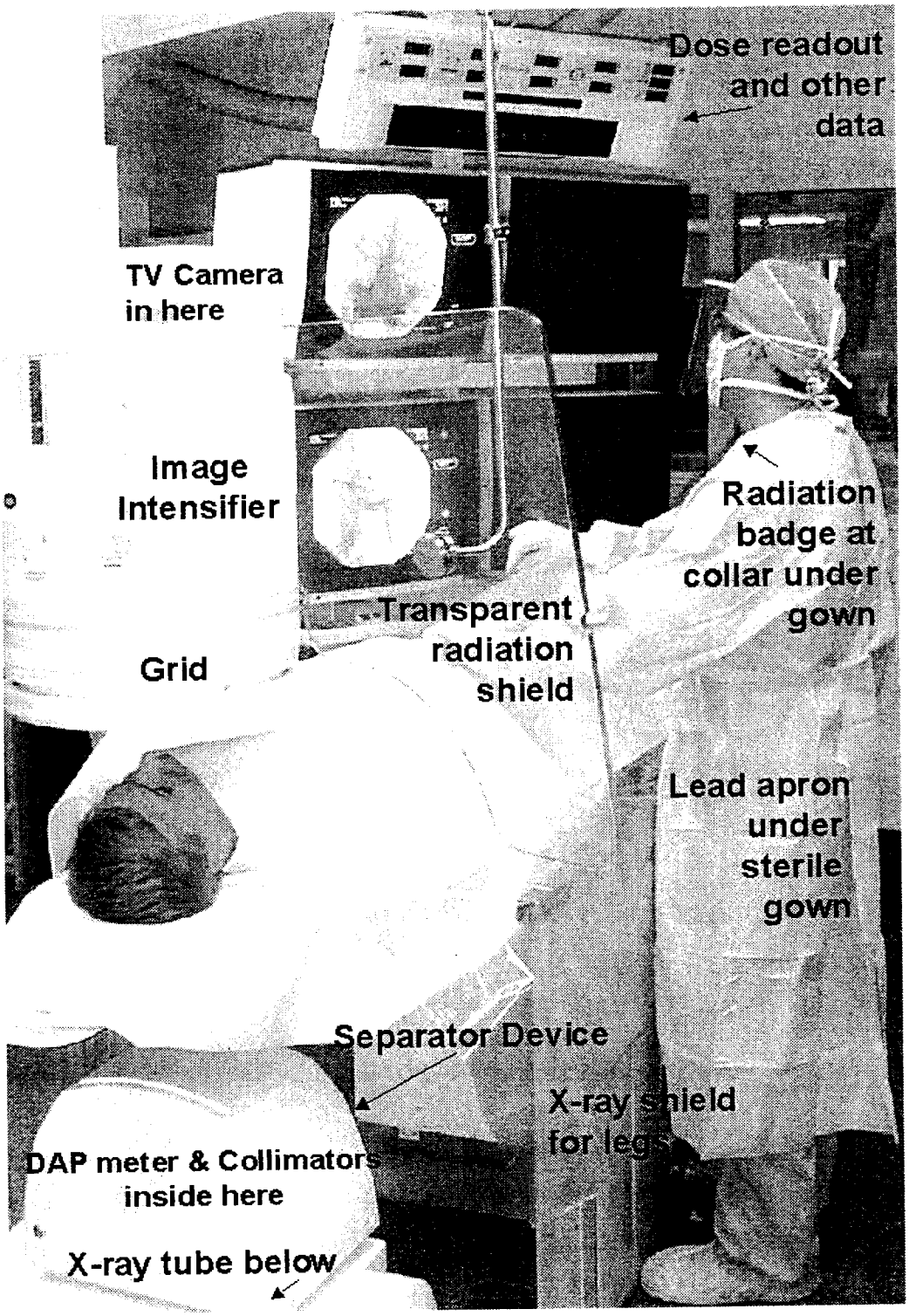
Operators of equipment must receive specific training on their units since the configuration of the system control panel and other features usually differ from machine to machine. Most machines have special controls to adjust dose rate and image quality for specific applications. It is essential that users understand the function of and the result of applying each of these controls. An improper choice can result in severe health detriment for patients and practitioners.

-Training

For new equipment an application specialist from the manufacturer normally provides training. This individual will travel to your facility to instruct staff in the proper operation of the unit. Larger facilities also employ a medical physicist who performs evaluations on the performance of x-ray equipment. Many medical physicists are board certified and can provide information about equipment, radiation management, safety and biological effects. You should not hesitate to approach these professionals with your questions.

Nurses or physician assistants may sometimes be asked to operate x-ray equipment during procedures. If this is the case in your facility, prudence would dictate that they be trained in its safe and proper operation and in the biological hazards associated with its use. In some localities, regulations may require special training or licensing and prohibit use by untrained personnel. However, it is the physician who remains responsible for assuring that the x rays are safely and properly applied and that appropriate radiation protection measures are followed.

Fundamental Features of the Fluoroscopic Setting — A Neuroangiography Suite



Fundamental Properties of X rays

-X Rays and Light

Ultraviolet light, visible light and **x rays** consist of a multitude of individual particles of radiation called photons. Light photons and x-ray photons are each a form of electromagnetic radiation and have analogous properties:

- Light photons pass through some objects like glass or the cornea and lens of the eye. *X rays are far more energetic and penetrate the body, some passing completely through it.*
- Light interacts with human tissue such as the retina and the skin, effecting vision and a sun tan. *Most x rays interact in the human body.* Some are completely absorbed; others are deflected away from their normal course of travel. Those relatively few x rays that successfully pass through the patient make the radiograph.
- Light that is too intense causes blindness and skin burns. *Very high exposure to x rays causes cataracts, skin necrosis and other permanent changes in the skin.* The severity of the effect is related to the energy absorbed by the tissue, i.e., the dose.
- Chronic exposure to ultraviolet light can lead to skin cancer. *Any exposure to x rays is thought to have the potential to cause cancer that may develop years later.*
- We protect ourselves from intense sunlight by wearing sunscreen or sunglasses. *We protect ourselves from x rays by wearing lead aprons, protective lenses, and using other forms of shielding.*

When x rays interact in a patient, many are scattered in random directions from the exposed volume of the patient. *These scattered x rays are the principal source of radiation exposure to personnel during fluoroscopy.* Since chronic exposure to x rays can lead to increased health risks, ***learning to manage radiation well is an investment in good health—yours, your co-workers, and your patients!***

-Radiation Quantities and Units

A quantity of x rays can be described in a variety of ways. The chosen method of quantification depends on what one wishes to communicate about the radiation. *If the purpose is simply to specify the amount of radiation that exists at a position in space, such as the output of a fluoroscope, then **air kerma** is the quantity of choice.* If the potential health consequences are the issue, the **absorbed dose** or **effective dose** might be quoted. *Absorbed dose is used if the concern is the risk for inducing a skin injury, cataract, or a cancer in a specific organ. Effective dose is a hypothetical entire-body dose that would produce the same quantitative risk for cancer or heritable effects as the dose actually delivered to the specific organ.* Equivalent dose is another quantity of interest, but it is not relevant to fluoroscopy. These quantities are defined and discussed below.

Absorbed dose

X rays ionize human tissues and deposit energy. This is the first step in a series of events that may lead to a biological effect. *The concentration of energy deposited locally in tissue is called the **absorbed dose*** and provides an important measure of the potential for biological effects. The term "absorbed dose" is often truncated to just "**dose**". Whenever the term "dose" is used without additional modifiers, the concept of "absorbed dose" is to be understood. *Absorbed dose is measured in units of **gray (Gy) or***

milligray (mGy$_t$), where the subscript "t" specifies the dose as being in tissue. One gray of absorbed dose in tissue is equivalent to an energy deposition of 1 joule in 1 kilogram of tissue mass. A typical fluoroscopic examination of the lower GI tract results in a skin dose of about 100 mGy$_t$ (0.1 Gy$_t$). The dose required to produce desquamation is more than 10,000 mGy$_t$ (10 Gy$_t$). [Note: **entrance skin dose** is the dose located at the surface where the x rays enter the patient. Dose inside the patient is less and decreases by about a factor of 2 for each 4 cm of depth. The exit skin dose for a 25-cm thick abdomen is only about 1 – 2 % that of the entrance dose.]

Absorbed dose rate is the rate at which absorbed dose accumulates. It is typically measured in units of mGy$_t$/min or mGy$_t$/h. A fluoroscope typically produces an entrance dose rate to the patient's skin of about 30 mGy$_t$/min. The dose rate to unprotected tissues of an attending staff member one meter away would be approximately 0.03 mGy$_t$/min (1.8 mGy$_t$/h).

An outdated unit of absorbed dose commonly used in the United States is the **rad**. This unit has been replaced by the standard international unit of gray. *One rad is equivalent to 10 mGy$_t$.* One Gy$_t$ is equivalent to 100 rad.

Free-in-air air kerma

The quantities used to measure how much radiation is present at a specific position include ***free-in-air air kerma*** and ***air kerma rate***. "Free-in-air" means that the measurement is done in air away from any surface that might increase the measurement by reflecting or scattering radiation into the area of interest. *At diagnostic energies, "air kerma" is essentially the energy deposited per mass of air or the absorbed dose to air at the position of interest. Air kerma is measured in units of* ***gray (Gy$_a$)*** *or* ***milligray (mGy$_a$)***, where the "a" specifies the dose as being in air. [We note that the quantities of **air kerma** and **absorbed dose in tissue**, although measurably different, have the same units – gray (Gy) or milligray (mGy). To distinguish these two quantities and avoid confusion, we put subscripts on the units to identify them as a unit of air kerma (Gy$_a$ or mGy$_a$) or as a unit of absorbed dose in tissue (Gy$_t$ or mGy$_t$).] There is no fixed relationship between free-in-air air kerma and the absorbed dose to tissue when the patient is at the same position. However, for usual fluoroscopic field sizes the relationship may be approximated as follows:

Absorbed dose to skin in mGy$_t$ ≈
1.4 •free-in-air air kerma in mGy$_a$

The quantities of **exposure** and **exposure rate**, although outdated, are often used instead of air kerma and air kerma rate. The unit of exposure used in the United States is **roentgen (R)**. *One R of exposure is equivalent to 8.76 mGy$_a$ of air kerma.*

Equivalent dose

Equivalent dose *is a tissue dose that accounts for the different ionizing properties of other forms of radiations that are not of concern to fluoroscopy.* However, for radiation protection purposes, regulatory dose limits to specific body sites, such as hands or lens of the eye, are quoted in units of equivalent dose. The units are **sievert (Sv)** and **millisievert (mSv)**. When used for fluoroscopy and diagnostic radiology, an absorbed dose in mGy$_t$ is the same quantitative value as an equivalent dose in mSv, i.e., 1 mGy$_t$ = 1 mSv.

In the United States, a unit of equivalent dose that is often used is the **rem**. This outdated unit

has been replaced with the international standard of sievert. *One rem is equal to 10 mSv. One Sv is the same as 100 rem.*

Effective dose

Effective dose *is a quantity devised to account for the fact that exposures to people are not typically spatially uniform.* For example, the lead apron blocks most of the exposure to the thorax and abdomen of fluoroscopy personnel, but the head, legs and arms are unprotected. *The effective dose is that dose which would have to be given to your entire unprotected body to produce the same health risk as the nonuniform dose that you received while wearing the apron.* It is measured in units of sievert (Sv) and millisievert (mSv). For radiation protection purposes, regulatory limits on whole-body exposures to personnel are given in terms of effective dose. Such doses cannot be measured directly. They are extracted from the data generated from film badges or other types of personal radiation monitors. A typical monthly film badge reading for a fluoroscopist who wears the badge at the collar might be about 0.3 to 3.0 mSv. As a regulatory convenience, the extracted effective dose is sometimes quoted as 1/3 the collar reading, or about 0.1 to 1.0 mSv for our example. In reality, the true effective dose is less than this. Your monthly effective dose from naturally existing radiation, such as radon gas, cosmic radiation, and naturally existing radioactivity is about 0.3 mSv.

In the United States, effective dose is often quoted in units of rem. The rem is outdated and has been replaced by the sievert. In our example, 0.3 mSv is 30 mrem.

Dose-area product

The overall carcinogenic risk to a patient depends on the absorbed dose in tissue and the amount of tissue exposed. Recall that absorbed dose refers to the concentration of energy deposited locally at any point in tissue and is the quantity that best reflects the potential for injury at that point. It does not depend on the area exposed. **Dose-area product (DAP)**, on the other hand, depends directly on area since it is obtained by multiplying the dose in air (i.e., the air kerma) times the area of the beam. DAP thus refers to the concentration of energy imparted to a cross sectional area of air. Note that this quantity increases with increasing beam area (field size), even if the air kerma remains unchanged. DAP reflects carcinogenic risk better than absorbed dose because it includes the size of the exposed area. Narrower beams result in lower DAP and thus less risk because a smaller amount of tissue is exposed.

DAP may be used to monitor radiation output from radiographic machines, including fluoroscopes. Typically the device used to measure DAP is placed near the x-ray source before the beam enters the patient (see page 4). The measurement is usually provided in units of $cGy_a \bullet cm^2$ (1 cGy_a = 1 centigray$_a$ = 10 mGy_a). To obtain a measure of the risk for injury to the skin where the beam enters the patient, absorbed dose can be derived by dividing the DAP measurement by the area of the beam at the skin. This yields the air kerma at the skin, which can be converted to tissue dose through the equation on the previous page. Using DAP to monitor radiation usage is discussed further in the subsection entitled: "Monitoring doses to patients".

Biological Effects

Potential biological effects of radiation are classified as either **stochastic** or **deterministic**. Stochastic effects include neoplasm and heritable changes in reproductive cells. Deterministic effects include cataract and radiation-induced epilation, erythema, and necrosis. The differences in these two categories result from the fact that changes in a single cell are sufficient to cause stochastic effects but deterministic effects cannot be induced unless there are changes in many cells.

Ionizing radiation can induce a change in the genetic material of a single cell that might initiate development of a neoplasm, a stochastic event. Theoretically, this could occur at any dose level. However, at low doses the likelihood of inducing those precise changes necessary to cause the effect is very small. This probability increases with increasing dose because more interactions occur and thus the likelihood of inducing the necessary changes in one cell increases. *Thus, for stochastic effects, the effect might be produced at any dose and the probability of inducing the effect increases with increasing dose. The severity of the effect is independent of dose.*

For deterministic effects, changes must occur in many cells before the effect, such as erythema, manifests itself. For these events to occur, a certain dose level must be reached. This is known as the threshold dose since the effect cannot be induced at lesser doses. As dose increases above the threshold the likelihood and the potential severity of the effect increases. *Thus, for deterministic effects, a threshold dose exists and the likelihood of the effect occurring, as well as its severity, increases as dose increases beyond the threshold.*

Radiation-induced Cancer

Interactions of x rays in tissues cause ionization and a subsequent breakdown of biomolecules. The biomolecular components may chemically interact with other biomolecular material, causing further changes in cellular matter. Following low-dose exposure to x rays, these events are likely to be inconsequential to the tissue due to the repair mechanisms that nullify induced changes. However, it is always possible that permanent changes in the genetic material of one cell may be induced. These changes could be passed on to future generations of cells. The possibility exists that specific changes in the genes may initiate carcinogenesis. The **latent period** between irradiation and diagnosis may be as short as two years or as long as many decades. *It is hypothetically possible that any dose of radiation, no matter how small, could induce cancer.* Because of the low frequency of occurrence of such an event, it is not possible to prove or disprove this hypothesis. It is known that doses in excess of 200 mGy_t can induce cancers and the likelihood increases as the dose goes up. For an entire-body absorbed dose of 200 mGy_t the risk might be in the range of 0.2% - 1.6%.

Cancers in patients

Figure 1 is a breast cancer induced in the early 1950's (24) by extensive fluoroscopy and diagnosed in the early 1960's. There is always a long delay between exposure and diagnosis and it is not possible to biologically distinguish a radiation-induced cancer from a cancer of other etiology. Therefore, it is very difficult to identify a radiation-induced cancer. This case represents the rare instance wherein the historical circumstances strongly point to previous fluoroscopies as the cause of this cancer. In this case, the

patient underwent fluoroscopy of the lung more than 200 times with the breasts facing the x-ray tube. The cumulative absorbed dose to the patient's breast probably exceeded 40 Gy_t. ***Small doses from modern equipment might induce cancers***, but the frequency of induction would be too low to detect. *Because radiation at any level has the potential to cause cancer, fluoroscopy must be used with a strong measure of restraint.*

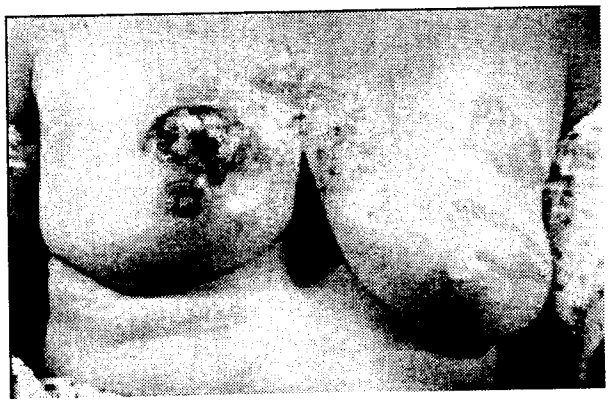


Figure 1. Breast cancer induced by fluoroscopic x rays. (Adapted with permission from MacKenzie I. Breast cancer following multiple fluoroscopies. Br J Cancer 1965; 19:1-8)

Cancers in physicians

Physicians who performed radiography and fluoroscopy in the first half of the 20th century died of cancer at a rate exceeding that of other physicians (25,26). With the implementation of sound radiation protection, this excess rate has fallen in fluoroscopists practicing later in the century. However, some cancers, such as multiple myeloma, are still found to be slightly in excess. Because radiation-induced cancers are a potential risk to any employee exposed occupationally to radiation, the only sensible approach is to learn how to minimize one's risk by minimizing exposure. There are no levels of exposure thought to be completely safe, but sound practices will keep the risks at acceptably low levels.

Lesson learned #1: X rays are a carcinogen and any dose of x rays has the potential to cause cancer. Fluoroscopists must diligently exercise sound radiation management to minimize risk to patients and to personnel.

-Radiation-induced Heritable Effects

It also may be possible that heritable changes in the genome of reproductive cells will affect descendants (27). The likelihood of this occurring in humans is extremely low, and has never been unequivocally demonstrated in any human. In fact, some humans have been rendered temporarily infertile by radiation only to recover and later parent normal children. The daughter of one such person is now a medical doctor.

All estimates of radiation-induced heritable risk in humans are derived from studies in animals. The only way to minimize this potential risk is to minimize the dose to as low as reasonably achievable. For patients, gonadal shields can be used to minimze dose to reproductive organs when they do not interfere with the intended diagnostic result. For personnel, proper radiation protection, including wearing of protective apparel, using shields, and monitoring exposure, is effective. These are discussed in detail later under commandment #9.

-Radiation-induced Injuries

If the dose from x rays is very high, cell damage is extensive. Repair mechanisms are overloaded. Cell death and tissue breakdown can occur. Figures 2 and 4 - 11 demonstrate this effect for medical fluoroscopy. ***X rays of sufficient intensity to cause such effects do not cause any sensation during the irradiation.*** Visual evidence of induced erythema may occur soon after the fluoroscopy but does not usually become apparent until days or weeks later. If the dose

exceeds certain threshold levels, tissue degeneration may develop over many months into ulceration and dermal necrosis (Figs. 3 - 7). Some single delivery (non-fractionated) threshold doses for certain effects are given in Table I. While these thresholds are based on current information, the reader should realize that they apply mostly to people with healthy skin, apply only to doses delivered in a very short period of time, and that there may be a wide variation of sensitivities among individuals. These thresholds should be used as guides, not as well-defined universal constants.

Table I. Potential effects in skin from fluoroscopy
(Adapted from Ref. 28 and revised according to recent information provided by private communication with J. W. Hopewell, 1999).

Effect	Single-dose threshold (Gy_t)	Onset
Early transient erythema	2	~2 – 24 h
Main Erythema	6	~10 d
Temporary epilation	3	~3 wk
Permanent epilation	7	~3 wk
Dry desquamation	14	~4 wk
Moist desquamation	18	~4 wk
Secondary ulceration	24	>6 wk
Late erythema	15	8 -10 wk
Ischemic dermal necrosis	18	>10 wk
Dermal atrophy (1st phase)	10	>12 wk
Dermal atrophy (2nd phase)	10	>1 y
Telangiectasia	10	>1 y
Dermal necrosis (late phase)	> 12?	>1 y
Skin cancer	None known	>5 y

Injuries to practitioners

Figures 2a – 2d represent a self-portrait series of a physician's hands years after intense exposure to fluoroscopic x rays (29). The physician (Mihran Krikor Kassabian, MD) took these photographs to encourage the prevention of such injuries in the future. Dr. Kassabian died of radiation-induced cancer in 1911 at the age of 40. This text is dedicated to his message of prevention.

Injuries to hands still a problem – true vignette #1

Injuries to hands of fluoroscopists still occur. In November of 1997, a physician presented his hands for examination to one of the authors (19). Radiation dermatitis was visible from the knuckles to the fingertips. The skin appeared scaly and discolored. There was no hair in the affected areas. The fingernails had brown striations. The similarities to Fig. 2a, although not as severe, were striking. His procedures involved the placement of needles and catheters into the spinal canals of patients lying prone on the examination table. Contrary to advice in this monograph, the physician was instructed that it was appropriate to use the machine with the x-ray tube above the patient. He frequently placed his hands in the direct beam. This combination of x-ray source orientation and frequent hand exposure led to years of excessive skin doses. Subsequently, his hands developed radiation dermatitis that was diagnosed about 3.5 years after commencement of his duties. It is not likely that the hands will recover completely from these injuries and long-term effects are a concern. The physician stated that his partner in practice also had symptoms. The authors are aware of additional recent cases of radiation effects in interventionalists.

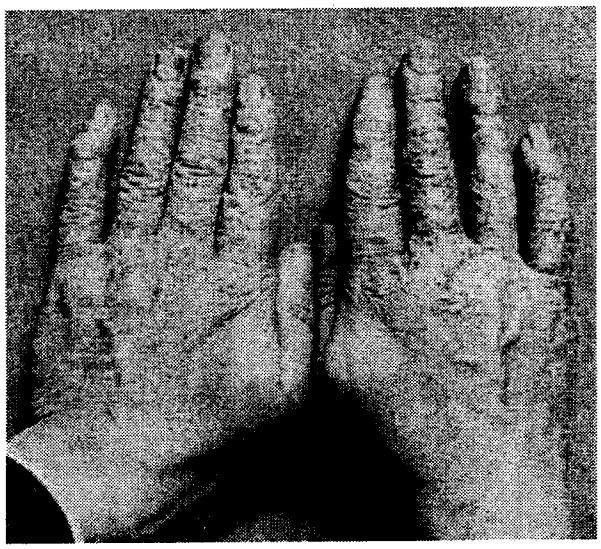


Figure 2a. Hands of Mihran Krikor Kassabian, M.D. after about seven years of direct irradiation from fluoroscopy (age about 33 y). In addition to the chronic radiation dermatitis, the nails are discolored. (From: Kassabian MK. Röntgen Rays and Electro-Therapeutics with Chapters on Radium and Phototherapy. Second Edition. Philadelphia: J. B. Lippincott Company, 1910; figure 209A.)

