Ionizing Radiation Safety

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Acknowledgement to the AONA Orthopedic Trauma Lecture Archives

Learning outcomes

- Why is this important
- Describe the physical and biological facts of radiation
- Demonstrate an understanding of how to use x-rays during orthopaedic procedures and decrease exposure
- Understand how to protect patients, teams and surgeons from radiation during surgery

Modern Orthopaedics and Ionizing Radiation

Increased use of radiation

- Diagnostic accuracy
- Minimally invasive procedures
- Intramedullary (IM) nailing
- Surgical efficiency

Always need to justify why you need this radiological investigation

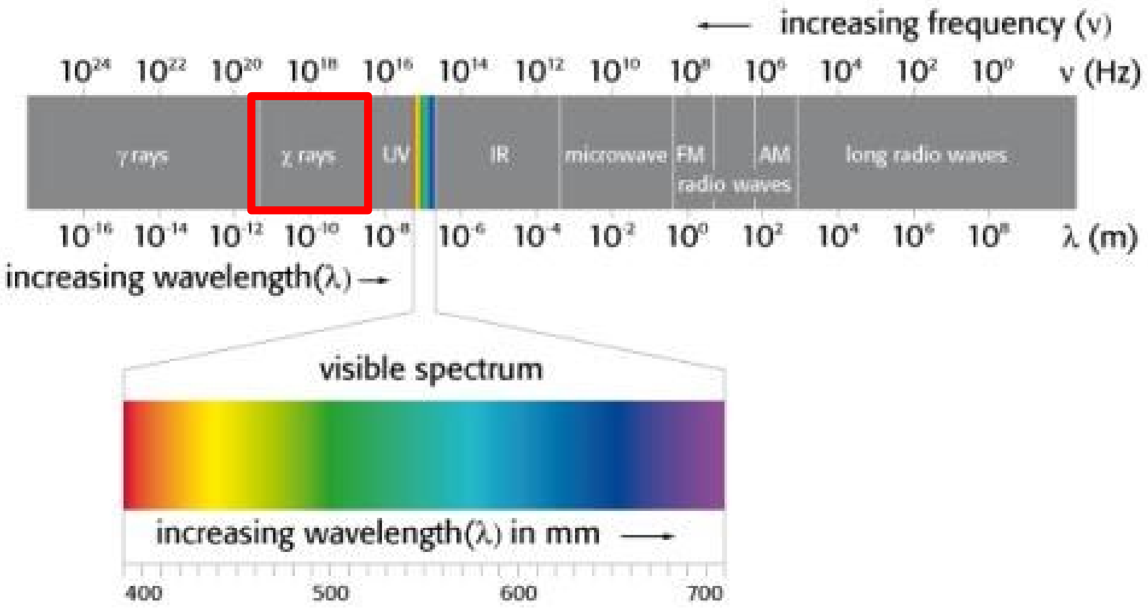
Why?

- As a surgeon you are responsible for ordering this "test"
- Radiation is dangerous and effects cumulative
- Must be used only as needed
- Limit the potential problems to your patients and you
- Other imaging uses sound waves(ultrasound), magnetic waves(MRI) and not tissue damaging

Physical facts

- Radiation is energy from electromagnetic waves
  - Ionizing radiation penetrates biological tissue

- Frequency: $2.5 \times 10^{17} – 6 \times 10^{19}$ Hz



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