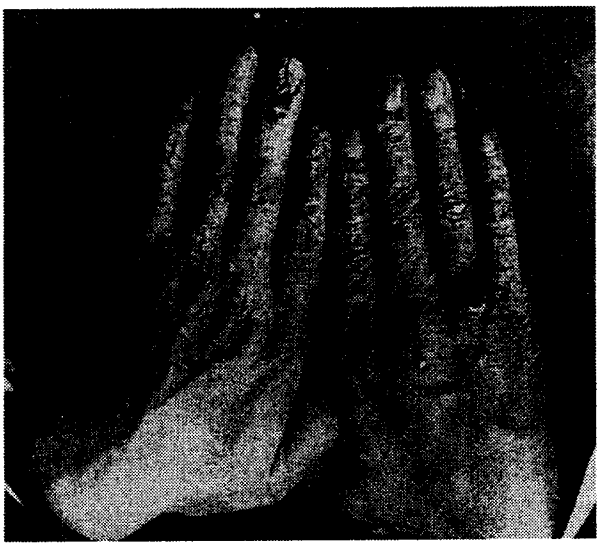


Figure 2b. Deterioration of hands of fluoroscopist in Fig. 2a about six years after image in 2a. Note the brittle, cracking nails and neoplasms. (From: Archives of the American College of Radiology, Reston, VA)

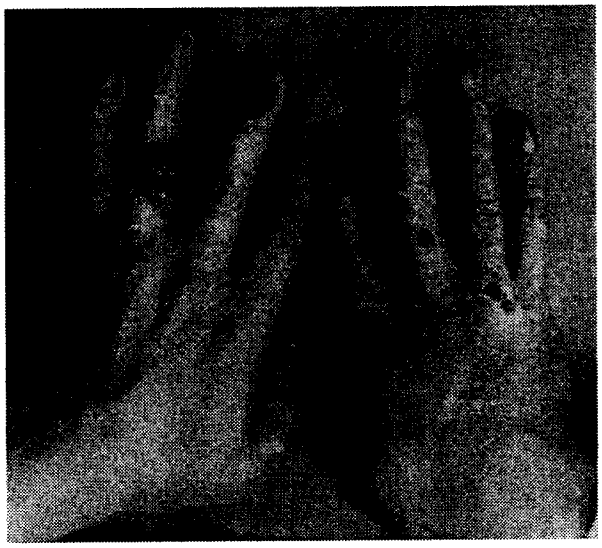


Figure 2c. Further deterioration of hands about one year after condition in Fig. 2b. (From: Archives of the American College of Radiology, Reston, VA)

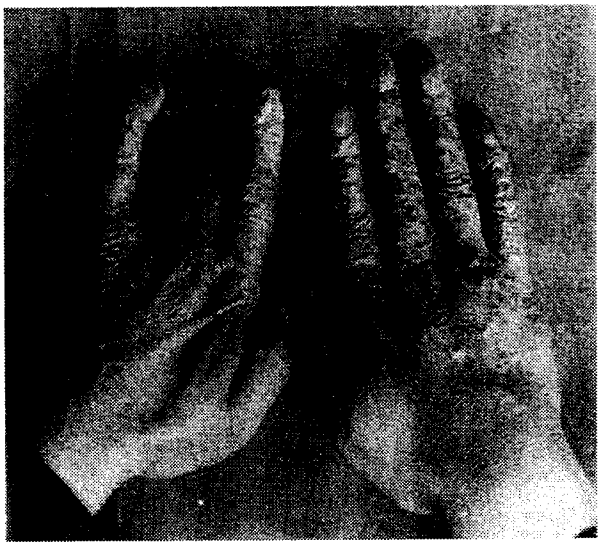


Figure 2d. Amputations and condition of hands five months after picture in Fig. 2c and shortly before death. (From: Archives of the American College of Radiology, Reston, VA)

Figure 3 demonstrates a wound on the finger of a dentist who routinely exposed his hand to x rays while holding the dental films during examinations. The cumulative damage over time resulted in ulceration. *This occurred in the late 1980's and demonstrates how small doses of radiation delivered repeatedly can accumulate to erode the skin.*

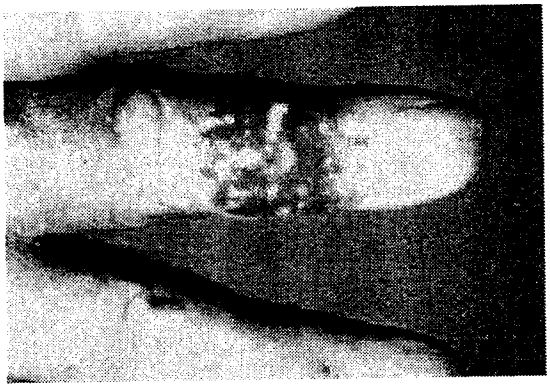


Figure 3. Dentist's finger after chronic exposure to x rays. (Courtesy of J. G. B. Russell)

Lesson learned #2: Fluoroscopists must know how to avoid chronic irradiation of their hands. This requires knowledge of how to orient the fluoroscope in relation to themselves and the patient. It also requires that they avoid direct irradiation of their hands, except under rare circumstances when patient care may require it. See commandment #9.

Injuries to patients

Figures 4 - 11 depict the severe consequences of high dose rates and long exposure times that result in large radiation doses to the patient. The notion that radiation injury is not possible today due to improved fluoroscopic equipment is not true. The injuries illustrated here occurred during fluoroscopic procedures in the 1990's. Although wounds of this severity are rare, doses required to produce such injuries can be readily achieved with modern equipment. There are two very important facts about radiation-induced effects: 1) there is **no sensation of temperature rise** at the time of irradiation that forewarns an exposed individual about the adverse event, and 2) manifestation of the effect is almost always delayed with respect to the irradiation. Therefore, unlike heat from a match that alerts an individual about the danger of getting too close, there is no preventative sensation from fluoroscopy that skin damage or a cancer is being induced. *Thus, in the absence of any warning signals, keeping radiation dose below thresholds for injury is the responsibility of the operator.*

Figure 4 depicts a radiation-induced injury in a patient who had three angioplasty procedures. An erythema appeared promptly after the third angioplasty and remained evident after several months (Fig. 4a). In Fig.4b the area of exposure appears to be healed, but there is a notable lack of skin tone due to the destruction of melanocytes. Figure 4c shows the deep necrosis that later developed as a result of radiation damage to the vascular system of the dermis. Figure 5 shows a similarly protracted development of a burn in a different patient following cardiac angioplasty (20). Erythema developed after 14 days with progression into ulceration and poor healing. The wound is shown about 12 months after the procedure. Wolff (21) has since communicated on six other cases of radiation dermatitis with a wide range of severities [see Wagner (17)].

Figures 6a – 6e depict a radiation burn induced in the right arm just above the elbow of a patient who underwent radiofrequency cardiac catheter ablation for arrhythmia. The inferior aspect of the right

Figure 4a. Erythema several months after angioplasty.

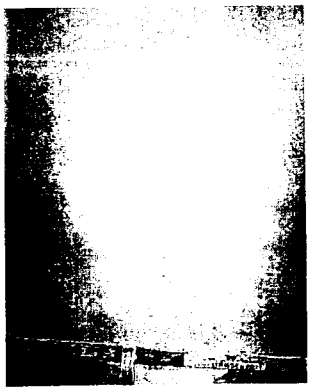


Figure 4b. Healing of patient in Fig. 4a five months after procedure.

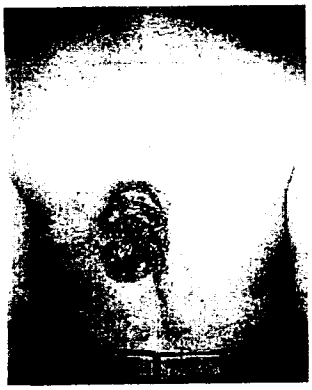


Figure 4c. Wound in patient of Fig. 4a at 22 months after angioplasty.

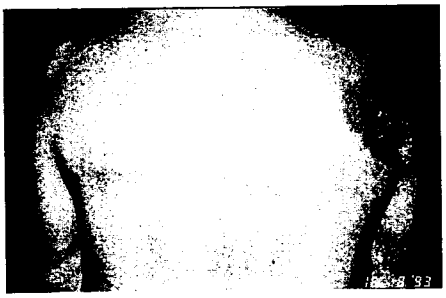


Figure 5. Fluoroscopically-induced ulcer. (Adapted with permission from: Wolff D and Heinrich KW. Strahlenschäden der Haut nach Herzkatheterdiagnostik und –therapie: 2 Kasuistiken. Hautnah derm 5: 450-452, 1993)

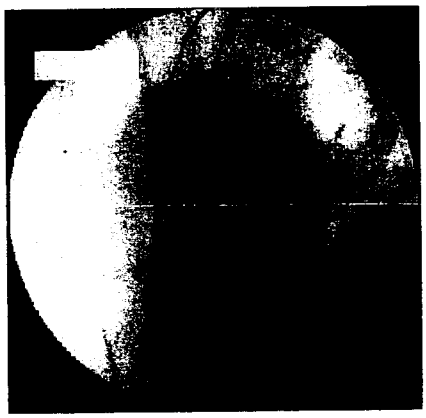


Figure 6a. EP catheter ablation, fluorograph with humerus in beam.

Figure 6b. Erythema about 3 weeks after procedure in Fig. 6a.

Figure 6c. Ulcer about 5 months after procedure in Fig. 6a.

Figure 6d. Extent of injury with humerus visible about 6.5 months after procedure in Fig. 6a.

Figure 6e. Surgical flap about 10 months after procedure in Fig. 6a.

humerus of the patient is visible in the fluorographic image of 6a. The arm of the patient was positioned in the direct beam very near the port of the x-ray tube. The separator cone was removed (the separator cone is shown in Figs. 12, 13, and 15 and discussed in commandment #4). The skin of the arm was therefore about 20-25 cm from the x-ray source. The presence of the arm caused the automatic brightness control to increase the x-ray intensity to a very high level in order to penetrate the extra soft tissue and bone. These factors produced dose rates at the arm that likely exceeded 0.5 Gy_t per minute (50 rad /min). If the high dose rate mode was engaged, the rates could have been in excess of 1.8 Gy_t /minute (180 rad /min). The total fluoroscopy time was about 20 minutes. The dose to the arm probably exceeded 25 Gy_t (2500 rad). Figure 6b is

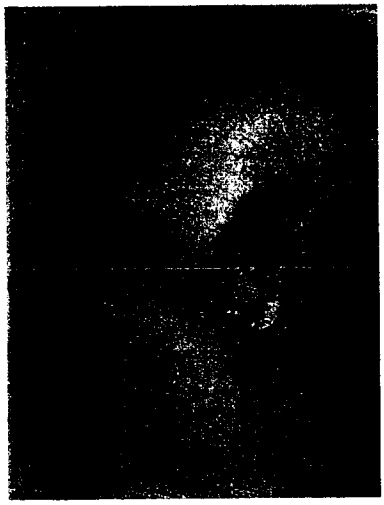


Figure 7. Radiation ulcer following PTCA. (Adapted with permission from: Søvik E et al. Radiation-induced skin injury after percutaneous transluminal coronary angioplasty. Acta Radiologica 37: 305-306, 1996.)

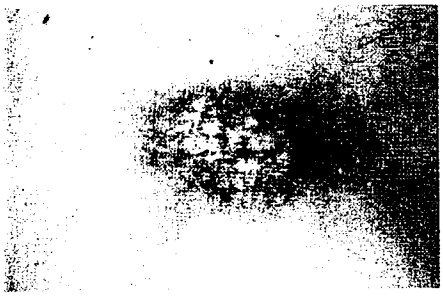


Figure 8. Radiation dermatitis of 5 to 6 years duration. Patient under-went two PTCA procedures about 1 year apart. Lesion commenced around 1.5 years later. Dose was about 18 Gy. (Adapted with permission from: Lichtenstein et al. Chronic radiodermatitis following cardiac catheterization. Arch Dermatol 132: 663-667, 1996. Copyright 1996, American Medical Association.)

Figure 9. Injury on midback following 3 TIPS procedures. (Reprinted with permission from the American College of Gastroenterology: Nahass GT, Cornelius L. Fluoroscopy-induced radiodermatitis after transjugular intrahepatic portosystemic shunt. American Journal of Gastroenterology 1998; 93, 1546 – 1549.)

Figure 10. Poikilodermic area subsequent to ulceration in 75-year-old woman, 11 months after PTCA with ~42 minutes of fluoroscopy. (Adapted with permission from: Wolff D. (1998). Research thesis, private communication.)

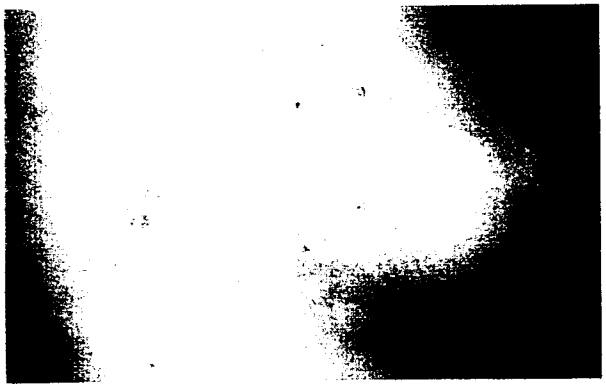


Figure 11. Skin changes on right side of thorax and breast following two attempts at cardiac ablation procedure in 17-year-old patient. Dose ~ 11 – 15 Gy_t. Patient has difficulty raising right arm. (Adapted with permission from: Vañó E, et. al. BJR 1998; 71, 510-516.)

a photograph of the erythema that occurred about three weeks after the procedure. Necrosis is evident 5 months later (Fig. 6c). The extent of the injury is demonstrated at 6½ months in Fig. 6d, which shows the exposed humerus. A surgical flap is in place at 10 months (Fig. 6e). The flap remained intact at 18 months after the ablation procedure. No further follow-up is available.

Figure 7 shows another ulcer that developed following percutaneous transluminal coronary angioplasty (PTCA) (14). Initial symptoms of injury were evident after about three weeks and the wound progressed into an open ulcer weeks later. The procedure included 68 minutes of fluoroscopy and 34 seconds of cine at 50 frames per second. High dose rate was employed for about 40 minutes at an estimated 370 mGy_t per minute. For the remainder, the fluoroscopic dose rate was about 120 mGy_t per minute. Dose was estimated at 16-18 Gy_t.

Acute and chronic radiation-induced dermatitis have recently been reported (7) in patients who underwent multiple cardiologic procedures (Figure 8). In two cases, patients were unaware of any changes for years before the onset of chronic radiodermatitis. In two other cases, patients recalled episodes of acute radiodermatitis that subsided before onset of the chronic condition several years later. All these patients underwent two or more cardiologic procedures that exposed the same skin area for long durations. Estimates of cumulative skin doses ranged from about 11 Gy_t to 35 Gy_t.

Fig. 9 is an image of skin injury following three transjugular intrahepatic portosystemic shunt procedures (9). The total procedure times summed to about 12 hours (not the x-ray-on time). Weeks after the last procedure there was a painful eruption 20-cm x 15-cm with a focally necrotic ulcer that healed into a stellate depigmented firm plaque.

Fig. 10 shows a poikilodermic area following ulceration on the right side of a patient about 11 months after PTCA that involved more than 42 minutes of fluoroscopy (17,21). Fig. 11 illustrates a large area of telangiectasia and other skin changes following two attempts at ablation for arrhythmia that resulted in approximately 100 minutes of fluoroscopy on-time (16). Approximately 12 hours after the second attempt, an erythema developed in the right axilla. At one month the area was red and blistering. At two years the area was described as an atrophic indurated plaque, 10- x 5-cm with lineal edges, hyper- and hypopigmentation, and telangiectasia. The patient was described as having difficulty raising her right arm. The absorbed dose in this case was estimated to be perhaps in the range of 11-15 Gy_t. In both cases the radiation dose to the right breast was substantial. The woman in Fig. 11 was 17 years old while the woman in Fig. 10 was 75 years of age. Radiation-induced breast cancer is much more likely to develop in women exposed prior to age 20 y.

As these figures indicate, extreme fluoroscopic radiation results in very severe effects that develop over extended periods of time. The injuries cause permanent disfigurements in the patients.

At least 40 other cases of injuries have been reported to the FDA in past years (13). The number of reported injuries to the skin of patients, who have had high-dose fluoroscopy and fluorography, continues to increase (see refs. 1 – 18, 20, 21). Only sound radiation management practices will reduce these events. As part of a complete safety program, a medi-

cal physicist should check the outputs of fluoroscopy units on a routine basis to ensure the equipment is operating within appropriate limits.

Lesson learned #3A: Radiation-induced skin injury in a patient is possible and can be severe. It can result from a single long procedure or from doses accumulated over multiple procedures. *Radiation dermatitis is delayed, from weeks to years after the exposure. A conscientious effort should be made to avoid prolonged exposure to the same area of the skin.* To reduce the risk of injuries, sound radiation management practices must be employed. A proficient understanding of this program's commandments is recommended.

Lesson learned #3B: *No body parts other than those essential for the completion of a procedure should be in the field-of-view during fluoroscopy or fluorography.* Exposure rates to the patient can be extremely high if any part of the patient is in close proximity to the source, especially if the separator cone is removed.

-Radiation-induced Cataract

Radiation-induced lens opacities occur only after acute doses in excess of about 1 Gy_t. Vision impairing cataracts are likely to occur at doses in excess of 5 Gy_t. The threshold for chronic exposure is much higher. In adults the time from exposure to development of a cataract is a year or more. Because doses necessary to cause cataracts are high, there need not be a major concern for fluoroscopists and their patients as long as simple precautions are employed (see discussions under commandments #8 and #9). When not followed, the potential for inducing cataract becomes very real. In 1998, Vañó et. al. (22) reported on cataracts induced in physicians and assistants who participated in interventional procedures using equipment with the x-ray tube mounted above the table, contrary to advice in this program. This configuration caused large doses accumulated over many years to the eyes of the individuals concerned.

In rare instances, some interventional procedures in the head may deliver cataractenogenic doses to the lens of a patient. Shielding of the patient's eyes from direct beam irradiation by collimation is recommended (see "Practical application" in commandment #8).

Fluoroscopy

Fluoroscopy is the momentary production and display of serial x-ray images for the purpose of observing real-time motion of internal anatomic structures.

-X Ray Production

X rays are produced by the rapid deceleration of high velocity electrons (Fig. 12). This is achieved in an x-ray tube by accelerating electrons in a vacuum across a very high voltage and then abruptly stopping them in a heavy metal tungsten target. *X rays are present only when the switch that controls the high voltage is engaged by the operator.* Understanding how to control the acceleration and flow of electrons is essential to understanding radiation management.

Electron flow in an x-ray tube is expressed in ***milliamperes (mA)*** *and is called the* ***tube current****. The tube current (mA) controls the rate at which x rays are produced.* Higher tube currents increase the x-ray intensity. The common film-based radiograph is acquired with tube currents in the range of 100 – 800 mA. The duration of the exposure is short, typically on the order of 10 – 500 milliseconds. Fluoroscopy, on the other hand, is long-duration dynamic x-ray imaging acquired at reasonably low x-ray rates to

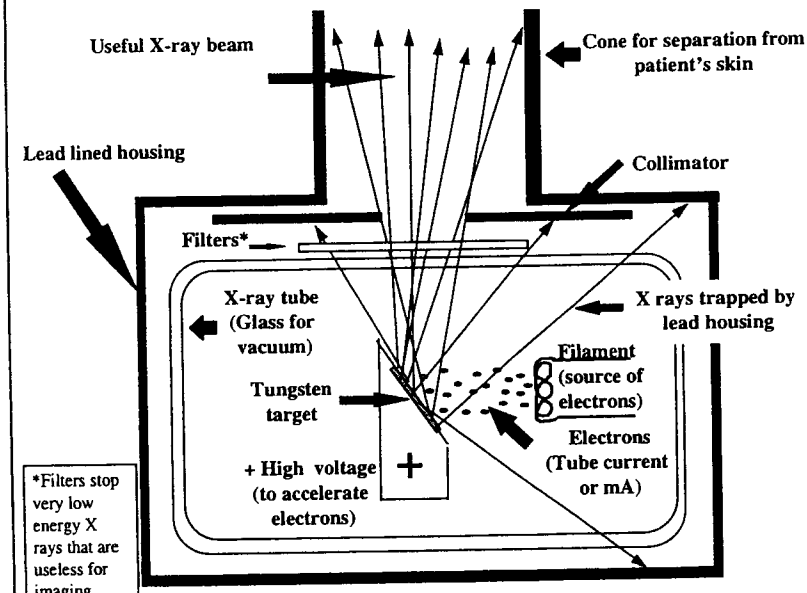


Figure 12. The x-ray tube and x-ray production.

prevent buildup of excessive radiation dose in the patient. Conventional fluoroscopy is performed at much reduced tube currents, up to and sometimes exceeding 5 mA. (As explained later, some units far exceed this.) The duration of fluoroscopy is typically a few minutes, but can be much greater, depending on the goals of the procedure.

The energy of the x rays is controlled by the tube voltage. The **high voltage** is expressed as **kilovolt peak (kVp)** and usually ranges from about 60 up to about 125 kVp. The kVp affects the penetration and the intensity of the x rays. *Higher kVp x rays are more penetrating and fluoroscopic tube currents at these kVp's can be markedly reduced.* If the mA is appropriately reduced, increasing the kVp usually results in reduced exposure rate to the patient. But higher kVp's also reduce image contrast. *In general, high kVp and low mA is employed to keep entrance skin dose at a minimum, especially in large patients. The tradeoff is reduced image quality. Therefore, kVp depends on patient size and is a compromise between image quality and patient dose rate.*

-Filtration

Not all x rays are alike. Fluoroscopic x rays have a wide spectrum of energies. *The very low energies don't penetrate the patient and are useless for imaging. They do however contribute to patient dose.* Filtration removes most of the very low energy x rays from the beam. **Filtration** of an x-ray beam refers to the metal foils or plates that cover the exit port of the x-ray tube (see Fig. 12). Typical filtration is 3 mm of aluminum. Some modern fluoroscopes provide options for heavy x-ray beam filtration (e.g., 0.2 mm copper or more) under some conditions. This filtration more effectively removes dose-enhancing low-energy x rays than does the typical filtration made from aluminum. To maintain optimal contrast, these special heavily filtered fluoroscopes may also operate at lower tube potentials than

might otherwise be used (e.g., less than 70 kVp). The result is reduced x-ray exposure to the patient with no loss in image contrast. However, to be effective, the tube current of such a fluoroscope must be set very high. Currents of 10 - 30 mA are frequently employed for this type of filtration scheme. Specially designed x-ray tubes must be employed to sustain such currents for fluoroscopy. These types of currents would be unusual in the normal setting. Therefore, with some special equipment, unusually high tube currents are to be expected. *The physician should be aware when equipment has this special feature and know when it is engaged because the high tube currents might otherwise mistakenly lead to the idea that dose rates are high.* When heavy filtration is combined with variable pulsed fluoroscopy, dose savings can be exceptional (see discussion of commandment # 10, pulsed fluoroscopy) and instantaneous tube currents may reach 100 mA.

-How Fluoroscopy Works

X rays produced in the x-ray tube spread out (fan out) from the source before they enter the patient (Fig. 13). X rays are reduced in number as they penetrate anatomy. Most are absorbed or scattered and relatively few completely penetrate the body. The x rays that do pass through the patient enter the **image intensifier (II)** (Fig. 13). This device converts the x rays into a visible light image that can be captured by a television camera and then displayed on a TV monitor. *Adjustment of the kVp and the mA of the x-ray tube controls the contrast and brightness of an image*[1]. *The kVp and mA also control the dose rate to the patient.* To keep the image sufficiently bright, the operator can manually change the kVp and mA or the machine can automatically make the adjustments. The system that automatically adjusts kVp and mA is called the **automatic dose-rate control (ADRC)**. This is part of the **automatic brightness control (ABC)** that maintains the displayed image at an appropriate brightness. The brightness of the image is therefore directly affected by the dose rate to the patient. In addition to image brightness, the ADRC may also respond to other changes in the system, such as a change in **source-to-image-intensifier distance (SID)** if the machine has this capability. The ABC might adjust other factors to accommodate the changes in dose rate, such as TV gain or the f-stop on the optics. *For our purposes the important concept is that we know how to manually adjust kVp, mA (and SID) to achieve the lowest dose rate for the procedure.*

-Dose and Dose Rates

X-ray dose rate to the patient is greatest at the skin where the x rays initially enter the patient. *Fluoroscopic dose rates at the skin may vary from less than 10 mGy_t/min up to and exceeding 500 mGy_t/min.* Therefore, a very long examination involving 30 minutes of on-time fluoroscopy could result in a dose of less than 300 mGy_t or more than 15000 mGy_t (15 Gy_t), depending on the operation of the equipment. *While a dose of 300* mGy_t *will produce no apparent*

[1]The contrast and image brightness discussed here are due to changes in how the x rays interact in the patient. They are not related to the contrast and brightness controls on the TV monitor. The controls on the TV monitor only affect the electrical conditions inside the monitor and they must be properly adjusted prior to x-ray application.

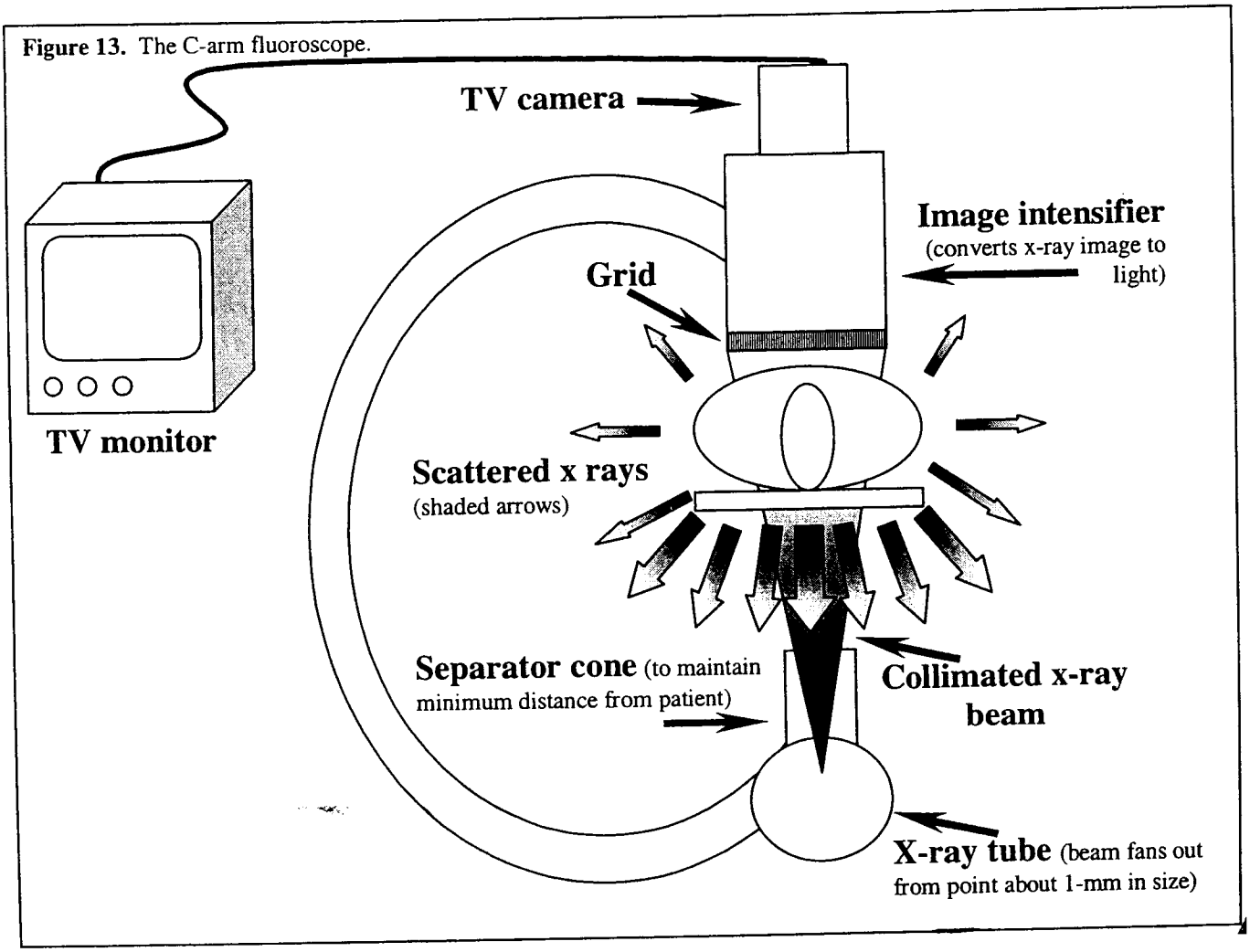
effect, 15 Gy can cause severe skin effects that develop slowly and may take months to heal. Dermal atrophy may develop after several months and become more severe after a year. Dermal necrosis may slowly evolve over many months. It is therefore extremely important that physicians know how to minimize radiation doses to patients in order to avoid short-term (< 2 years) radiation injuries (e.g., burns) and long-term (>2 years) harm (e.g., cancer).

-Fluoroscopy versus Fluorography

The relatively low dose rates used in fluoroscopy produce an image quality that is substantially inferior to that of conventional radiography. However, these low dose rates are necessary to keep cumulated radiation dose to patients at reasonably safe levels. **Fluorography** is the use of the fluoroscopic apparatus to acquire and digitally record a series of higher quality static images. Conventional film imaging may also be used for acquisition, but this method is rapidly declining in favor of digital imaging. The quality of these fluorographic images is similar to radiographic images. ***However, dose rates from fluorography are typically about 10 – 60 times greater than those from fluoroscopy.***

Fluorographic modes include **digital angiog-**

Figure 13. The C-arm fluoroscope.



raphy (DA), digital subtraction angiography (DSA) and **cineangiocardiography** (**cine**). The ratio of radiation dose to the patient from fluoroscopy and fluorography ranges from almost all from fluoroscopy in orthopedic procedures to approximately 70% from fluorography for complex neurointerventional and cardiac studies. *The physician's prudent use of high dose fluorography is a major component of radiation management, especially for the patient. Physicians must not allow the superior-quality images to lure them into the unnecessary application of these elevated-dose techniques.*

-Ten Commandments for Controlling Image Quality, Dose, and Dose Rate

For fluoroscopy and fluorography, the following are the principal factors that control image quality, radiation dose rate, and total radiation dose to the patient and to personnel:

1. ***The size of the patient***
2. ***Tube current***
3. ***kVp***
4. ***Proximity of the x-ray tube to the patient***
5. ***Proximity of the II to the patient***
6. ***Image Magnification***
7. ***The use of a grid***
8. ***X-ray field collimation***
9. ***Shielding and position of personnel relative to patient and equipment***
10. ***Beam-on time***

For each of these ten factors, a key point is summarized later in this text. These key points comprise **ten commandments** for controlling risks. A summary of these discussions can be found in Table V.

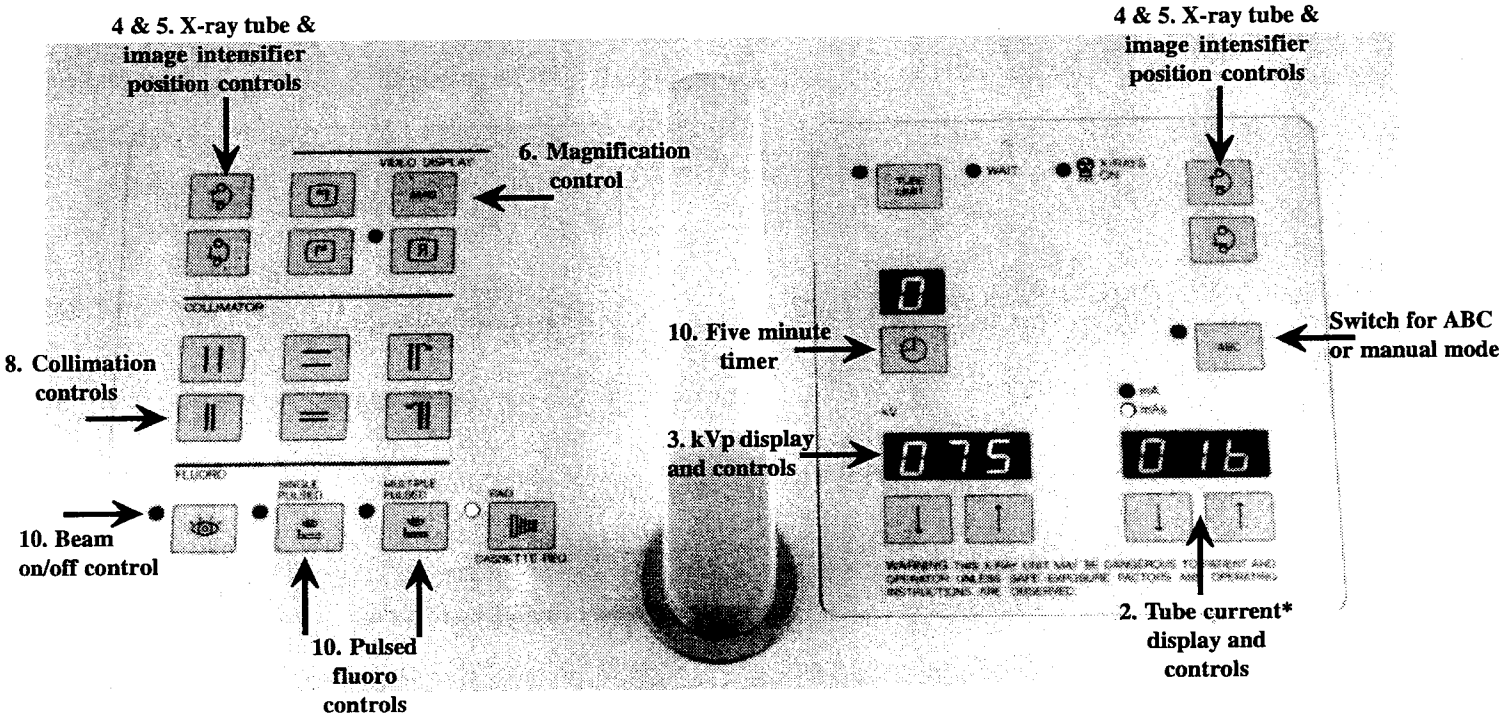


Figure 14. Control panel for typical mobile C-arm fluoroscopic unit. The numbered items are those controls for which specific radiation management points (commandments) are made in the text. Items not numbered are also discussed under separate topics. Item 2 has an asterisk* because the display is showing mAs used for digital radiography, not mA for fluoroscopy which more typically has values of 1 -5 mA. (Photo courtesy of Picker International, Inc., Cleveland, OH)

An operator's control panel of a mobile C-arm fluoroscopy unit is shown in Fig. 14. Although other control panels will look quite different from this one, this operator's panel demonstrates most of the fundamental controls for managing radiation output and image quality. Each control is identified by the numbered item in the list above. Shown are controls for tube current (2), kVp (3), vertical movement of the C-arm (4 & 5), image magnification (6), collimation (8), and beam-on time and control (10). Other controls and indicators are also present. These are explained in the figure and some are discussed later in this document.

In the *manual mode* of operation, the operator controls everything except item #1, the size of the patient. The kVp and mA are set at the controls indicated in Fig. 14. In the *automatic mode*, the machine assumes control of items 2 and 3 (mA and kVp). How the machine adjusts the mA and kVp will depend on several factors, including the manufacturer's choice of design and operator selectable criteria. Selectable options may include different dose rate control modes and establishment of the initial kVp. The control panel will indicate the changing kVp and mA.

The operator controls items 4 through 10 in both manual and automatic modes. *Thus, the operator must understand how to properly select the appropriate ADRC or ABC control settings and how to control items 4 - 10 in order to maximize image quality and reduce doses to the patient and personnel.* To help ensure proper function of the ADRC, ABC, collimation, pulsed fluoroscopy, etc., it is essential that the machine be routinely checked by a medical physicist and serviced by qualified personnel.

#1. The Size of the Patient

As the fluoroscopic beam is positioned over thicker or denser areas of a patient, the transmission of x rays through the patient decreases. This decreases the brightness and the quality of the image. To maintain a sufficiently bright and clear picture on the monitor it is usually necessary to increase the entrance dose applied to the patient's skin. This is done by increasing both the **penetrability** (kVp, see discussion in commandment #3) and the **intensity** of x rays (kVp and/or mA, see discussion in commandment #2). The dose rate required to achieve good image quality for a large patient can exceed that of a thin patient by a factor of ten or more! How fast the dose rate increases with increasing patient size depends on how the ADRC or the operator controls the mA and kVp. Dose rates to personnel also increase in a like manner with larger patients because more radiation of a higher energy is needed to penetrate through the patient and the larger patient scatters a larger proportion of these x rays into the room. Additionally, since image quality usually decreases in larger patients, procedures tend to take longer, increasing radiation on-time.

Commandment #1:	**Remember, dose rates will be greater and dose will accumulate faster in larger patients.**
Concise summary #1:	As patient size increases, image quality decreases, patient dose increases, and personnel dose increases.
Quiz #1:	What measures can be taken to reduce radiation dose and dose rate in large patients? (See Appendix for answer.)

#2. Tube Current (mA)

Unless other dose compensating measures are engaged, *entrance dose rates to the patient and to personnel increase in proportion to an increase in tube current.* Doubling the tube current doubles the dose rate to the patient and to personnel in the room. Changing the tube current (mA) changes the x-ray production rate but does not affect the penetrability. Penetrability is affected by filtration and kVp. In general, the adjustment of tube current must be coordinated with an appropriate adjustment of the kVp (see commandment #3). (See also Fig. 14, item 2.)

An increase in tube current does not result in increased dose to the patient when other dose modifying actions are taken to compensate for the increased mA. An example discussed previously is the engagement of a heavy metal-foil filter option (see: Fundamental Properties of X Rays – Filtration). These filters absorb most of the non-penetrating x rays, but they also reduce, to a lesser extent, the intensity of the penetrating x rays. Higher tube current is necessary so that a sufficient number of penetrating x rays pass through the more absorbing filters. While the tube current for conventional filtration might be a few mA, that for a heavily filtered beam might be 15 mA. Even though higher tube current is necessary, the net result is to reduce dose to the patient. Dose rates to personnel will either decrease or not change much.

As a further example, mA usually increases if the x-ray tube is moved back away from the image intensifier and the patient (see commandment #4), but other dose compensating factors such as increased distance and collimation compensate for the increased mA. The net result is usually a decrease in entrance dose to the patient and very little change in dose to personnel in the room.

In the absence of other dose modifying changes, an increase in mA increases dose to the patient and to everyone in the room. *This occurs, for example, when a higher dose rate option is selected for the ADRC.* This option is discussed later (see: -The combined importance of commandments 2 & 3). Image quality will be enhanced in this mode with concomitant increases in dose to the patient and to personnel.

Commandment #2:	**Keep the tube current as low as possible.**
Concise summary #2:	If dose-compensating measures are not enacted, an increase in mA increases image quality, dose to the patient, and dose to personnel.
Quiz #2:	The technique displayed on your monitor indicates a fluoroscopic tube current of 15 mA. What does this mean in terms of dose rate to the patient and to personnel in the room? (See Appendix for answer.)

#3. Tube Kilovoltage (kVp)

As kVp is increased, x-ray production and the penetrability of the x rays increase. In general, higher kVp's are required in larger patients to keep the dose rates at an acceptable level while maintaining adequate image brightness. *Typically, a higher kVp with low mA* (e.g., 100 kVp at 1 mA) *will result in a lower dose rate than a lower kVp with a high mA* (e.g., 70 kVp at 4 mA). Operating at too low a kVp will result in unnecessary dose to the patient and to personnel. For most fluoroscopy systems in use today, the automatic dose-rate control (ADRC) and automatic brightness control (ABC) establish the kVp and mA according to predefined methods. However, the physician may have important options that govern how the predefined method works. For completeness of this discussion, both manual and automatic control of kVp will be reviewed.

-Systems under Manual Control

For manually operated machines, the operator should establish a low tube current (~1 mA or less) and adjust the kVp upwards as needed to obtain a sufficiently bright image (See Fig. 14, item 3). Higher kVp's will result in lower image contrast. If the image does not contain sufficient contrast for the fluoroscopic procedure, then the kVp should be lowered slightly with appropriate increases in mA. This should be continued until a satisfactory combination of image contrast and image brightness is achieved.

-Systems under Automatic Control

For systems operating in automatic mode, various dose rate control options may be available that determine how the machine adjusts kVp. For example, the initial setting of the kVp (sometimes called the floor kVp) may determine how the ADRC functions. In one unit this floor is the lowest kVp at which the unit will operate. Dose rate to the patient is lower when the floor kVp is set high. If set inappropriately low, the dose rate to the patient will be greater than necessary (30). How these features work is different for different models of equipment. Properly setting these options is essential to minimizing dose and optimizing image quality. If there are questions on how to use these controls, consult with a representative of the company or a medical physicist before proceeding.

Commandment #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.**

Concise summary #3:	As kVp increases, image contrast decreases, patient dose decreases if mA is appropriately reduced, and dose to personnel in the room usually either decreases or does not change much (if the mA is appropriately reduced).

Quiz #3:	Why does higher kVp and lower mA decrease dose to the patient while also decreasing image contrast? (See Appendix for answer.)

The combined importance of commandments 2 & 3:

How a machine automatically adjusts kVp and tube current determines the trade-off between image quality and dose rate. Some machines have a variety of dose rate options. *For each specific unit, fluoroscopists must understand the options available and realize how these affect dose rate in addition to image quality.*

-Selectable Dose Rate Controls

Some modern fluoroscopy units have options that allow the operator to select the level of image quality (for example: high, medium, or low). These settings alter how the ADRC works. Typically, as image quality improves radiation dose rate increases. On a low image quality setting dose rate might be low but the image may appear snowy (noisy). ***In many cases, these noisy images are quite acceptable for the procedure and the low dose rates should be used whenever possible.*** In higher image quality modes, radiation to the patient and staff will increase, generally by 20 to 50%, but this depends on system design. *The physician should work with these dose-rate control devices to determine the level of image quality appropriate for the examination. Always use the lowest dose rate commensurate with appropriate patient care.*

-High-Dose-Rate Fluoroscopy

Some fluoroscopic units have ***high-dose-rate*** *capability wherein the unit can be operated with unlimited levels of dose rate to the patient.* The name assigned to this mode of operation varies among manufacturers. In this mode the machine adjusts the mA and/or the kVp upward and dose rates can be very high. (The FDA has placed restrictions on the maximum dose rate permitted in this mode for machines manufactured after May 19, 1995. Machines built before this date may still operate without limit.) A continuous audible tone indicates when this mode is engaged. ***This can be a dangerous mode and should be used only briefly under extreme circumstances,*** such as to perceive fine detail for delicate work or when the image is too dark because the patient's anatomy cannot be penetrated in the normal mode.

-Recorded Fluoroscopy

The United States Food and Drug Administration does not regulate fluoroscopic exposure rates when dynamic imaging is recorded. The intent of this rule is to permit the physician to obtain high quality serial imaging, when necessary, to benefit the medical care of the patient. In some instances, fluoroscopic equipment has been outfitted with video tape recorders or other image recording methods with the explicit purpose of legally boosting dose rates beyond the regulatory fluoroscopic limits with no intent to use the recording for medical purposes. This is a regulatory loophole that permits physicians to perform fluoroscopy at unnecessarily high dose rates (too high a mA) but which provides far-improved image quality over conventional fluoroscopy. *This circumvention constitutes abuse of the regulatory intent.* Cumulated exposures to patients and to personnel are excessive under these circumstances. If the fluoroscopic system produces inferior image quality, it should be serviced or replaced with better equipment that can produce higher quality imaging at dose rates within the regulatory standard. If higher dose rates are periodically necessary to view fine detail, a high dose rate unit should be purchased and prop-

erly employed for those procedures. **Bypassing the regulatory limit by employing the indiscriminate use of recorded fluoroscopy must be strictly forbidden.**

-Cardiologic Digital Recording and the Cine Loop

Cineangiocardiography (cine) plays an essential role in interventional cardiology. This technique uses a recording medium (e.g., digital disk) to capture cardiac dynamics (see commandment #10 section on cine fluorography for a technical description). The dynamic loop of the cardiac cycle can then be replayed for review. *These high-quality recordings are captured using much higher tube currents than used for fluoroscopy. Dose rates to the patient and to personnel are consequently much higher during these runs.*

Unless required for permanent documentation as part of the patient's medical record, these images are often reviewed and then erased when the next run is recorded. Although the ease of digitally recording multiple runs has increased the value of cine to the cardiologist, the ease of activation makes this feature susceptible to overuse. Cine must be selectively used on a limited and intermittent basis to study the progress of a procedure. Since the dose savings realized by eliminating unnecessary cine runs will be substantial, the physician must make a conscious effort to avoid nonessential runs.

Some equipment allows for capture of cine images at different selectable dose rates, to accommodate different needs during a procedure. If dose rate (i.e., tube current and exposure time per frame) can be reduced for certain types of use, considerable savings in radiation usage will be realized. Frequently, an intermediate dose rate mode is perfectly adequate for clinical purposes and should be used in place of full-dose-rate cine, especially for discardable runs.

-Digital Fluorography

Frame rates from serial digital fluorography, DA and DSA, are typically much less than that of cineangiocardiography, which reflects the lower need for fine temporal resolution. Doses per frame are usually higher than that in cine, rendering a higher quality sequence of static images. Unlike conventional film imaging, digital fluorography can be acquired at a wide range of techniques [kVp, tube current and exposure time (mAs)] and still produce adequate image quality. Serial fluorographic imaging is usually performed at tube currents about 100 times higher than normal fluoroscopy in order to capture a high quality static image in a very brief exposure (~0.01 – 0.1 seconds). Doses per frame of imaging from **digital angiography (DA)** and **digital subtraction angiography (DSA)** are on the order of 3 – 5 mGy_t. Since 1 – 6 frames per second are typically acquired, the resulting dose rates to the patient are about 200 – 1800 mGy_t per minute. Techniques exceeding that necessary for appropriate image quality result in unnecessary dose to the patient. The physician should work with their technologists and representatives of the manufacturer to establish the appropriate techniques and dose settings per frame of imaging.

#4. Proximity of the X-ray Tube to the Patient

X rays originate and emanate from a small area inside the x-ray tube. This area is about 1-mm wide and is called the "focal spot". As the distance from the focal spot increases, the intensity rapidly decreases. This is analogous to heat from a lighted match. The flame produces an extremely intense heat from a very small area close to the match, but the heat diminishes rapidly with distance. The potential for skin injury is very high if one is near the flame but is reduced markedly as the distance from the flame is increased. Similarly with x rays, ***as one increases the distance between the source of x rays and the patient's skin surface, the x-ray intensity is reduced and the potential for skin injury decreased.*** The control for adjusting the proximity of the x-ray tube to the patient is shown in Fig. 14, items 4. (For some machines with variable **source-to-image distance (SID)**, the ADRC might adjust radiation output with SID. This sophistication is not universally available.)

In procedures involving lateral and oblique fluoroscopy (or isocentric fluoroscopy as used in special cardiologic or neurologic procedures), the geometry of the examination places an important limitation on the maximum distance that the source can be maintained from the patient. For example, when viewing the patient in a lateral or an oblique position, the x-ray source is usually much closer to the skin surface than it would be for a posteroanterior view (x rays entering posteriorly and exiting anteriorly). *In lateral and oblique orientations, the entrance dose rates at the patient's skin can be much higher than those measured in AP or PA views.* Recent articles have reported patients with severe skin burns as a result of too much radiation dose in the oblique and near-lateral orientations during cardiologic procedures (Figs 5, 6, 10 & 11; Refs. 16, 17, 20, 21). Therefore, *it is important in all procedures to keep the patient's skin surface at maximum distance from the x-ray source.* This commandment is designed primarily for the safety of the patient. ***It serves mostly to minimize the concentration of x rays at the skin surface.***

The fact that regulatory agencies place restrictions on the radiation output of fluoroscopes is common knowledge. However, this restriction is too frequently misinterpreted. For example, the restriction that the output of the common fluoroscope may not exceed 100 mGy_a/minute at the compliance testing point (10 R/minute in the U.S.A.) does not mean that the entrance skin dose to the patient cannot exceed 100 mGy_t/minute. In fact, the entrance skin dose rate can readily reach 200 – 250 mGy_t/minute. This is due to radiation that is scattered back to the skin surface from the tissues inside the patient and because the x-ray source is often closer to the patient than the compliance testing point. These two factors elevate the dose rate to well beyond the compliance limit. Rates are even higher for high-dose-rate modes and fluorography.

The amount of radiation scattered into the room depends on how collimation and the distance between the x-ray source and the image intensifier (SID) change. *If collimation remains confined to the area of interest, scatter in the room usually doesn't change much and might be reduced.* [Scatter will also depend on whether the SID control is engaged. See discussion on SID control in next section.]

When maximizing source-to-skin distance, image quality might change because the size of the image is reduced. This change in image size is due to

the change in position of the patient relative to the x-ray tube and image intensifier.

-The Separator Cone (or Spacer Device)

The United States Food and Drug Administration (FDA) requires that fluoroscopic x-ray machines be designed so that the patient's skin is at least a specified fixed distance from the x-ray source. All fluoroscopy machines are designed with the x-ray source behind a device that forces a minimum separation of the source from the skin of the patient. This minimum source-to-skin distance depends on the type of fluoroscope and the date it was manufactured. In conventional fluoroscopy, such as that used in gastrointestinal work, the source is located under the table and at a fixed distance from the patient. C-arm type units have plastic cones or other devices that serve as spacers to maintain a minimum separation (Figs. 12, 13 &15). *The purpose of this regulation is to prevent the dangerous situation in which the intense beam emerging from the x-ray source is too close to the patient's skin.* For modern machines that are fixed in a room, a minimum distance of 38 cm between the source and the end of the spacing device is required. For mobile units this distance is 30 cm. However, for some procedures this physical constraint makes it difficult to maneuver the C-arm around the patient.

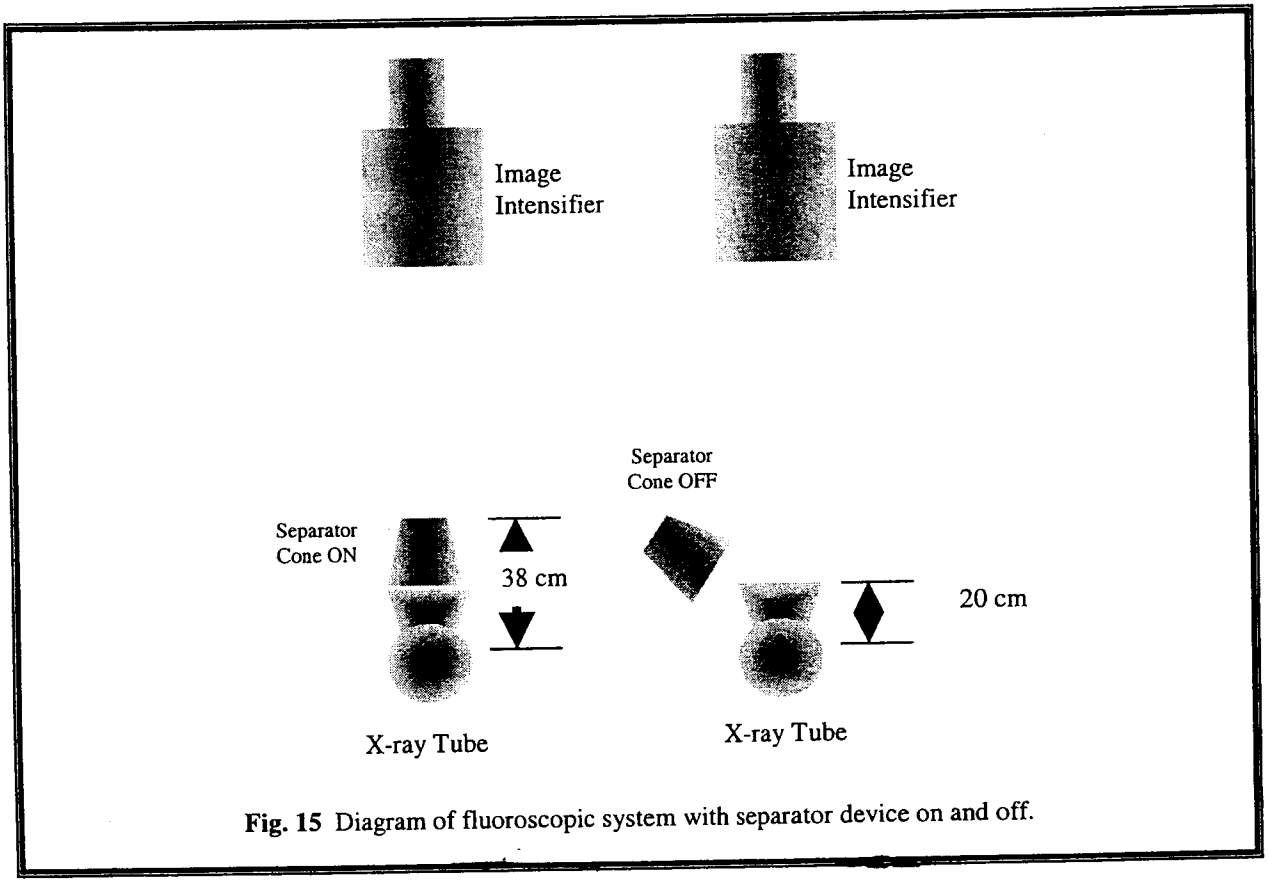


Fig. 15 Diagram of fluoroscopic system with separator device on and off.

Notes on SID control: SID control is an acronym for "source-to-image-distance control" on systems that have variable SID. For C-arm units, the maximum air kerma rate allowed by regulation is usually around 100 mGy/min at 30 cm from the image intensifier. The SID control allows the unit to maintain this level as its maximum rate for any SID. When fluoroscopy dose rates approach the maximum permitted, the relationships discussed for commandments 4, 5, and 6 may not be completely applicable for units with SID control. Such sophisticated control, in various forms, is available on modern equipment.

To provide some flexibility, the FDA permits machines to be designed with removable spacers (Fig. 15). For diagnostic procedures the device is to remain attached to the x-ray source. For special surgical procedures, the device may be removed and the minimum distance can be as short as 20 cm. *This creates a potentially dangerous situation and the physician should make special efforts to maximize the distance of the x-ray tube from the patient's skin.* ***No body parts should ever be in contact with the port of the x-ray tube during fluoroscopy or fluorography.*** Once special surgical procedures are completed, the spacer device is to be reattached to the x-ray source. However, too often these devices are removed and never reattached. The danger of the close source can only be avoided if the physician is conscientious about maximizing the distance between the x-ray tube and the patient. If attention to this detail is neglected, the patient's skin will be unnecessarily close to the source. Dose rates at short distances can be extreme (greater than 0.5 Gy_t per minute) and the thresholds for epilation, erythema, and severe injuries can be reached in a matter of minutes.

#5. Proximity of the Image Intensifier to the Patient

The image intensifier should be as close to the patient as possible to reduce radiation dose. For a fluoroscopic system with fixed distance between the x-ray source and the image intensifier, entrance dose to the patient decreases either as the patient is moved closer to the image intensifier or as the image intensifier is moved closer to the patient because the x-ray tube is further away (see commandment #4). Controls to adjust this distance are shown in Fig. 14, items 5.

If the x-ray source and the image intensifier can be moved independently, then after the patient is positioned on the table at the appropriate height, it is always best to move the image intensifier as close as possible toward the patient. [Note: the x-ray tube should, of course, be as far away as is practicable.] When the image intensifier is independently moved closer to the patient, the production of x rays decreases because of the shorter distance between it and the x-ray source. *Thus, placing the image intensifier as close to the patient as possible yields a lower dose rate to the skin where the beam enters the patient.*

Commandment #4:	**Keep the patient at maximum distance from the x-ray tube.**

Concise summary #4:	Keeping the x-ray source as far away from the patient's skin as possible will minimize dose rate to the skin. If collimation is confined to the area of interest, scatter in the room either decreases or doesn't change much. Image quality depends on image size, which is slightly reduced.

Quiz #4:	For an x-ray source with distance adjustment independent of the image intensifier, you notice that the mA increases as you move the x-ray tube from 40 cm to 60 cm from the patient's skin (see diagram in the appendix). The collimators are fully open to the input area of the image intensifier. Why does the patient's skin dose rate decrease and dose rates to personnel not change much? (See Appendix for answer.)

Keeping the image intensifier close to the patient serves mostly to minimize the concentration of x rays at the skin surface where the beam enters the patient. Whether scatter in the room decreases depends on how collimation and the distance between the source and image intensifier change. If collimation remains confined to the area of interest, scatter in the room is reduced, otherwise it doesn't change much. One other advantage for the operator may be that the image intensifier acts as a shield when it is close to the patient because it absorbs x rays scattered off the exit-beam surface of the patient. When placing the image intensifier close to the patient, the size of the image is reduced and image quality might change. This change in image size is due to reduced geometric magnification.

Neuroradiologic procedures are usually performed with an *isocentric configuration* (i.e., no matter how the C-arms are oriented around the patient, the anatomy of interest remains in the center of the image) and the image intensifier is intentionally separated from the patient. Cardiologic procedures also employ an isocentric configuration. The image intensifier may be separated from the patient to accommodate difficult angulation or to ease the maneuverability of the C-arm around the patient. Some invasive procedures require a large gap between the patient and the image intensifier to provide an appropriate working space for the invasive devices. This is true for many surgical procedures and in pain management. If circumstances mandate that fluoroscopy be done with a large air gap of more than 25 cm between the patient and the image intensifier, then the physician should consider removing the grid, if possible (see commandment #7). This should reduce patient dose without loss of image quality because scatter radiation is not likely to interfere with image contrast.

Commandment #5:	**Keep the image intensifier as close to the patient as possible**

Concise summary #5:	Keeping the image intensifier close to the patient minimizes entrance skin dose rate. If collimation is confined to the area of interest, scatter in the room decreases. The effect on image quality depends on image size, which is reduced.

Quiz #5:	When the image intensifier is brought closer to the patient in a system where its motion is independent of the x-ray tube, you notice that the mA goes down. Collimation remains confined to the area of interest. What happens to dose rates in the room? (See Appendix for answer.)

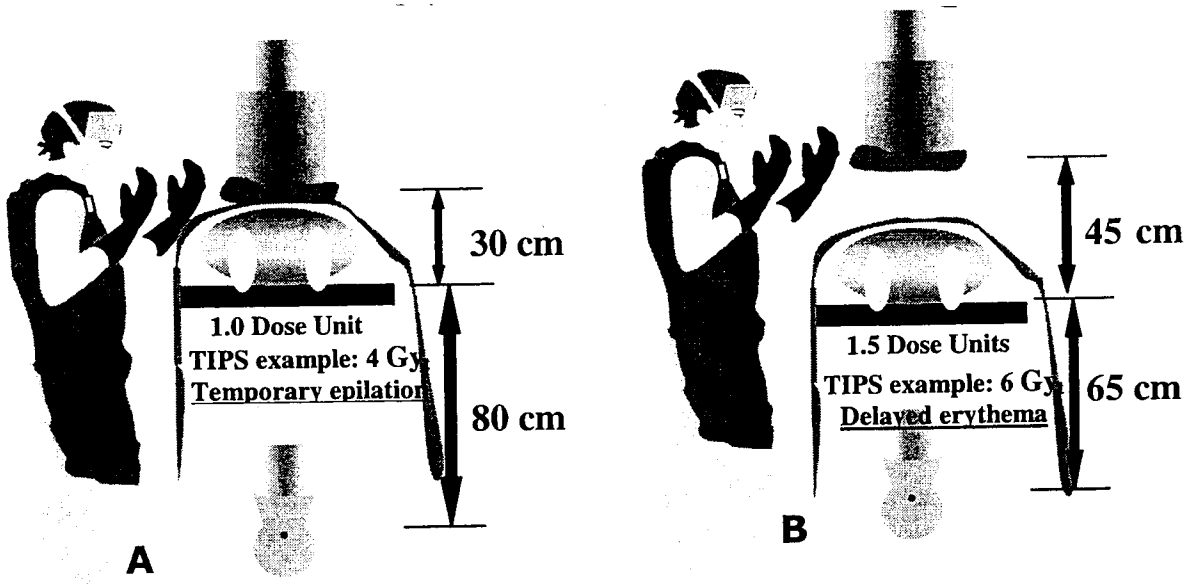
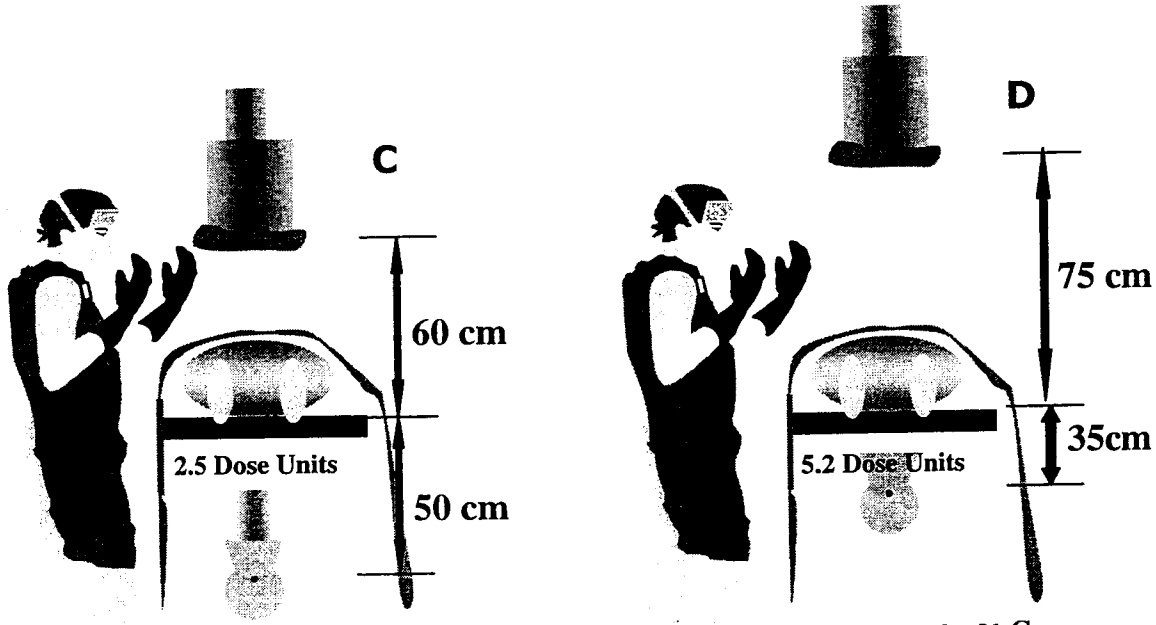


Figure 16. This figure demonstrates how the entrance dose to the skin of a patient depends markedly on the position of the fluoroscope relative to the patient. Note that the spacer cone is removed in Fig. D. For a prolonged interventional procedure, maximizing the distance from the X-ray source to the patient's skin could easily make the difference between no noticeable skin reaction and a severe burn. For example, if 4 Gy_t were delivered using geometry A (as perhaps in a long TIPS procedure) the dose using geometry D would be 21 Gy_t -- a difference of 17 Gy_t (1700 rad)!



-The combined importance of commandments 4 & 5

-Patient Dose and the Position of the Fluoroscope

Figure 16 demonstrates how the positioning of the C-arm can dramatically affect radiation dose to the skin of the patient. Figures 16A to 16D depict differences in the proximity of the x-ray tube to the patient's skin. In all cases the distance of the x-ray tube from the image intensifier is 110 cm and the kVp, tube current, fluoroscopic time, and magnification mode of the image intensifier are assumed to be unchanged. Only the geometric magnification changes (see commandment #6). Figure 16 and Table II provide an example of a prolonged TIPS (transjugular intrahepatic portosystemic shunt) procedure to demonstrate how the different geometries can have a tremendous effect on dose to the patient and on biological response. There is more than a factor of five difference in dose between the geometry of Fig. 16A and Fig. 16D. *This can easily mean the difference between no noticeable skin reaction and a third degree burn, or worse. Differences in geometry of as little as a few centimeters can have a major impact on dose to a patient's skin.* For example, the difference in dose between a source-to-patient distance of 70 cm and 65 cm is 0.8 Gy_t (80 rad) for the TIPS example of Table II.

Table II. Effects of geometry on dose to skin for prolonged TIPS procedure.

Reference figure	Distance of x-ray source from patient	Skin dose relative to Fig. 13A	Skin dose to patient for prolonged TIPS procedure	Potential delayed skin reaction	Difference in dose between reference geometry and ideal geometry of A
16A	80 cm	1.0	4.0 Gy_t (400 rad)	Temporary epilation	0.0 Gy_t (0.0 rad)
Not shown	70 cm	1.3	5.2 Gy_t (520 rad)	Temporary epilation	1.2 Gy_t (120 rad)
16B	65 cm	1.5	6.0 Gy_t (600 rad)	Erythema	2.0 Gy_t (200 rad)
16C	50 cm	2.6	10 Gy_t (1000 rad)	Atrophy, telangiectasia	6.0 Gy_t (600 rad)
16D	35 cm	5.2	21 Gy_t (2100 rad)	Necrosis	17 Gy_t (1700 rad)

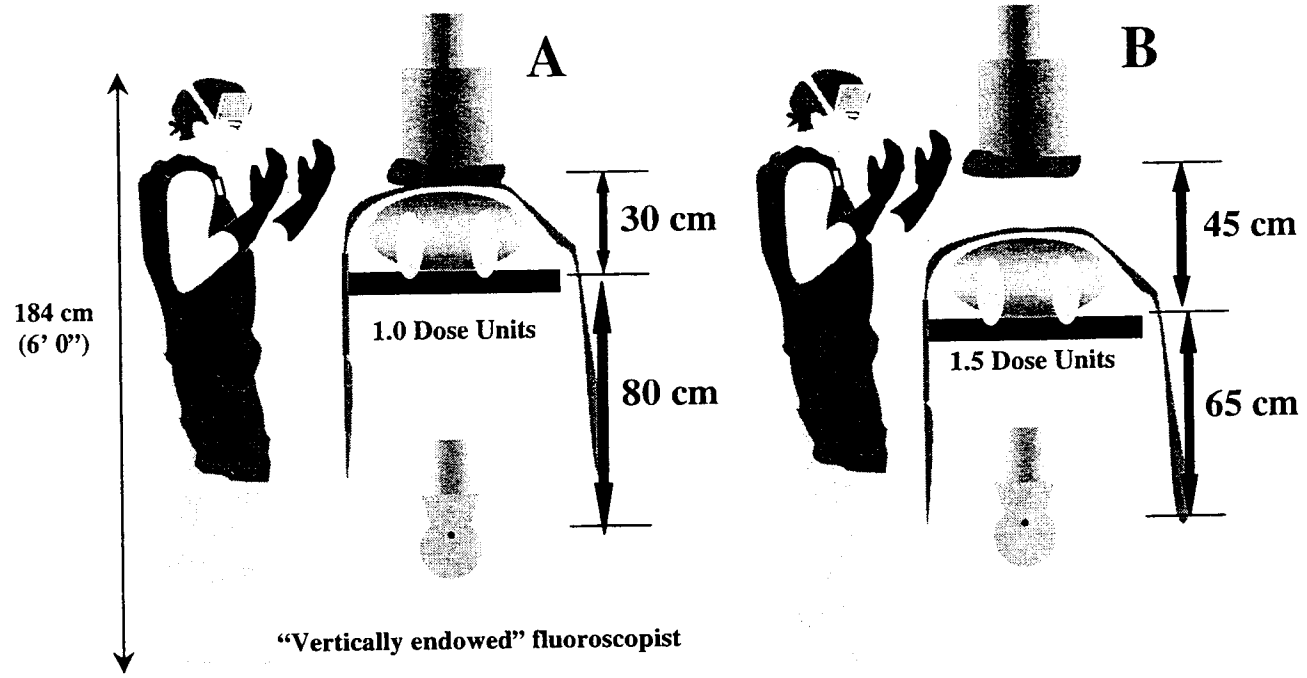
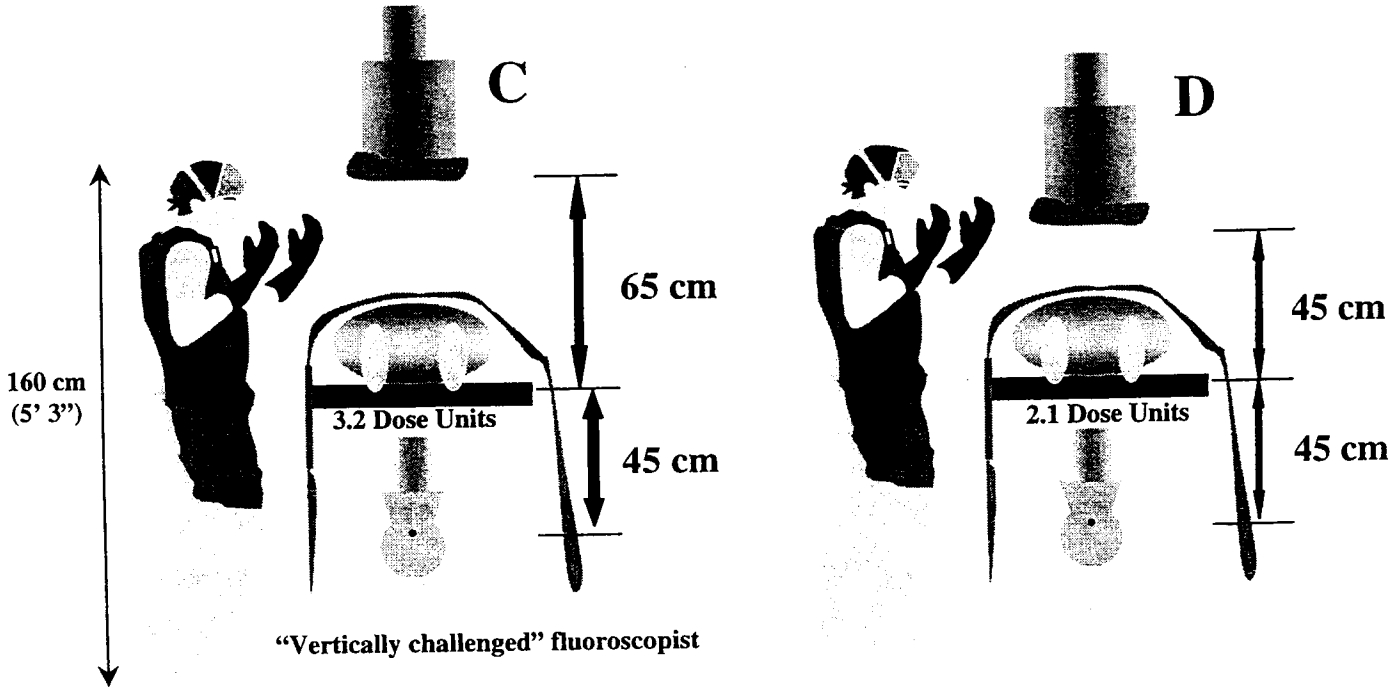


Figure 17. The "vertically endowed" fluoroscopist has the advantage here. Fig 17A is the ideal geometry, but may not be practical either because of the fluoroscopist's height or because the area fluoroscoped may have invasive devices protruding from the patient. Geometry depicted in Fig 17B is more typical when a gap is required between the patient and the image intensifier. Fig. 17C shows the case of a "vertically challenged" fluoroscopist. Fig 17D shows that keeping the image intensifier close to the patient can reduce some of the disadvantage in shorter physical height.



-Patient Dose and Physician Height-

Tall physicians may have no difficulty in maintaining good geometry, as depicted in Fig. 17A (no invasive devices present) or 17B (invasive devices present). Physicians who are "vertically challenged" may find that a geometry more like Fig. 17C may be necessary. Note that the table is lower to accommodate the physician's height. However, when the table is low, the floor may prevent the physician from moving the tube appropriately away from the patient. At one institution a platform was built to assist a "vertically challenged" physician. Although platforms can reduce this disadvantage, we advise caution in their use because they may create a hazard, resulting in injury to personnel or even the patient. If the position of the image intensifier is independently adjustable, the physician can and should control dose to the patient by moving it as close to the patient as possible. Figs. 17C and 17D show how the dose is reduced by about 30% simply by moving the image intensifier 20 cm closer to the patient, all other conditions remaining the same (note: the mA will be adjusted by the ABC). If the image intensifier can be moved closer, the dose would be further reduced. If not, the physician might consider removing the grid, if this option is available. Removing the grid is likely to reduce the dose by another 30% or more. [In some machines, SID control might provide adjustments to the ABC that maintains the entrance exposure rate at a level different than those that don't have SID control.]

-Patient Dose and Invasive Devices-

During certain invasive procedures, placing the image intensifier close to the patient would restrict the physician's working area. Syringes, catheters, or other devices may be protruding from the patient (e.g., from the back at the spine). For reasons discussed in commandment #9, the preferred orientation for protection of personnel is to keep the image intensifier above the patient and the x-ray tube below. An adequate distance between the patient and the image intensifier (Fig. 17B) must be maintained to provide working space for manipulation of invasive devices and to prevent collisions when moving the C-arm. Since the image intensifier and the x-ray tube are fixed in opposing orientations, the constraints on the image intensifier may also place severe constraints on how far the x-ray tube can be positioned from the patient. While not recommended, the separator cone is sometimes removed from the x-ray tube to allow for freedom of movement of the C-arm around the patient. For large patients, the port of the x-ray tube may actually come into contact with the patient's skin. As discussed previously, if the separator cone has been removed and the port is close to or in contact with the skin, the potential for a injury is maximum. ***Extreme caution is advised and this configuration should be diligently avoided!***

The standard geometry used for fluoroscopy of areas where invasive devices are inserted (Fig. 17B) serves to increase dose rates to patients because commandments 4 and 5 are difficult to implement. For these procedures, particular attention must be given to other measures to reduce doses to patients, such as short exposure times and removal of the grid, if this option is available. Use of good collimation will ensure that scatter does not degrade image quality.

#6. Image Magnification

While magnification of the image improves the visibility of detail and is often useful and necessary during fluoroscopy, it frequently results in increased dose rate to the patient. Magnification can be achieved in two ways: electronically and geometrically. Electronic magnification controls the focus of the image intensifier and is an option that the physician can choose by pushing a button. Geometric magnification is achieved by changing the position of the patient relative to the x-ray tube and image intensifier. The advantages and disadvantages of each are discussed below.

-Magnification options of the image intensifier

Electronic magnification (field-of-view size)

Some image intensifiers have only one field size; a typical size is 9-inch (23-cm) diameter. Others are designed for multiple field-size viewing (field-of-view or magnification modes) and may include two, three, or four modes of different imaging diameters. These different field sizes are the electronic magnification options of the image intensifier. Magnification is achieved by making the usable x-ray field smaller and displaying this smaller field over the full viewing area of the monitor. Some standard modes of operation from greatest to least magnification are 4 inch (10 cm), 6 inch (15 cm), 9 inch (23 cm), and 12 inch (30 cm). The fluoroscopic unit in Fig. 14 has two field sizes that are selectable as "mag"-on mode (6" or 15-cm diameter input) and "mag"-off mode (9" or 23-cm input).

The entrance dose rate is often related to the magnification selected. *The mode of least magnification (largest field) usually delivers the lowest dose rate.* How the dose rate to the skin of the patient changes when magnification is employed depends on how the system is designed by the manufacturer. For some designs, the dose rate does not change. More frequently, it increases. This increase may be as much as a factor of two or more for each magnification increment. A medical physicist should be consulted if there is a question on how the system works.

In the United States the maximum dose rate for fluoroscopy must not exceed the maximum permitted by regulation, regardless of the magnification mode of the image intensifier. For the most part, this means that the maximum rate may not exceed about 100 mGy_a/min (see footnote 2) at the compliance testing point (note: this is about 140 mGy_a/min). There are other regulatory limits for some machines.

If the manufacturer has designed the system to maintain the same entrance dose rate, regardless of electronic magnification mode, then the physician can operate in the magnification mode of choice. However, typical systems will increase dose as magnification increases. For these types of systems the operator must be aware of some important dose-management concerns. If a physician is not certain how the fluoroscope works, then the following principle should be heeded. *To optimize overall radiation management, use the least magnification consistent with the goals of the procedure and reduce the irradiated volume of the patient by employing narrow collimation (commandment # 8).*

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[2] At the time of this printing, the maximum rate at the compliance test point was 10 R per minute (87.6 mGy_a) in the United States. The FDA has suggested that this be changed to 100 mGy_a per minute.

When magnification is employed, dose rates to personnel in the room commonly increase, but could decrease or not change much. What happens depends on how collimation, kVp, and tube current respond to the change in electronic magnification. If collimated field area is unchanged, dose rates in the room still usually go up because kVp and tube current usually go up.

Geometric magnification

Geometric magnification is achieved by increasing the distance between the patient and the image intensifier or by decreasing the distance between the x-ray tube and the patient. Increasing distance of the image intensifier is contrary to commandment #5 (keep the image intensifier as close to the patient as possible). Decreasing the distance of the x-ray tube is in opposition to commandment #4 (keep the x-ray tube at maximal distance from the patient). However, geometric magnification has some advantages from a procedural point of view. Examples include those using an isocentric configuration or those that require fluoroscopy of the area where invasive devices are introduced. Two things are of note regarding dose rates when using this technique. *First, dose typically increases with the square of the magnification.* That is, if magnification increases by a factor of two, dose rate increases by a factor of four. *Second, maximum dose rates in this configuration may exceed the regulatory limit of ~140 mGy$_t$/min.* This is because compliance dose rates are tested only at a point representing conditions of low geometric magnification (patient closest to the image intensifier as in Fig. 16A). When the patient is positioned for geometric magnification, dose rate to the patient's skin increases. The increases in dose shown in Fig. 16 are a direct result of the changes in geometric magnification.

Dose rates to personnel in the room usually increase with increased magnification, but this depends on how tube current, SID, and collimation are adjusted with magnification.

Commandment #6: **Don't overuse geometric or electronic magnification.**

Concise summary #6: Magnification almost always results in increased dose rate to the patient's skin. The least magnification consistent with the goals of the procedure should be used in conjunction with collimation to manage radiation properly. Electronic magnification, rather than geometric magnification, is less likely to result in too high a skin dose rate. Image quality under magnification fluoroscopy usually improves. Dose rates to personnel in the room may increase or not change much as magnification increases.

Quiz #6: Many fluoroscopes adjust dose rate under electronic magnification according to the square of the magnification factor. How does dose rate to the patient change as one shifts from a 24-cm field of view (no magnification mode) to a 12-cm field of view (magnification mode)? (See Appendix for answer.)

#7. The Grid

*A **grid** is a flat plate device that improves image contrast by selectively shielding the image intensifier from scattered x rays* (Fig. 18A. See also Fig. 13). It is positioned in front of the image intensifier to improve image clarity, although this causes the radiation dose rate to the patient, as well as scatter to personnel, to increase. Many GI fluoroscopic units have an automatically retractable grid that can be removed by the press of a button during fluoroscopy. In some C-arm units, the grids are manually removable. Grids should not be removed if not designed for that purpose. If the grid is removed, the radiation dose rate to the patient decreases, sometimes by a factor of 2 or more. However, image contrast might be compromised (Fig. 18B). (It is also very important that removable grids be handled with great care to prevent nicks or dents that could ruin their effectiveness. **Grids are fragile and costly devices.**)

Two circumstances in which it is advantageous to remove the grid include:

1) Pediatric patients or small adults generate very little scatter. It may be possible to perform fluoroscopy without the grid for these patients.
2) For procedures that employ a large space between the patient and the image intensifier, very little scatter reaches the image intensifier (Fig. 18C). Good collimation further minimizes the image-degrading effects of scatter. The grid serves little purpose in this case. The fluoroscopist should consider removing the grid if the image intensifier cannot be positioned closer than 25 cm to the patient. This occurs, for example, in many pain management procedures and during neuroangigraphic work. Söderman et al. (34) have demonstrated that removal of the grid during neuroangiography reduces dose to the patient by about 34%, with no noticeable affect on image quality.

Commandment #7:	**If image quality is not compromised, remove the grid during procedures on small patients or when the image intensifier cannot be placed close to the patient.**

Concise summary #7:	A grid improves image quality by removing scatter radiation. The use of a grid increases patient dose and doses to personnel in the room.

Quiz #7:	Why is the use of a grid more important for fluoroscopy in adults than it is for fluoroscopy in infants? (See Appendix for answer.)

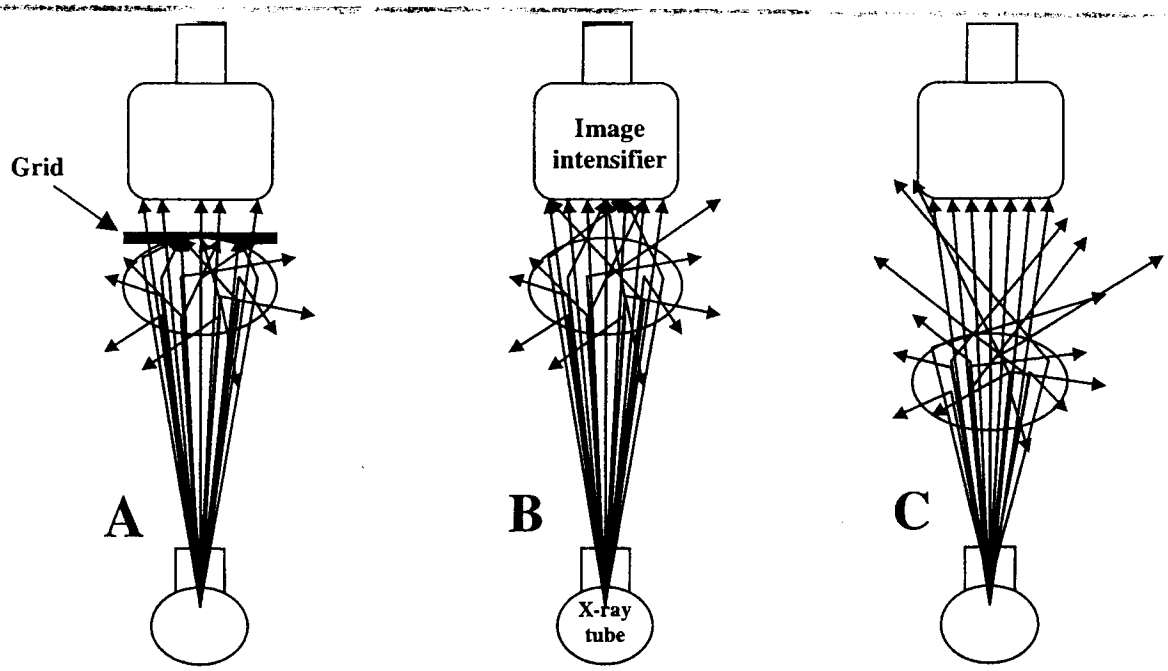


Figure 18. The grid and scatter. In A, the grid is in place and effectively stops image-degrading scatter radiation (bent arrows) from reaching the image intensifier. (The remaining scatter goes into the room, but this scatter does not affect the image.) The grid permits most, but not all, of the image-forming x rays to pass through to the image intensifier (straight arrows). In B, the grid is removed. Scattered x rays now reach the image intensifier, reducing image contrast. This is usually unacceptable for medical tasks. With the grid removed, all image forming x rays enter the image intensifier. In C, the air gap provides enough space so that the scattered x rays now pass out of the range of the image intensifier. This scatter no longer degrades image quality. If such an air gap is used, the grid serves no purpose and removing it permits all the image-forming x rays to be used. Removing the grid in this case lowers dose rate to the patient without degrading the image quality.

#8. X-Ray Field Collimation

Collimators are x-ray blockers that are located just outside the x-ray tube (see Figs. 12 & 19) and are used to define an opening through which the x rays can pass. The shadows of the collimators' blades should be minimally visible on the TV image when the blades are fully open. The collimators' blades can be manually adjusted to reduce or enlarge the area of the visible image, and thus the area of the patient that is exposed. *The fluoroscopist must apply collimation to minimize the area of the radiation field in order to control image quality and to reduce the amount of radiation necessary to complete the procedure* (Fig.19). As the collimators open to expose a larger area of the patient, more image-degrading scatter radiation is produced. Tightly collimating to the area of interest reduces scatter radiation and this improves image quality. Reducing the field-size by tight collimation also reduces the risk to the patient because the carcinogenic risks are proportional to the volume of tissue exposed. Controls to adjust the collimators are shown in Fig. 14, items 8. (Note: Sometimes closing the collimators too much will result in an overly bright image, unusually high tube current (mA), or other unusual effects. This occurs because the blades block part of the area used by the ABC to control brightness. Just open the collimators slightly and the image should return to normal.)

One of the biggest problems in implementing collimation is that the x rays must be on so that the operator can watch the blades move to the desired positions. Some manufacturers provide a software preview of collimator adjustment that requires no engagement of x rays to position the blades. The area defined by the blades appears as a computer simulated rectangle overlying the last image hold (see commandment #10). This feature has proven very useful in reducing unnecessary fluoroscopy time and improving the utility of the collimators.

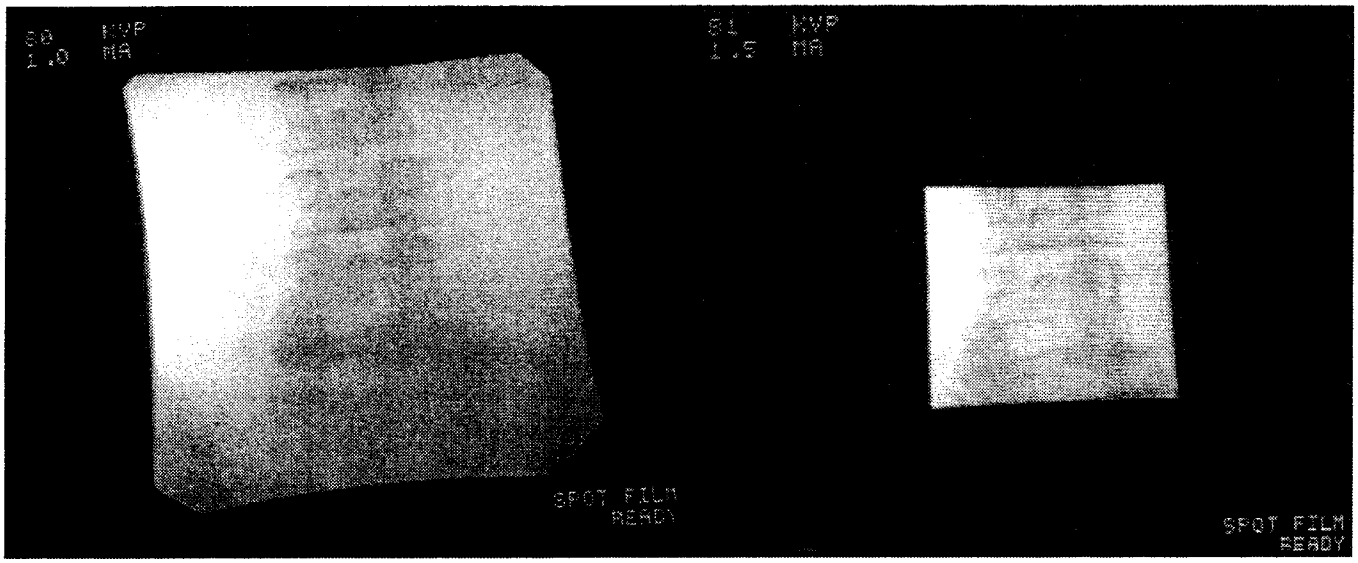
Radiation dose to personnel in the room is caused by scattered radiation. The volume of tissue irradiated strongly influences the amount of scatter that is generated. This is demonstrated in Fig. 19. If the field dimensions are increased by a factor of 2 by opening the collimators, then the volume of exposed tissue increases by a factor of about 4. Thus the dose to personnel in the room also increases by a factor of 4. *Large reductions in dose rate to personnel in the room can be realized if the radiation field is manually collimated to the smallest area of interest.*

Practical applications:

1. For some invasive procedures a large air gap between the patient and the image intensifier is used to accommodate invasive devices. This air gap greatly reduces the image-degrading effects of scatter. Tight collimation further reduces scatter. This renders the functionality of the grid superfluous. If the grid is removable, removing the grid will result in a lower dose rate to the patient and there is not likely to be any loss in image quality. Lower dose rate also reduces risks to personnel, especially to the physician's hands.

2. Lateral fluoroscopy of the spine with the patient prone on the table is a common projection employed in some procedures, such as in pain management. In this orientation the part of the laterally projecting x-ray field that is above the back of the patient is unattenuated and strikes the image intensifier with its full intensity. This produces an intensely bright area in the image just above the spine. The operator should rotate the collimators so that the blades are parallel to the surface of the back. *With this orientation, closing down the collimators to block the unattenuated beam is an effective way to improve image quality and reduce risks to the hands if manipulation of interventional devices is required.*

3. Cataracts are a potential risk for patients undergoing high-dose interventional procedures in the head. The threshold for radiation-induced cataract is about one Gray. For interventional procedures, such doses to the side of the head are relatively common. The primary source of radiation exposure to eyes originates from direct exposure from the lateral x-ray beam. *The physician can reduce such exposure by shielding the eyes on the lateral side. This is most easily achieved by using tight collimation.* The collimator must be closed down to shield a large portion of the orbit that is closest to the x-ray tube. *(The frontal view should be performed with the x-ray tube posterior to the head and the image intensifier anterior.* This ensures that the eyes receive only the much reduced exit-beam dose and not the much higher entrance dose. *If performed with the x-ray tube anterior, the potential for cataractogenic doses is greatly increased.)*



A **B**

Figure 19. The effects of collimation are illustrated in Figs. A and B for viewing the lumbar spine. (A human spine imbedded in a plastic manikin is used for demonstration.) In Fig. A the field-of-view is about four times larger than in Fig. B. Irradiation in Fig. A exposes four times more patient tissue than in B, and therefore puts four times the tissue at risk for radiation-induced effects. Scatter radiation to personnel in the room from the exposed volume of tissue is also four times greater. Collimation in B reduces risk to the patient, to personnel, and improves image quality by reducing scatter in the image. (The astute observer will note that the tube current and kVp in B are greater than that in A, resulting in increased x-ray intensity for B. This means that the dose to the exposed skin in B is slightly higher. In reality it is not 50% higher as is implied by the increase from 1.0 to 1.5 mA. This is due to reduced scatter that exists at the surface because of the collimation. The overall balance remains significantly in favor of narrow collimation.)

Commandment #8:	**Always collimate down to the area of interest.**

Concise summary #8:	Applying tight collimation improves image quality by reducing scatter, lessens the radiation burden to the patient by reducing the volume of tissue exposed, and reduces dose to personnel in the room by reducing scatter.

Quiz #8:	After applying tight collimation you notice that the tube current increases. Is this normal and what should be done about it? (See Appendix for answer.)

#9. Dose monitoring, shielding & positioning of personnel

While the principal source of radiation for the patient is the x-ray tube, the principal source for the operator and other personnel is scatter from the patient. A secondary source is the leakage of some x rays through the shielding of the x-ray tube. Leakage is usually much less of a concern than scatter from the patient.

As soon as the x-ray switch or pedal is disengaged, x rays cease to exist in the room and the patient is no longer a source of scatter radiation. The operator has full control over x-ray production. While the x rays are on, the most important means by which physicians can reduce dose to themselves and personnel is by using shielding and properly positioning personnel relative to the patient and the fluoroscopic equipment. Monitoring radiation exposure to personnel provides the means to measure the effectiveness of shielding and positioning.

-Protective Aprons

All personnel who are not positioned behind a radiation barrier must wear a protective apron during the procedure. We recommend that this apron have shielding characteristics equivalent to that of 0.5 mm of lead which will shield the protected areas of the operator from approximately 90% of the scattered radiation. The lead equivalencies are usually printed on a tag located on the apron. Lead aprons should be properly stored on a hanger and handled with care because the protective lining can be damaged and this may compromise their shielding characteristics. Aprons should be checked annually for holes, cracks or other forms of deterioration.

-Radiation Monitoring for Personnel

Unless protected by a radiation barrier, personnel who perform fluoroscopic procedures are usually required to wear a personal radiation-monitoring device, typically a film badge or a badge containing a stimulable luminescent dosimeter. We recommend that personnel wear these monitors anteriorly on their collars outside the lead apron to measure the dose to

Radiation mis-monitoring – true vignette #2

One of the authors received an inquiry from an individual who wanted to know if 200 mSv, accumulated over 20 years of work in a cardiac catheterization laboratory, was a large amount of radiation. Upon further discussion, it was learned that this was the dose reported on a cardiologist's radiation badge. He only wore the badge some of the time and it was usually worn under the lead apron (contrary to advice in commandment #9). The true radiation exposure was therefore unknown, but could have been hundreds of times higher to his face and head. As the conversation continued, the author learned that the middle-aged physician had brain cancer. The ultimate question was whether the radiation exposure received over twenty years could have caused the cancer.

While radiation has been weakly associated with cancers of the central nervous system (primarily in children), there can be no definitive answer to the caller's question. What is known is that there was poor radiation management for twenty years. Had the physician been properly monitoring his radiation exposure, he would have known the conditions of the working environment and corrective action could have been initiated early on. Because of the unknown etiology, it cannot be asserted that this would have prevented the cancer, but radiation as a likely agent would have been essentially eliminated.

the unprotected head and neck. If this dose is kept within our guidelines, the dose under the apron will be very low and very acceptable. If the monitor is worn under the apron, dose to the head and neck will be unknown. This is unacceptable. (See vignette #2.) Badge readings should be reviewed with the radiation safety officer. Table III provides our recommendations for actions associated with monthly readings on collar badges. These recommendations are more conservative than regulatory limits and represent what the authors feel are reasonably achievable goals.

Real-time monitors, that produce an audible signal to inform the wearer about elevated exposure rates, are available. These devices warn physicians when their working habits result in exposures that require precautionary action. They also serve as an effective training tool for beginners. Physicians who perform two or more procedures a day may find them of considerable benefit for encouraging good working habits.

Table III. Recommended actions for monthly collar badge readings

Typical monthly reading in mSv (reading in mrem)	Recommended actions
<1.0 mSv (< 100 mrem)	**No actions** recommended, continue safe practices.
1.0 – 4.0 mSv (100 – 400 mrem)	**Evaluate** work habits to reduce dose if possible, **consider** using extra shielding.
>4.0 mSv (> 400 mrem)	**Investigate** causes, **evaluate** work habits, **add** shielding and **implement** other dose reducing actions.

-Using Distance as a Shield

The distribution of stray radiation in a procedure room during lateral fluoroscopy is illustrated in Figure 20. Increasing the distance of personnel from sources of radiation can markedly reduce their radiation dose. The rule that relates distance with dose reduction is known as the **"inverse-square law"**. This "law" says that dose rate drops precipitously as distance from the source (e.g., the patient) increases. Specifically, the dose rate decreases by the inverse square of the relative increase in distance. For example, the rate at 2 meters is ¼ that at 1 meter. At 3 meters it's $^1/_9$ that at 1 meter. In Figure 20 the relative kerma decreases from a value of 4.0 next to the patient on the x-ray tube side to a value of 1.0 when distance

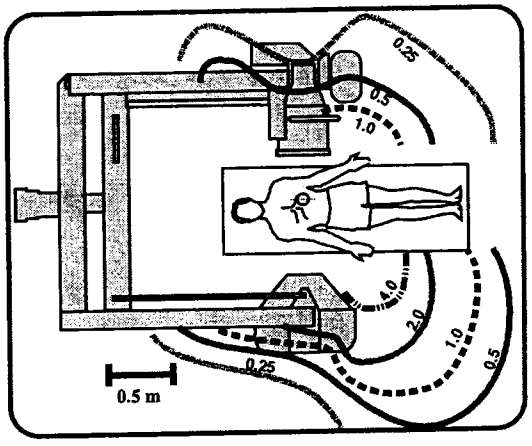


Figure 20. Distribution of stray radiation around a laterally positioned fluoroscope. Relative air kerma levels are shown for 150 cm (~5') above the floor or at roughly head level. The distance bar at bottom left represents an 0.5 m scale. (Reproduced with permission from Balter S. Stray radiation in the cardiac catheterization laboratory. In: Nickoloff EL, Strauss KJ. Categorical Course in Diagnostic Radiology Physics: Cardiac Catheterization Imaging, Radiological Society of North America, 1998, 222 – 230.)

from the patient is doubled. *Physicians should develop a habit of taking one step back from the irradiated area before they engage fluoroscopy.* This will markedly reduce their overall exposure, particularly that to their head, arms, hands, neck and legs.

-Leaded Eye Wear, Thyroid Shields, and Head Shields

Leaded eye wear and **thyroid shields** are recommended if monthly collar badge readings exceed 4 mSv (400 mrem). While their use is generally optional, they are effective at all dose levels and will prevent large lifetime accumulations to the thyroid and eyes. Protective eyewear may be the apparatus most likely to be required for regulatory compliance in a high-dose environment. Practically speaking though, the threshold for induced cataract is so high for chronic exposure that it is unlikely to ever be a significant risk, as long as proper safety techniques are employed. (Radiation-induced cataracts in personnel have been reported in environments that do not employ common safety practices. See reference 22.) *To be effective, eyewear must be equipped with side shields to reduce dose from the lateral direction.* Leaded goggles will also serve as a protective splash shield.

Head shields (Fig. 21) are transparent shields that are usually suspended from the ceiling. They protect the entire face and neck and are designed to be easily accessible in the fluoroscopic environment. The illustration on page 4 demonstrates the use of another form of ceiling-suspended shield (McMahon Medical, Inc., San Diego, CA). For mobile or fixed room fluoroscopy, shoulder mounted face shields will have the same effect if they are available. Otherwise the combination of protective eyewear and a thyroid shield may be used.

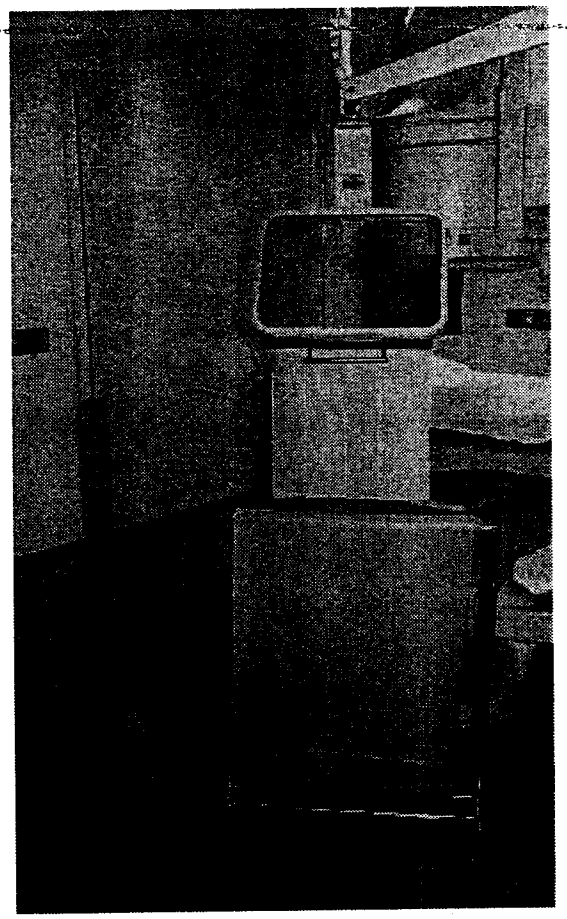


Figure 21. Variety of shields for protection during fluoroscopy. Suspended from the ceiling is a shield for the head and neck area. The tall standup shield is used for whole body protection and the shorter shield protects the legs from radiation scattered under the table from the patient.

-Mobile Barriers

Flat panel mobile shields (Fig. 21) are very effective whole- or partial-body shields. They must be placed between personnel and the irradiated area of the patient. They also should be between personnel and the x-ray tube. They are recommended for all ancillary personnel who must be in the room but who are not performing patient-side work.

Physicians or assistants located at tableside may accumulate large radiation doses to their legs if they spend long hours performing fluoroscopy. This is because the x-ray tube is usually below the table and backscatter off the patient is most intense under the table. Lower-extremity shields Fig. 21 can be used to shield the legs and feet of operators (see also page 4 for a lower-extremity shield mounted at tableside).

-Hand Protection

We personally observed dermal atrophy of the forearm and hands in one physician and radiation dermatitis in the hands of two other physicians who performed fluoroscopy for several years. These effects occurred in the mid-1990's. Radiation dermatitis in physicians' hands is demonstrated in Fig 2a. General concern over radiation exposure has convinced some physicians to wear special **hand shields** or sterile **x-ray attenuating surgical gloves**. The gloves are thin to provide tactility and they come in sterile packaging. Hand shields are thicker protective covers that do not interfere with finger movement. ***However, physicians should be warned that such devices are not likely to protect hands if placed fully into the beam.***

When placed fully in the x-ray field, gloves and shields add to the attenuation of the beam. This reduces image brightness. On most fluoroscopes the automatic brightness control (ABC) detects this and radiation output is increased to penetrate the "protective" gear. The net result is no significant reduction in hand exposure and increased patient exposure. The image of the hand inside the glove gives a false impression of actual "protection" because only one layer of glove protects the hand while the x rays must penetrate two layers to produce the image. The gloves themselves also tend to produce a large amount of scatter radiation that is not seen in the image but which does irradiate the hand. For these reasons, ***physicians must not be lured into a false sense of security and mistakenly rely on gloves as their principal means of protection during fluoroscopy.*** *Protective hand gear can be relied on only to protect against radiation outside the field of view of the ABC.* Some gloves reduce the scattered radiation to the hands by about 35%, others by much less, and some are of very little protective value. To protect hands during fluoroscopy, we recommend the following:

1. K*eep hands out of the beam as much as possible.* If the image of your fingers or hands appears on the monitor, they are being directly exposed. *Hands should be pulled back from the imaged area and away from the image intensifier unless physical control of invasive devices is required for patient care during fluoroscopy.* Use remote handling devices when possible, such as forceps or other specially designed instruments.

2. *Work on the exit-beam side of the patient whenever possible.* **For an adult abdomen, exit radiation is only about 1% the intensity of the entrance radiation.** For vertical projections the x-ray tube should be below the table. For oblique and lateral beams, it is best to stand on the side of the patient where the image intensifier is located. If proper collimation is always employed, working on the exit-beam side near the image intensifier ensures that the exposure to your hands is from exit radiation only.

For some procedures the logistics of positioning the x-ray machine, sterile trays, and medical

personnel dictate that the physician must work on the x-ray tube side of the patient. Extra care must be exercised in this situation to ensure that hands are only rarely, if ever, exposed to the direct beam. *While the occasional exposure to the hands will not result in any noticeable effect, repeated exposures with this geometry can quickly elevate dose to the hands beyond recommended limits* (see Fig. 2). [Also, see practical application 2 under commandment #8.]

3. *Wear a ring badge to measure your hand exposure* (see Fig. 22). This should be done monthly for a period of several months. The ring detects radiation only at the base of the finger. Dose at the fingertips may be significantly higher. The ring should be worn on the dominant hand on the finger closest to the beam. This is usually the middle or the index finger, but wearing it on the ring finger might be more comfortable. The sensitive badge area should be turned to face the oncoming beam (see Fig. 22). Refer to Table IV for guidance on monitoring. These recommendations are designed to assure that dose to the hands remains within the commonly recommended maximum annual limit of 500 mSv. Ring dosimeters can be sterilized if necessary (contact the supplier for recommended methods).

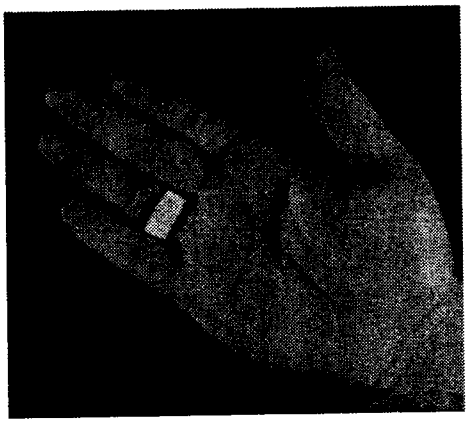


Figure 22. The ring badge for monitoring dose to the hands. The white sensitive area is turned inward on the hand to measure exposure from the beam that is directed upward from beneath the patient.

Table IV. Recommended actions following monthly hand-dose monitoring.

Monthly ring dose	Action	Continue monitoring?
<3 mSv (300 mrem)	Dose sufficiently low to discontinue monitoring.	Discontinue for now; repeat monitoring in a year.
3 mSv – 10 mSv (300 mrem – 1 rem)	Efforts to reduce dose are recommended.	Yes
>10 mSv (1 rem)	Immediately adjust habits to reduce dose.	Yes

Equipment Design Safety Features

Conventional GI fluoroscopy

For fluoroscopy of the gastrointestinal tract, the equipment is usually designed with the x-ray tube permanently mounted underneath a fixed table and the image intensifier positioned over the patient. The sides of the table contain lead shielding and the units are equipped with leaded drapes at the side of the image intensifier that absorb radiation scattered at right angles from the patient. The image intensifier itself is shielded to provide an extra measure of protection from x rays that scatter inside the image intensifier. At the side of the table and below the tabletop, there is an open slot that permits free movement of the cassette tray. A shielded flap or hinged bar should cover this slot during fluoroscopy. *This entire configuration is chosen in order to optimize radiation protection to personnel in the room.*

The leaded drapes are designed as separate strips so that a physician can insert his or her hands to perform a procedure without removing the drapes. The physician should very rarely, if ever, fluoroscope with hands in the beam. If the drapes are an impediment to the proper completion of a procedure, then they can be removed, but they must be replaced for use in other procedures.

All personnel not immediately involved with patient care, should step back a suitable distance from the patient, wear lead aprons, or step behind a radiation shield.

Remote control fluoroscopy

In some forms of remote control fluoroscopy the x-ray tube is positioned above the patient with the image intensifier under the table. In this situation the radiation reflected off the patient is at a high intensity and it is not appropriate for physicians to perform in-room procedures with these machines unless some extra special precautions are taken for the operator and other personnel in the room. In general, *these devices are designed for remote control use where the operator and all assistants will position themselves in a shielded booth while remotely manipulating the machine for acquisition of the images.* No protective aprons need be worn in this setting. *Fluoroscopy should never be performed in-room on a remote control unit unless there is special consultation with the radiation safety office.* [Radiation–induced cataracts have been reported in individuals who performed in-room fluoroscopy with these types of machines without using special precautions (22).] As always, it is recommended that fluoroscopists and technologists wear radiation badges whenever x-ray-producing devices are used.

C-arm fluoroscopy

In C-arm fluoroscopy there are no shielded drapes, no shielded table, and the examinations are usually performed in the room, not remotely. ***In these configurations it is very important that the operator pay attention to radiation management practices specific to these devices.***

With the C-arm oriented vertically, the x-ray tube should be located beneath the patient and the image intensifier above. This configuration makes use of the patient as a shield to reduce radiation exposures to personnel, especially to the physician's hands if they are in the beam.

When using lateral and oblique projections, radiation levels are least intense on the exit beam side (image intensifier side) of the patient. Figure 20 illustrates how stray radiation levels are distributed around a lateral C-arm. For example, in the lateral orientation scatter is frequently about four times greater on the x-ray tube side than on the image intensifier side. This ratio may be more or less depending on the size of the patient and section of the body irradiated. Therefore, for the purposes of radiation protection, standing on the image intensifier side of the patient is the best choice. (This assumes the x-ray tube is appropriately aligned with the image intensifier and that collimation is properly employed. This alignment of the fluoroscope should be checked at least annually. As a simple real-time assurance of this requirement, the edges of the collimators should be adjusted so that they are seen on the monitor.)

If assistants to the procedure must be positioned on the x-ray tube side, they should be provided with extra shielding, such as a mobile barrier or head shield. *All individuals who are in the procedure room and who are not behind a shielded barrier must wear a radiation monitoring device (e.g., a radiation "badge") and a protective apron (we recommend an apron of 0.5 mm lead-equivalency).* Personnel not immediately involved in the procedure should position themselves behind a radiation shield or maximize their distance from the patient while wearing a lead apron.

In many situations the physician is required to work on the x-ray tube side. For example, cardiologists often work in a bi-plane configuration and stand next to the laterally projecting x-ray tube located on the right side of the patient. The left arm and left side of the cardiologist's body are closest to the irradiated area of the patient and can accumulate a high radiation exposure over time. *If it is necessary to stand on the x-ray tube side, physicians and other assistants should wear lead aprons that cover their exposed side. We also strongly recommend ceiling suspended radiation shields to reduce exposure to the head and neck* (see vignette #2 and illustration on page 4). To best monitor radiation exposure, radiation badges should be worn outside the apron on the left side of the collar or attached to the left side of the thyroid shield. Face shields, thyroid collars, and/or protective eyewear may also be of benefit. The undertable tube combined with the lateral tube produces a large amount of scatter to the legs. Stepping away from the patient during fluoroscopy or using leg shields is recommended for those fluoroscopists who perform numerous procedures in this configuration. (Minor skin changes in the legs of some cardiologists and radiologists, such as hair loss and slight increases in pigmentation, have been personally communicated to the authors.)

Invasive devices and doses to patient and staff

Fluoroscopy with x-ray tube under table

Fluoroscopy at the area of the patient where medical devices are inserted poses a particularly difficult problem for radiation management. This is demonstrated in Figs. 23A and 23B. ***Figure 23A, with the x-ray tube under the patient, is the configuration preferred for the protection of personnel.*** In this configuration the patient shields the face and hands of personnel from the more intense x-ray field that enters the patient. However, because a large gap is required between the patient and the image intensifier, the entrance skin dose to the patient is not

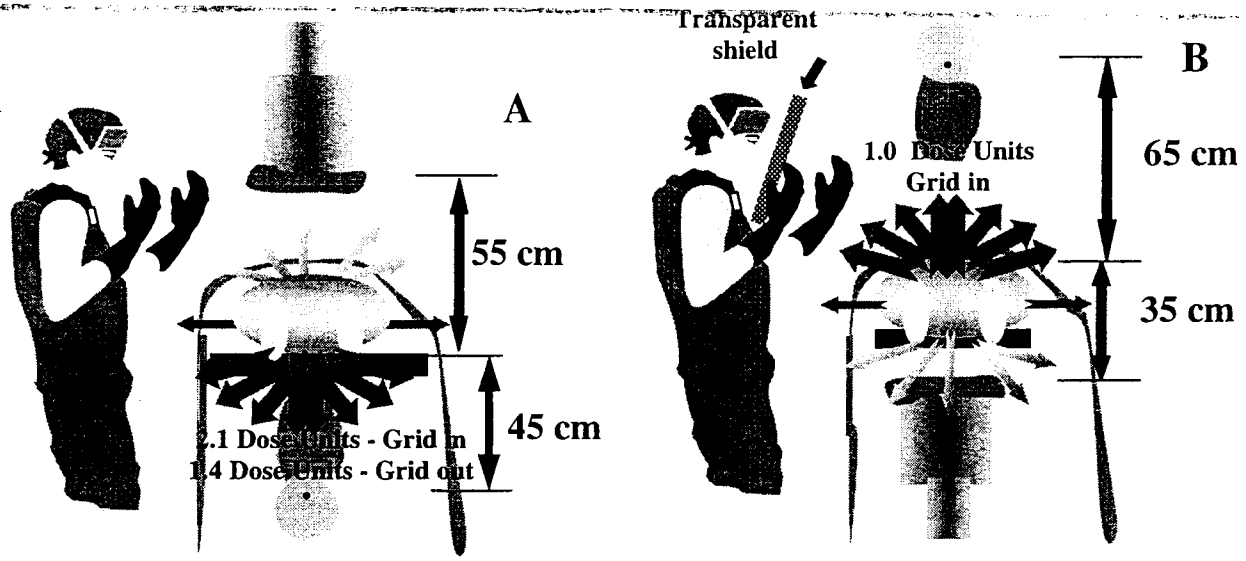


Figure 23. Comparison of under table and overhead geometries. Although dose to the patient is lowest with the x-ray tube above the patient as in B, doses to personnel are lowest with the x-ray tube below the patient as in A. Configuration A is generally recommended. **See precautions for use of configuration B.**

ideally managed. This is because the x-ray source is closer to the patient than in the ideal case (Fig. 16) and the image intensifier is away from the patient. When procedures are unusually long or exposure rates unusually high, the risk for a skin injury is higher than that with ideal geometry. However, the grid is unnecessary because the function of the grid is effectively achieved by the air gap. If the grid can be removed, this may help mitigate patient dose without undo loss in image quality, particularly if tight collimation is used.

Due to the large amount of scatter under the table, using leg shields or stepping away from the patient during fluoroscopy is recommended for fluoroscopists who perform most of their work in this configuration. Removal of the grid will also help prevent excessive irradiation from under-table scatter by simply reducing the input dose rate to the patient.

Fluoroscopy with x-ray tube over table

The configuration in Fig. 23B (tube over table) is preferred by some because the physician can easily create a large working space between the patient and the x-ray tube. Note that the image intensifier is close to the patient and the grid is in place. While this geometry has the potential advantage of minimizing the dose to the skin of the patient, it is decidedly more difficult to manage exposure to personnel. *The hands of personnel who attend the patient may be exposed to the full intensity of the direct beam* (see vignette #1). *This configuration also exposes the head of the operator to the most intense scatter from the patient.* We have personally observed monthly expo-

sures to the face and hands of a few tens of millisieverts (a few rems) for physicians who use this geometry. *Since this configuration may result in unacceptably high exposures, it is not recommended for routine use.* Radiation-induced cataracts have been reported in personnel who have used this configuration (22). We only recommend its use in special situations wherein it expedites the procedure, avoids excessive dose to the patient, and is performed under the supervision of expert radiation safety guidance (see, for example, our discussion on thoracic fluoroscopy in women). Radiation management precautions should include:

1. *Move the x-ray tube away from the skin as far as practicable (commandment # 4).*

2. *Move the image intensifier as close to the patient as possible (commandment #5).*

3. *To protect the head and neck area, use a transparent shield with sterile covers, if necessary; or step back from the patient before engaging fluoroscopy.*

4. *Have assistants use extra shielding or stand well back from the patient (more than 2 meters is recommended).*

5. *Hands must routinely be pulled back from the field of view during fluoroscopy. Insertion of hands in the field should only be on those rare occasions when patient care critically depends on it. Monitor hand dose as described in Table IV.*

6. *Use collimation to control image quality and reduce scatter (commandment # 8). The collimator blades must be visible in the image and closed down to the appropriately small area.*

7. *Keep the beam-on time of the study as short as possible (commandment # 10).*

Radiation management upside down – true vignette #3

Upon reviewing reports of radiation badge monitoring for their facility, the Radiation Safety Officer (RSO) noted that the film badge readings of several pain-management staff were consistently high. However, the pain-management physician had minimal readings. This peculiar finding prompted an investigation.

The practitioner, it turns out, never wore his radiation badge (contrary to advice in commandment #9), which explained his low readings. When asked about his use of the fluoroscope, he proudly demonstrated that he always kept the x-ray tube under the patient and as far away as possible. He also trained other physicians to use this setup. Unfortunately, the physician had confused the image intensifier with the x-ray tube and, in fact, had been keeping the x-ray tube above the patient, all contrary to commandments # 4 and 5. A close look at the physician's hands revealed chaffing, discoloration and epilation, clear signs of radiation dermatitis from inappropriate use.

When the RSO asked the physician and staff to demonstrate the use of the collimators, a series of blank stares ensued. No one knew that the unit even had a collimating system, contrary to commandment #8.

In addition to this, the RSO had noted that the low dose rate options on the unit had had their buttons taped over in such a way as to render them unusable, contrary to commandments 2,3, and 10.

This vignette demonstrates well that the use of the fluoroscope in unqualified hands can lead to health consequences.

Radiation management that works – true vignette #4

A physician, who was involved in a heavy workload of pain management, was concerned about her personal radiation-badge readings, which were about 10 – 20 mSv per month. The badge was worn at the collar outside the lead apron and represented the dose to her head and neck. In order to improve radiation management, her fluoroscopic habits were analyzed. The physician was orienting the fluoroscope correctly with the source under the patient, but she was unaware that she could employ a lower dose rate mode (see commandments 2,3,and 10). Upon reduction of the dose rate, the physician noted that the images were of a lesser quality but were perfectly adequate for patient care. In addition, the physician found that it was possible to step back from the patient before engaging fluoroscopy, without jeopardizing patient safety (commandment #9). With these two changes the monthly radiation-badge readings dropped to 0.2 – 0.5 mSv/month. Her diligence at wearing her radiation monitor caught the problem early in her career, saving her a lifetime of high-dose exposures.

-Pregnant Personnel

Pregnant women may continue to work in fluoroscopic areas, but they should wear an extra radiation monitor at the level of the abdomen underneath the lead apron. This serves as a monitor for the dose to the conceptus. Some choose to change abdominal badges every two weeks to maintain a frequent update of the dose to the conceptus. Others prefer to change the badges on the normal monthly schedule. Monitoring at intervals greater than one month (e.g., quarterly) is not recommended. Some find special real-time personnel monitors useful. A record of the dose to the abdomen should be maintained to ensure that the dose is within recommended standards. The under-apron badge should not measure more than 0.5 mSv (50 mrem) in any one month. Remedial action should be taken if the reading is in excess of 0.3 mSv (30 mrem). [These should not be construed as dangerous levels, they are merely levels chosen to ensure compliance with recommended limits.] Some physicians choose to monitor before they become pregnant to correct potential problems before pregnancy.

A wrap-around apron with 0.5-mm lead equivalent in front and 0.25 mm in back is recommended. Special lead aprons with a 1-mm lead-equivalent patch over the pelvis have been used to provide extra protection for the conceptus or a lap apron can be worn underneath the regular apron to provide the same effect.

Commandment #9: **Personnel must wear protective aprons, use shielding, monitor their doses, and know how to position themselves and the machines for minimum dose.**

Concise summary #9: Proper use of protective equipment is essential to radiation management for personnel. Knowing how to position the fluoroscope around the patient and how to position oneself for minimum radiation dose is critical to minimizing one's long-term exposure to radiation. Special precautions are recommended for pregnant women.

Quiz #9: Cite the two most important rules for minimizing radiation dose to the operator's hands. Cite two ways, other than the use of protective gear, to minimize your overall exposure to radiation. (See Appendix for answers.)

#10. Beam On-Time

Control over beam-on time is almost always the most important aspect of radiation management. ***This is the Golden Rule to minimize risk from fluoroscopic radiation.*** Exposure time may be controlled either by a button on the control panel (Fig. 14, item 10 at bottom of figure) or by a foot pedal. X rays exist only while the switch is engaged. When disengaged, no x rays exist anywhere in the room. Keeping fluoroscopic beam-on time and the number of image acquisitions for an examination to a minimum will prevent unnecessary radiation dose the patient, operator, and other personnel. In the past, excessive use of x rays during a single procedure was tempered by the fact that the x ray tubes were not capable of sustaining long durations of operations. Today, technology has created x ray tubes very capable of sustaining extremely prolonged use. In other words the restrictive technical boundaries of radiation application in fluoroscopy and fluorography have been essentially removed, placing greater responsibility on the operator to manage the radiation application appropriately by restricting its use to only that which is essential. Physicians should make a deliberate effort to ensure that the fluoroscopy and fluorography times are effectively used.

It is essential to disengage fluoroscopic exposure whenever the image on the monitor is not being used. Avoid long durations of continuous fluoroscopy. Intermittently use the radiation to complete the procedure. Avoid the temptation to keep the x-ray beam on while studying the image. ***For foot pedals, practice tapping the x-ray control and then maintaining a mental picture of the image while contemplating the procedure. Absentmindedly leaving the x rays on while viewing other factors associated with the procedure, such as direct observation of the patient or communication with other personnel in the room, must be strictly avoided.***

Excessive on-time - true vignette #5

The switch used to engage fluoroscopy requires a continuous pressure and it automatically disengages when released. This is a safety feature that applies to hand controls as well as to foot controls. (The switch is called a "dead-man" switch because it shuts down if the operator falls dead.) The intent of the dead-man switch is to ensure that x rays are applied only when needed by the physician (commandment #10). The authors of this manual were personally involved in one circumstance where a surgeon used a heavy object to keep the foot switch continually engaged during his procedures. His excuse was that it was a distraction to have to repeatedly engage the fluoroscope. Such behavior constitutes abuse of a safety device and is justification to revoke fluoroscopic privileges.

-Last-image Hold

Most modern fluoroscopes have digital technology in which the last frame or last few summed frames of the fluoroscopic image can be stored in memory and displayed for continual visualization after the beam is turned off (***last-image hold***). This feature can be used to allow the physician time to study the progress of the procedure without using live fluoroscopy. Considerable savings in dose to the patient and to personnel can be realized by prudent application of this technology.

-The Fluoroscopy Timer

All fluoroscopic units have a **timer** (Fig. 14, item 10 center). On most units the timer remains silent for five minutes and then gives off a warning tone and is silenced only after being reset. In the future this timer may be programmable for other times. *The purpose of this timer is to help the physician keep track of fluoroscopic duration.* The cumulative fluoroscopy time should be reviewed as an effective quality improvement tool. A logbook can be maintained to record cumulative times. The reasons for times exceeding the norm should be reviewed and adjustments made in future procedures when indicated.

-Variable Pulsed Fluoroscopy

Variable pulsed fluoroscopy is a selectable feature that some manufacturers now incorporate into their systems to reduce patient dose and to enhance image quality. Recall that, with **conventional fluoroscopy**, a continuous stream of x rays is produced when the pedal or switch is engaged. In variable pulsed fluoroscopy, when the operator steps on the pedal, x rays are produced in short bursts (or pulses) and no x rays are produced during the intervals between pulses. The operator can select the number of pulses per second. Normally, dose rates with variable pulsed systems are lower with lower pulse rates. [This, however, is not always the case. See below ~~for details.]~~ ~~A further~~ understanding of these concepts is necessary to appreciate the opportunity for improving image quality and reducing dose during fluoroscopic procedures.

Image quality benefits and pulsed fluoroscopy

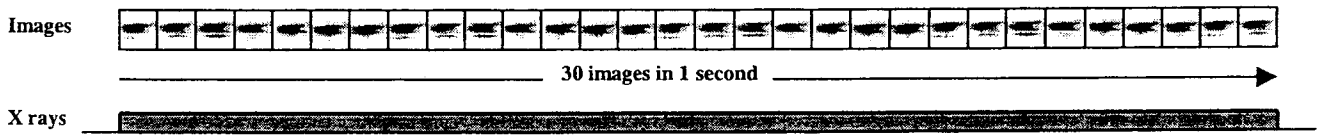
When viewing a motion picture on television or in a movie theater, the perception of continuous motion is created by flashing thirty still-frame images on the screen every second (25 images per second in Europe). In conventional fluoroscopy, each image on the TV monitor represents 1/30th of a second. But because the x rays are continuously produced, each image is actually a smear of what happened in the 1/30th of a second interval (Fig. 24A). Due to the pulsating motion of blood vessels and the vibrating motion of a catheter wire, the image of the catheter wire in the vessel during the 1/30th of a second interval can be significantly smeared, or blurred.

Image quality can be enhanced by pulsing the x rays once every 1/30th of a second but making the pulse only a fraction of the 1/30th of a second interval. For example, if the pulses are only 1/100th of a second long in each interval, then the motion blur (or smearing) is much reduced and the image resolution is enhanced. This is illustrated in Fig. 24B where 30 consecutive stop-action images of a galloping horse are shown during a 1-second interval. If each snapshot image of the galloping horse were flashed in front of us at 30 sequential images per second, we would perceive the motion as continuous and sharp.

To maintain image quality in 30-frame pulse imaging, the same x ray exposure must be employed for each image. To compensate for the fact that there are no x rays produced during the interval between pulses, the tube current during the short pulse in our example must be enhanced by a factor of 3.3. The **average** tube current, or mA, does not change, and so the dose rate to the patient does not change. *The result is improved image resolution with no change in dose rate.*

A. Continuous fluoroscopy

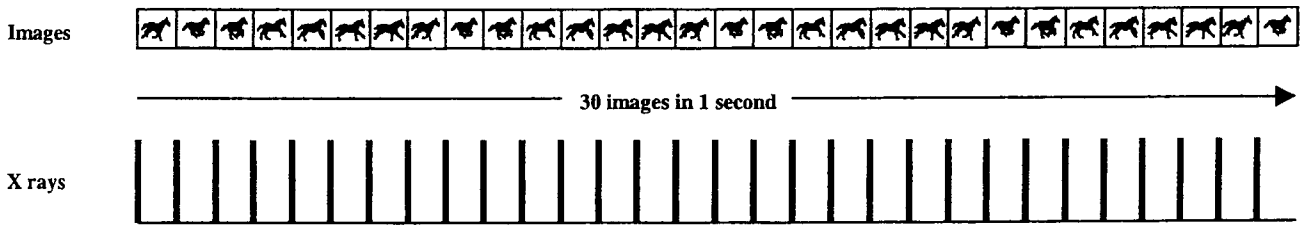
Blurred appearance of motion with continuous x-ray production because exposure time lasts the full 1/30th of a second for each image interval



Continuous stream of x rays produces blurred images in each frame

B. Pulsed fluoroscopy, no dose reduction

Sharp appearance of motion because each of 30 images per second is captured in a pulse (snapshot) of 1/100th of a second; exposure is the same as in A.

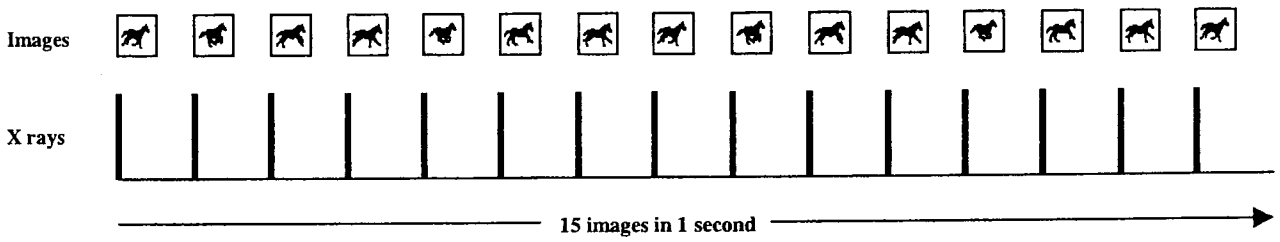


Each x-ray pulse shown above has greater intensity than continuous mode, but lasts for only 1/100th of a second; no x rays are emitted between pulses; dose to patient is same as that in A.

Fig. 24. Schematic video display of a horse galloping left to right across a TV monitor. The principles of pulsed fluoroscopy are evident if we imagine that the horse is the opaque tip of a catheter that is threaded through a vessel. In A, the movement appears as a blurred object moving left to right because with continuous fluoroscopy there is no stop-action imaging. In B, a short pulsed fluoroscopic output captures 30 stop-action images per second and the video displays these images in sequence to produce the sensation of motion.

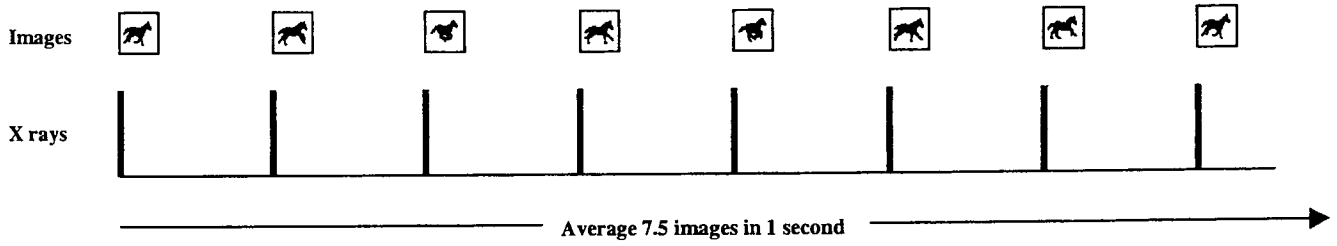
A. Pulsed fluoroscopy, dose reduction at 15 pulses per second

Sharp appearance of motion captured at 15 images per second in pulsed mode. Dose per pulse is same as in Fig. 24B, but only half as many pulses are used, thus dose is reduced by 50%. The tradeoff is a slightly choppy appearance in motion



B. Pulsed fluoroscopy, dose reduction at 7.5 pulses per second

Pulsed fluoroscopy at 7.5 images per second with only 25% the dose of that in Fig. 24A or 24B.



C. Pulsed fluoroscopy, dose reduction at 3.75 pulses per second

Pulsed fluoroscopy at 3.75 images per second with only 12.5% the dose of that in Figs. 24A or 24B.

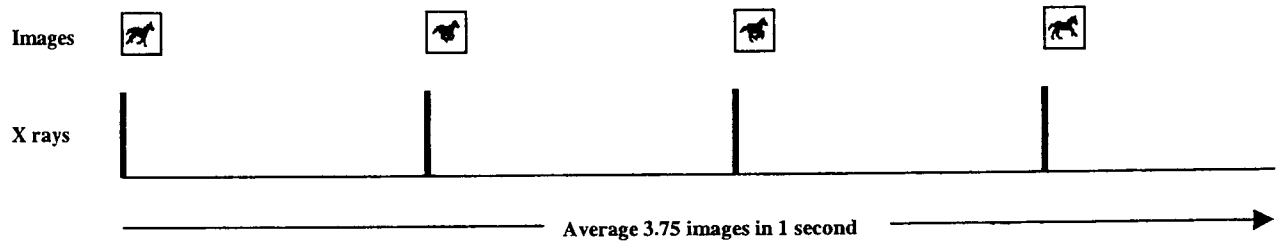


Fig. 25. Dose savings from variable pulsed fluoroscopy. In A, images are captured only 15 times each second. Since only half as many images are acquired as in Fig. 24 B, the patient dose is reduced by half! The tradeoff is that the image sequence appears to have a choppy motion. In B, the image rate is again halved. This produces an even choppier image motion, but the dose is again halved. In C, the image rate is even less with parallel effect and even more dose reduction.

Note: Tube current (mA) for pulsed fluoroscopy no longer has the same meaning as in continuous fluoroscopy because of the pulsed nature of the beam. Tube current is often quoted as the mA during the pulse, not the average mA. Since the length of the pulse can vary, the relationship of pulsed tube current to dose rate is not easily discerned. Pulsed tube currents can therefore be unusually high and still produce low dose rates due to the short pulse duration. The actual dose rate can only be known if there is a dose rate monitor to measure the output directly.

Dose savings from variable pulsed fluoroscopy

Dose savings can be achieved by reducing the number of pulses per second (the "variable" factor). While 30 images per second may be necessary to watch a ballerina move gracefully across the TV monitor, that many images per second is unnecessary to watch the advancement of a catheter or other medical device along a lumen. Usually about 15 per second, or less, will capture the motion necessary for medical care (Figs. 25A and 25B). Therefore, *in variable pulsed fluoroscopy only 15 or 7.5 pulses of x-rays per second may be necessary to capture the visual information. The same number of distinct images is flashed on the screen to yield a slightly choppy motion.* This theoretically reduces the dose by a factor of 2 to 4 (15 or 7.5 pulses of x rays as opposed to 30). In practice, the dose savings are not always the theoretical factor because the pulse intensity may be additionally enhanced to reduce "noise" or "snow" in the image. The savings are, however, usually very substantial. Reducing the number of pulses to less than 7 per second (Fig. 25C) will further reduce dose, but the dynamic motion becomes very choppy. The least number of pulses necessary to properly perform the procedure should be used.

A Warning

Different manufacturers implement pulsed fluoroscopy in a variety of ways. While many manufacturers have "pulsed fluoroscopy", not all manufacturers implement it with dose savings or image enhancing methods. In some cases the dose rates may even increase, rather than decrease, because the pulse intensities and durations are adjusted to increase x-ray output. This might be done to reduce image noise, for instance. Prior to using any "pulsed fluoroscopy" system, it is important that the fluoroscopist verify through independent testing how the pulsed modes function. Function can be verified by a medical physicist.

-Cine Fluorography

In cardiology, acquisition and rapid review of cardiac dynamics are essential. This is achieved either through the use of videotape or digital cine fluorography. Videotape produces an image quality inferior to that from digital imaging and is rapidly disappearing for this type of application. In digital **cine**, image dynamics are captured at rates of about 7, 15 or 30 frames per second to resolve the temporal motion of the beating heart. Entrance skin doses per image of cine are about 0.3 – 0.6 mGy_t, rendering high dose rates on the order of 140 - 1100 mGy_t per minute, but they can be higher, depending on many factors such as patient size, magnification, air gap, oblique imaging, etc. Poorly tuned equipment or poor techniques also contribute to markedly increased dose rates. Because of these high dose rates, all cine fluorography must be used judiciously for only short imaging sequences.

A mere 2 seconds of runtime can result in a skin dose of 7 – 60 mGy_t. If 30 runs occur during a procedure, this represents additional skin dose of 0.21 – 1.8 Gy_t. If it is possible to shorten the runs by 2 seconds, a substantial savings in skin dose is realized. Attention to these details becomes critical in interventional work when use of fluoroscopy and cine fluorography over the same skin area may be prolonged. Five to ten minutes of cine at the higher rates will cause serious skin injury. Less time is needed if conditions boost rates to even higher levels. ***Overuse as a substitute for fluoroscopy results in excessive doses to personnel and can cause serious injury to the patient.*** The temptation to use cine when fluoroscopy will do must be strictly avoided.

-Digital Fluorography

Advances in digital technology have made it possible for the physician to use radiation more effectively and have expanded the applications of medical x-ray imaging. These advances have also made it possible to acquire serial medical images at rates and quantities not possible with conventional film-based technologies. *Doses from serial digital imaging can markedly increase both patient dose and the possibility of a severe radiation-induced injury.* Physicians must therefore work with caution and make a conscientious effort to limit **digital fluorographic imaging** to the essential duration and numbers necessary for the procedure. The temptation to acquire more images because of the ease at which they can be collected must be strictly avoided.

-Aids to Reduce Use of Fluoroscopy and Fluorography

For specific procedures in radiology, orthopedics, pain management, and other specialties, there are numerous techniques that can be applied to reduce the need for fluoroscopy while introducing and positioning invasive devices. Some are as simple as applying markers on the skin of the patient or using a forceps or other similar devices to mark a position. Forceps might be used to move objects in the field while the x rays are engaged. Still other devices use laser beams to orient the position and help direct the introduction of surgical tools and devices. These guidance techniques and instruments can reduce the use of fluoroscopy by significant amounts and we encourage their use whenever practicable.

Commandment #10: Keep beam-on time to an absolute minimum!
—The Golden Rule

Concise summary #10: Minimizing the time that fluoroscopy or fluorography is used will reduce dose to all involved and the impact on image quality is nil or minimal.

Quiz #10: Cite two technological methods to reduce the beam-on time needed to complete a study. (See Appendix for answer.)

Table V. Summary of commandments 1 – 10. How individual factors affect radiation management. (An ↑ means the factor increases, ↓ means the factor decreases.)

Operational Factors	Radiation Management Factors		
	Image Quality	**Radiation Skin Dose to Patient**	**Radiation Dose to Staff**
1.) Patient Size ↑	↓	↑	↑
2.) Tube Current (mA) ↑	↑	↑	↑
3.) kVp ↑	↓ (Contrast goes down)	(Usually ↓ but only if mA is appropriately reduced)	(Depends on how tube current responds)
4.) Source-to-skin distance ↑	(Depends on magnification and image size)	↓	(Depends on how collimation is adjusted in response to change)
5.) Image Intensifier to Skin Distance ↑	(Depends on magnification and image size)	↑	(↑ if SID ↑ or if collimators open wider, otherwise no significant change)
6.) Image Magnification (electronic or geometric) ↑	(Usually ↑ but depends on focal spot size)	(Usually ↑ but depends on system design)	(Usually ↑ , but depends on system design and how collimation, kVp, and tube current respond.)
7.) Grid used	↑ for II close to adult patient	↑	↑
8.) Collimator Opening ↑	↓	(Skin dose is about the same but more tissue is exposed)	↑
9.) Room & Staff Shielding ↑	No Change	No Change	↓
10.) Beam On-Time ↑	No Change	↑	↑

Prolonged Procedures and Dose Management

The importance of applying the commandments to minimize absorbed dose to the skin of a patient during prolonged procedures is demonstrated in Fig. 26 (30). Even though changes in dose rate may be relatively small due to one less-than-ideal application of a commandment, small changes in many of the dose-management techniques can result in a very large increase in dose rate. Fig. 26 shows the skin dose to a patient who undergoes a prolonged procedure for placement of an intrahepatic portosystemic shunt, using a fluoroscope from a major manufacturer. Each bar represents the dose under different fluoroscopic conditions. The patient was very large with a 280-mm thick abdomen (see commandment #1). The unusually long procedure required 90 minutes of fluoroscopy and 100 fluorographic images (DA and DSA). The "standard" technique employed pulsed fluoroscopy at 7.5 frames per second (see commandment #10), a magnification mode using a field-of-view of 280 mm (see commandment #6), negligible air gap between the patient and the image intensifier (see commandment #5), and a 700-mm source-to-skin distance (see commandment # 4). Skin dose from this "standard" procedure is demonstrated by the clear bar. The gray bars demonstrate the skin dose when only one of the operating factors is altered for the procedure. The new setting of the operating factor is listed under the bar. These doses are modestly increased over the "standard". The largest single-factor change in dose results from the use of continuous-beam fluoroscopy rather than the 7.5 frames per second pulsed mode. This change causes the dose to increase by a factor of 2.6. The black bar represents the dose when all the gray applications are

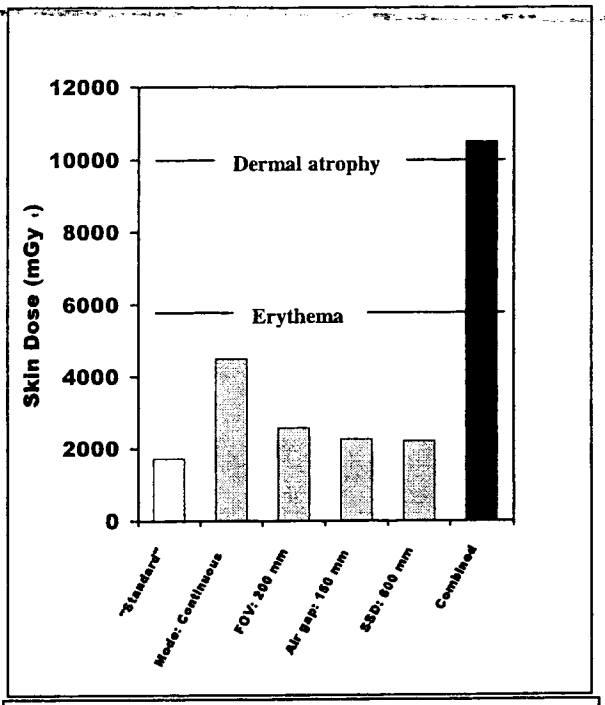


Fig. 26. Comparison of skin dose from prolonged fluoroscopic procedure using various operating parameters in a large patient (30). (See text.)
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simultaneously used in the procedure. The difference in the doses between the standard and the combined technique is 8.8 Gy! The dose to the skin from the "standard" technique would not be expected to cause any serious skin effect. From the combined technique erythema and dermal atrophy are anticipated.

The lessons of this exercise are twofold. First, *effective application of dose-reducing techniques as described in the commandments can result in very large savings in dose to the patient (as well as to personnel)*. Second, the *application of dose-reducing pulsed-fluoroscopy results in a very large savings in dose to the patient and to personnel.* (Caution: as previously indicated, not all pulsed-fluoroscopy modes result in dose-savings. Consult with the manufacturer or a medical physicist if there are questions related to your equipment.)

Other Methods to Protect Patients

Patient management

Detailed medical records can be very effective in managing radiation exposures to patients who receive multiple studies or who may require radiation therapy later. For procedures that involve a lengthy amount of fluoroscopy (about 20 minutes or more) or a known high dose to the skin, a record carefully identifying the area of exposed skin will alert other physicians about the need to be attentive about limiting irradiation of the same area. A record of the estimated skin dose would also be helpful (see "Monitoring doses to patients" later in this section). It may be advisable for patients who have prolonged procedures to be followed about 2 – 3 weeks later for potential development of any skin changes, unless the dose was monitored and found to be less than about 3 Gy_t. Documentation of any delayed reactions will assist in future care and will provide information that alerts physicians of the need to pursue dose minimization in the future.

If a patient has a previous irradiation history, then prior to any additional lengthy procedure the physician should examine the skin area to look for changes, such as telangiectases, epidermal thinning, dermal atrophy, or changes in pigmentation that are indicative of previous high exposures. Positioning the C-arm to a slightly different angulation might be a practical way to avoid overexposure of a specific area when procedures are prolonged. [Lichtenstein et al. (7) also suggest that the use of topical radioprotectors, such as leukotrienes and prostaglandins, might be considered when doses are high. These protectors must be applied before the procedure to be effective. However, there is no experience on their effectiveness in patients undergoing extended fluoroscopic procedures.]

Informed consent

For extended procedures where the fluoroscopic dose to the skin or eye is likely to exceed 2 Gy_t (more than about 30 minutes of standard fluoroscopy), the physician may wish to counsel the patient on the potential radiation effects as outlined in Table I. (See FDA recommendations on page 1.)

Patients with diseases that may render them radiosensitive

Some diseases may render patients sensitive to radiation and they may be at greater risk for adverse reaction from high doses received from interventional procedures (18). These include patients with ataxia telangiectasia, connective tissue diseases (collagen vascular disease), and diabetes mellitus. Such patients should be counseled about potential adverse reactions in the case of high doses to the skin. One patient with mixed connective tissue disease and diabetes mellitus experienced severe dermal necrosis after a transjugular intrahepatic portosystemic shunt procedure (18).

Pregnant patients

The possibility of pregnancy in any woman of childbearing age should be considered a potential contraindication to a fluoroscopic study of the pelvis unless the situation is a life-threatening emergency. Caution is also advised for procedures in the upper abdomen. Irradiation of the abdomen or pelvis of a potentially pregnant woman should be performed only after careful examination of the benefits and risks. If a patient of childbearing potential is thought to be pregnant or has not had a menstrual period within the previous 4 weeks, special consideration should be given prior to proceeding with a fluoroscopic examina-

tion. If the procedure will involve extensive fluoroscopy of the pelvis, a pregnancy test is advisable unless there is no reproductive potential. Potential risks to a conceptus will depend on the gestation age and radiation dose. These potential risks (and the most vulnerable period) include radiation-induced loss of pregnancy (0-2 weeks postconception), small head size (2-15 weeks postconception), intellectual deficit and mental retardation (8-15 weeks postconception), and induced childhood cancer, particularly leukemia (entire gestation). A consult with a radiation effects expert should be sought before proceeding in such circumstances.

Many options are available to help optimize benefit and minimize risk. Critical developmental periods might be avoided, patient position might be changed to reduce dose, the examination might be otherwise modified, and, if necessary, the dose can be monitored.

Use of a lead-apron shield for the patient is likely to provide an indirect message to the patient that you are taking every measure to protect her child; but, in fact, shielding is not likely to be of much benefit. The lead apron must not be placed in the direct beam since the additional attenuation will only cause the ABC to increase radiation output in order to penetrate the shield. The shield will not protect much against scatter because scatter is generated inside the patient, not external to her. The best way to protect the conceptus is to use good collimation and keep the beam-on time as short as possible.

Shielding with a lead apron might help prevent the inadvertent direct irradiation of the conceptus by creating a radio-opaque boundary that warns the physician of the proximity of the conceptus during panning of the fluoroscope. If shielding is used, ***it is important that the shield be positioned on the x-ray tube side of the patient*** so that the beam is intercepted before it enters the patient. If placed on the image intensifier side, the conceptus will still be directly irradiated because the shield does not block the beam before it enters the patient. However, the image will give a false impression of protection because the shield will block the beam before it enters the image intensifier. Thus the image misleads the observer into believing the patient is protected.

Thoracic fluoroscopy in women

Breast cancer has been induced in women who had thoracic fluoroscopic evaluation for the treatment of tuberculosis. Some of these women were positioned with their breasts facing the x-ray tube. This might occur with today's procedures if the x-ray C-arm is oriented for an oblique view through the thorax, perhaps to view the spine. *This orientation of the x-ray c-arm and the patient may result in a situation where the breast is directly in front of the x-ray port. Outputs at the port can be very intense due to the close proximity to the source.* Intensities of more than 0.5 Gy_t per minute are possible, depending on the equipment and the size of the patient. There are a few considerations, compromises and actions to help the physician abate this breast exposure and the concomitant cancer risk. Consider any of the following:

1. *It may be reasonable to turn the c-arm over so that the x-ray tube is above the back of the prone patient* (Fig. 23B). The breast would receive only the much reduced exit dose. This violates the standard principles of good radiation management for personnel (Fig. 23A). However, this configuration is preferred to deliver less dose to the patient's breast. The precautions discussed under commandment #9 for this geometry should be followed.

2. Position the beam so that the breast is not in direct line with the x rays or consider using support materials to move some of the breast out of the direct beam. Remember to maximize the distance of the x-ray port from this area.

Monitoring doses to patients

The radiation dose to the skin that is delivered during routine diagnostic fluoroscopy is not usually measured. Instead, the general practice is to have the equipment periodically tested to ensure compliance with standards of performance. Other than this, the physician controls the application of radiation and should have sufficient training to keep the use to a minimum. As stated before, it may be beneficial for the physician to keep track of fluoroscopic on-time as a quality control measure. For most routine diagnostic studies, this should be sufficient to assure safety.

In some countries, it is common to record the dose-area product (DAP) for fluoroscopic procedures. Use of DAP meters is expanding in the United States. DAP is the air kerma multiplied by the field area. The real-time recording of this quantity is very useful because it fosters good radiation management habits. This quantity is minimized by reducing the dose and dose rate to the patient as well as by reducing the field size, which encourages good collimation. Comparing the results of one physician's studies to those of a physician who performs similar studies is also useful in identifying poor radiation management habits and correcting them.

For some procedures, e.g., interventional work, very high doses of x rays to the patient might be required. In these cases, **measurement of the absorbed dose to the skin is necessary** *to assure that it is at an acceptably low level for the procedure.* The United States Food and Drug Administration has recommended that this be monitored for patients whose skin dose might exceed 1 Gy_t (100 rad) or at a level that the facility decides is appropriate for patient care (23). Many devices are available to monitor doses without interfering in the proper completion of the procedure (31). The most effective real-time readout devices are computerized dose monitors, DAP meters, and scintillation dosimeters (31). Thermoluminescent and photoluminescent dosimeters are useful for after-the-fact analysis of dose. Scintillation and luminescent dosimeters may be placed directly on the skin of the patient (32). This is effective only if the dosimeter can be placed on the area of skin most heavily irradiated. Otherwise, they can be used as a portal monitor, much like the DAP meter. The DAP meter is built-in on many modern fluoroscopes. Dose to the skin can be estimated from the DAP readout (usually given in units of cGy-cm^2) by dividing the readout by the area of the beam at the surface of the skin. At least one manufacturer performs this division and provides this dose estimate as a real-time display. This technique will probably become more prevalent with newer equipment. Scintillation monitors are available as add-on devices to existing equipment. Computer-based dosimetry is an add-on device that monitors the performance of the fluoroscope to render a similar dose estimate. The proper use of these devices will probably require the assistance of a medical physicist, at least initially.

We recommend that physicians consider whole body dose of more than 50 mSv per dose monitoring as follows:

- for any procedure that may utilize more than 20 minutes of fluoroscopy;
- for any procedure that potentially involves direct irradiation of the pelvis a pregnant patient;
- periodically to assure that radiation doses are within acceptable norms;
- for training purposes.

-Regulations

All fluoroscopy equipment marketed in the United States must meet radiation control design specifications as mandated by the FDA. These include specifications on shielding, collimator function, source-to-skin distance, limits on x-ray intensities and many other features of design. These requirements have markedly reduced the potential for radiation injury from medical x-ray equipment. ***However, no regulation on design can guarantee safe use.*** *Almost all fluoroscopic machines can expose patients to unacceptable and dangerous levels of radiation. Operator training in the safe use of radiation is essential for good medical practice.*

Once equipment is put into service at a medical facility, the radiation control department of each state is responsible for enforcement of regulations. Compliance is enforced by inspectors who perform surveys at facilities. Although regulations may vary from state to state, most states have some common rules. The reader is cautioned that some state laws may be stricter (or less strict) than those specified here.

1. Most regulations state that *no occupationally exposed person may receive an effective dose equivalent in excess of 50 mSv (5 rem) per calendar year as a result of incidental exposure to radiation in the work place.* An annual dose of this level is exceptional and should not be considered routinely acceptable. We recommend that the annual effective whole-body dose not exceed 10 mSv (refer to Table III for our recommended monitoring guidance).

Your radiation badge measures the dose you receive. To ensure an accurate dose reading, badges should be changed every month, or at an interval consistent with the material used for dosimetry. You should review your exposures periodically to ensure that they are within limits acceptable for your practice. The radiation safety officer (RSO) is required to inform you if your badge readings exceed regulatory limits. (Note: Your effective whole-body dose may not match your badge reading because of shielding afforded during fluoroscopy by your protective apron. The relationship between your badge reading and your whole-body effective dose can be explained by your RSO. This relationship may have a regulatory interpretation that differs from state to state.)

2. When an employee in fluoroscopy informs the RSO that she is pregnant, *the conceptus may not be exposed to more than 5 mSv during the entire gestation.*

3. *There are no regulatory limits on the cumulative amount of radiation a patient may receive from diagnostic or interventional medical procedures.* The physician is the individual who has full control over and responsibility for this exposure.

4. Members of the general public, excluding patients, are not permitted to receive more than 1 mSv of radiation per year as a result of incidental exposure to ambient radiation generated by the use of medical x-ray equipment.

-Moving Forward

The FDA has issued an advisory on the harmful effects of x rays to patients and has noted that some prolonged uses of fluoroscopy have resulted in radiation burns. The advisory recommends that physicians be trained in the safe uses of x rays. This monograph was designed to help meet this goal. Your enforcement of the principles outlined in this document will be a major step in assuring the responsible medical use of x rays.

References

1. Carstens GJ, Horowitz MB, Pury PD, Panya AG. Radiation dermatitis after spinal arteriovenous malformation embolization: case report. Neuroradiology 1996; 38 Suppl 1: S160 – S164.
2. Dehen L, Vilmer C, Humilière C, Corcos T, Pentousis D, Ollivaud L, Chatelain D, Dubertret L. Chronic radiodermatitis following cardiac catheterisation: a report of two cases and a brief review of the literature. Heart 1999: 308-312.
3. D'Incan M, Roger H. Radiodermatitis following cardiac catheterization. Arch Dermatol 1997; 133: 242-243.
4. Knautz MA, Abele C, Reynolds TL. Radiodermititis after transjugular intrahepatic portosystemic shunt. South Med J 1997; 90:352-356.
5. Huda W, Peters K. Radiation-induced temporary epilation after a neuroradiologically guided embolization procedure. Radiology 1994; 193: 642 – 644.
6. Krasovec M, Trueb RM. Temporary roentgen epilation after embolization of a cerebral arteriovenous malformation. Hautarzt 1998; 49:307 – 309.
7. Lichtenstein DA, Klapholz L, Vardy DA, et al. Chronic radiodermatitis following cardiac catheterization. Arch Dermatol 1996; 132:663-667.
8. Nahass GT. Acute radiodermatitis after radiofrequency catheter ablation. J Am Acad Dermatol 1997; 36, 881-884.
9. Nahass GT, Cornelius L. Fluoroscopy-induced radiodermatitis after transjugular intrahepatic portosystemic shunt. Am J Gastroenterol 1998; 93, 1546 – 1549.
10. Poletti JL. Radiation injury to skin following a cardiac interventional procedure. Australas Radiol 1997; 41: 82 – 83.
11. Ridley EL. Physicians need education and TQM for fluoro safety. Diagnostic Imaging, February 1995, 15-16.
12. Rosenthal L, Beck TJ, Williams J, et al. Acute radiation dermatitis following radiofrequency catheter ablation of atrioventricular nodal reentrant tachycardia. PACE 1997; 20: 1834-1839.
13. Shope TB. Radiation-induced skin injuries from fluoroscopy. RadioGraphics 1996; 16:1195-1199.
14. Søvik E, Klow N-E, Hellesnes J, Lykke J. Radiation-induced skin injury after percutaneous transluminal coronary angioplasty. Acta Radiologica 1996; 37: 305-306.
15. Stone MS, Robson KJ, Leboit PE. Subacute radiation dermatitis from fluoroscopy during coronary artery stenting: Evidence for cytotoxic lymphocyte mediated apoptosis. J Am Acad Dermatol 1998; 38, 333 – 336.

16. Vañó E, Arranz L, Sastre JM, Moro C, Ledo A, Gárate MT, Mínguez I. Dosimetric and radiation protection considerations based on some cases of patient skin injuries in interventional cardiology. BJR 1998; 71, 510-516.

17. Wagner LK. Perspectives on Radiation Risks to Skin and other Tissues in Fluoroscopy. In: Radiation Protection in Medicine: Contemporary Issues. National Council on Radiation Protection and Measurements Proceedings No. 21. NCRP, Arlington, Virginia, 1999.

18. Wagner LK, McNeese MD, Marx MV, Siegel EL. (1999). "Severe Skin Reactions from Interventional Fluoroscopy: Case Report and Review of the Literature" Radiology (in press).

19. Wagner LK. (Personal communications with injured individuals).

20. Wolff D, Heinrich KW. Strahlenschäden der Haut nach Herzkatheterdiagnostik und –therapie 2 Kasuistiken. Hautnah derm 1993; 5: 450-452.

21. Wolff D. (1998). Research thesis, private communication.

22. Vañó E, Gonzalez L, Beneytez F, Moreno F. Lens injuries induced by occupational exposure in non-optimized interventional radiology laboratories. BJR 1998; 71: 728-733.

23. United States Food and Drug Administration. Public Health Advisory: Avoidance of Serious X-ray Induced Skin Injuries to Patients During Fluoroscopically-Guided Procedures. Rockville, MD, Center for Devices and Radiological Health, United States Food and Drug Administration, September, 1994.

24. MacKenzie I. Breast cancer following multiple fluoroscopies. Br J Cancer 1965; 19: 1-8.

25. Matanoski GM, Sartwell P, Elliott E, et al. Cancer risks in radiologists and radiation workers. In: Boice JD, Fraumeni JF Jr (eds), Radiation Carcinogenesis: Epidemiology and Biological Significance. New York: Raven Press; 1984: 83-96.

26. Smith PG, Doll R. Mortality from cancer and all causes among British radiologists. Brit J Radiolol 54: 187-194, 1981.

27. Otake M, Schull WJ, Neel JV. Congenital malformations, stillbirths, and early mortality among the children of atomic bomb survivors: A reanalysis. Radiation Research 122: 1-11, 1990.

28. Wagner LK, Eifel PJ, Geise RA. Potential Biological Effects Following High X-ray Dose Interventional Procedures. JVIR 1994; 5: 71-84.

29. Kassabian MK. Röntgen Rays and Electro-Therapeutics with Chapters on Radium and Phototherapy. Second Edition. Philadelphia: J. B. Lippincott Company, 1910.)

30. Wagner LK, Archer BR, Cohen AM. Management of patient skin dose in fluoroscopically guided interventional procedures. JVIR (accepted for publication), 1999.

31. Wagner LK, Pollock JJ. Real-time portal monitoring to estimate dose to the skin of patients from high dose fluoroscopy. BJR 1999; 72: 1 – 10.

32. Hwang E, Gaxiola E, Vliestra RE, Brenner A, Ebersole D, Browne K. Real-time measurement of skin radiation during cardiac catheterization. Cathet Cardiovasc Diagn 1998; 43: 367 – 370.

33. Balter S. Stray radiation in the cardiac catheterization laboratory. In: Nickoloff EL, Strauss KJ. Categorical Course in Diagnostic Radiology Physics: Cardiac Catheterization Imaging, Radio-logical Society of North America, 1998, 222 – 230.

34. Söderman M, Hansson B, Axelsson B. Radiation dose and image quality in neuroangiography: effects of increased tube voltage, added x-ray filtration and antiscatter grid removal. Interventional Neuroradiology 4: 199 – 207, 1998.

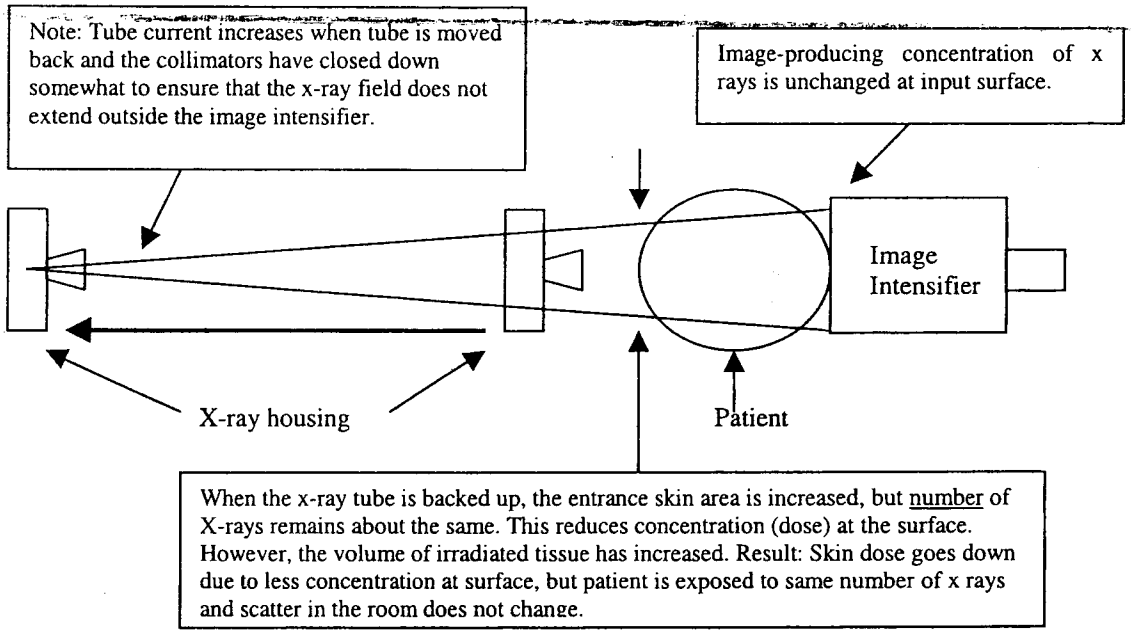
Appendix - Quiz Answers

1. What measures can be taken to reduce radiation dose and dose rate in large patients? **Answer:** For large patients undergoing long procedures, the risk for skin injury is increased. While burns from fluoroscopy are rare, when they occur they can be surprisingly intractable to treatment. Knowledgeable application of the other commandments is the best means of reducing this risk. In some procedures frequently accompanied by ascites, the physician can consider paracentesis prior to the fluoroscopic procedure. This will reduce patient size. Proper preparation of the patient prior to the procedure will also help eliminate some mid-procedure cancellations and will avoid repeated work.

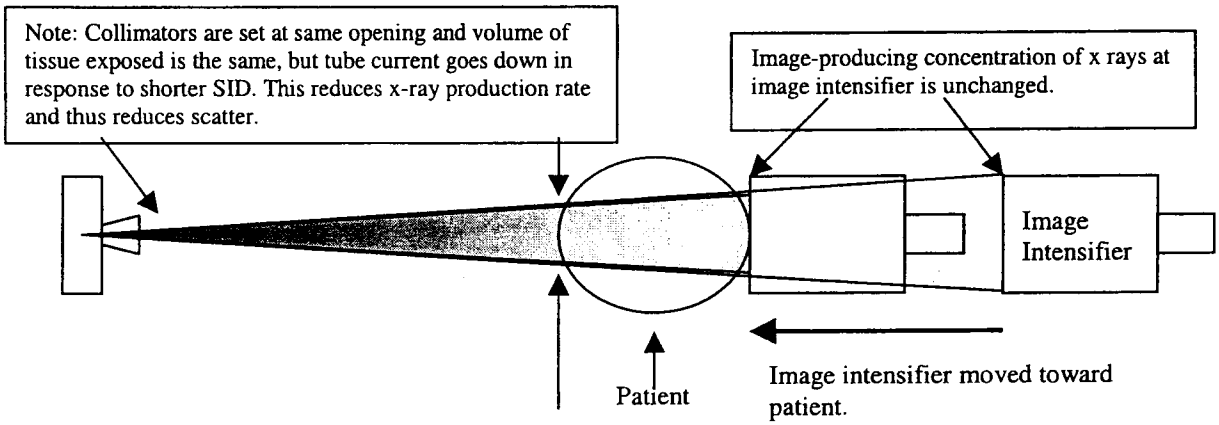
2. The technique displayed on your monitor indicates a fluoroscopic tube current of 15 mA. What does this mean in terms of dose rate to the patient and to personnel in the room? **Answer:** The implications of a fluoroscopic tube current of 15 mA depend on the type of equipment. For common fluoroscopic equipment, such a tube current would be extremely high and would imply a very high dose rate to the patient. A medical physicist should investigate the causes of this high tube current. Some units have special x-ray tubes and special filtration to tailor the x-ray beam energy for reduced skin dose. Tubes currents must be high for these modes of operation in order that a sufficient number of x rays penetrate the filters. In this case the implication is reduced dose rate, not increased dose rate.

3. Why does higher kVp and lower mA decrease dose to the patient while also decreasing image contrast? **Answer:** Increasing penetrability of the x rays reduces dose to the patient because a greater percentage of the x rays that enter the patient get through to make the image. Contrast, on the other hand, results from the differential penetration through neighboring tissues. As x rays become more penetrating, the differential penetration through neighboring tissues also decreases, thus decreasing image contrast.

4. For an x-ray source with distance adjustment independent of the image intensifier, you notice that the mA increases as you move the tube from 40 cm to 60 cm from the patient's skin. The collimators are fully open to the input area of the image intensifier. Why does the patient's skin dose rate decrease and dose rates to personnel not change much? **Answer:** For systems that provide independent control of the distance of the x-ray tube and the distance of the image intensifier from the patient, a complex interaction of controls takes effect. If the x-ray tube is moved further away from the patient without moving the image intensifier, the increased distance dictates that the x-ray production must increase to maintain the same image-producing dose rates at the image intensifier. However, the x-ray field must be restricted to remain within the image intensifier. This requires that the collimators in the x-ray tube housing be closed down somewhat, which in turn reduces the amount of radiation that escapes the x-ray source housing. The net effect of these changes is that the same **number** of x rays is used to produce the image. The reason why the dose rate to the patient goes down is explained in the figure below. Although the same total number of x rays enters the patient, they are **spread out** over a larger skin area and thus the concentration (i.e., the dose rate) at the skin surface is less. However, even though the dose rate decreases at the patient's skin, the volume of tissue irradiated has increased (see figure below). Since scatter increases with increasing volume of tissue but decreases with decreasing dose rate, the net effect of these compensating actions is that the amount of scatter in the room does not change.



5. When the image intensifier is brought closer to the patient in a system where its motion is independent of the x-ray tube, you notice that the mA goes down. Collimation remains confined to the area of interest. What happens to dose rates in the room? **Answer:** Since there is no change in collimation, collimation has no effect on changes in scatter in the room. In the figure below, as the image intensifier is moved closer to the patient, the decreased distance between it and the x-ray source dictates that the x-ray output be reduced to keep the intensity at the image intensifier the same. This reduces scatter radiation in the room. (This scenario depends somewhat on the effectiveness of the grid and assumes that the grid is always in place. It also assumes that SID control does not alter the machine performance.)



6. Many fluoroscopes adjust dose rate under electronic magnification according to the square of the magnification factor. How does dose rate to the patient change as one shifts from a 24-cm field of view (no magnification mode) to a 12-cm field of view (magnification mode)? **Answer:** Most fluoroscopy systems increase x-ray output as one shifts from a wider-field-of-view (less magnification) to a narrower one (more magnification). They do this to maintain image quality for the smaller field. This results in increased dose rate to the patient. Shifting from a 24-cm diameter image to a 12-cm diameter image increases magnification by a factor of 2. Dose rate to the patient therefore increases by a factor of about four. The increase will be less than this factor if kVp is increased to provide for a more penetrating beam. With electronic magnification, the kVp will increase if the dose rate would otherwise exceed regulatory limits.

7. Why is the use of a grid more important for fluoroscopy in adults than it is for fluoroscopy in infants? **Answer:** Scatter radiation reduces image quality. In infants all the primary factors that determine scatter content in the image are reduced. That is, dose rates are generally lower, beam energy is lower, and irradiated patient volume is lower. Scatter is therefore a much lower image-quality liability than it is in an adult.

8. After applying tight collimation you notice that the tube current increases. Is this normal and what should be done about it? **Answer:** Two factors are involved here. Tight collimation reduces scatter in the image and this reduces x-ray intensity to the image intensifier. To recover the loss in intensity, tube current or kVp is increased. This also slightly increases dose rate to the patient. In the normal procedure where total fluoroscopy on time is several minutes, this increased dose rate is usually more than compensated by the fact that less tissue volume is exposed, reducing scatter in the room and reducing overall radiation burden in the patient. A bonus is that image quality also improves due to the reduced scatter and the higher dose rate. A second factor that contributes to this phenomenon is that tight collimation may block part of the sensor area for the ABC, causing the ABC to drive the kVp and mA higher than necessary. If this occurs, open the collimators slightly and the kVp and mA should return to normal.

9. Cite the two most important rules for minimizing radiation dose to the operator's hands. **Answer:** 1) Keep hands out of the direct beam. 2) Work on the exit beam side (image intensifier side) of the patient.
Cite two ways to minimize your overall exposure to radiation without using manufactured protective gear. **Answer:** 1) Maximize your distance from the irradiated area of the patient. 2) Use beam orientations that use the patient as a shield.

10. Cite two technological methods to reduce the beam-on time needed to complete a study. **Answer:** 1) Last-image hold. 2) Variable pulsed fluoroscopy.

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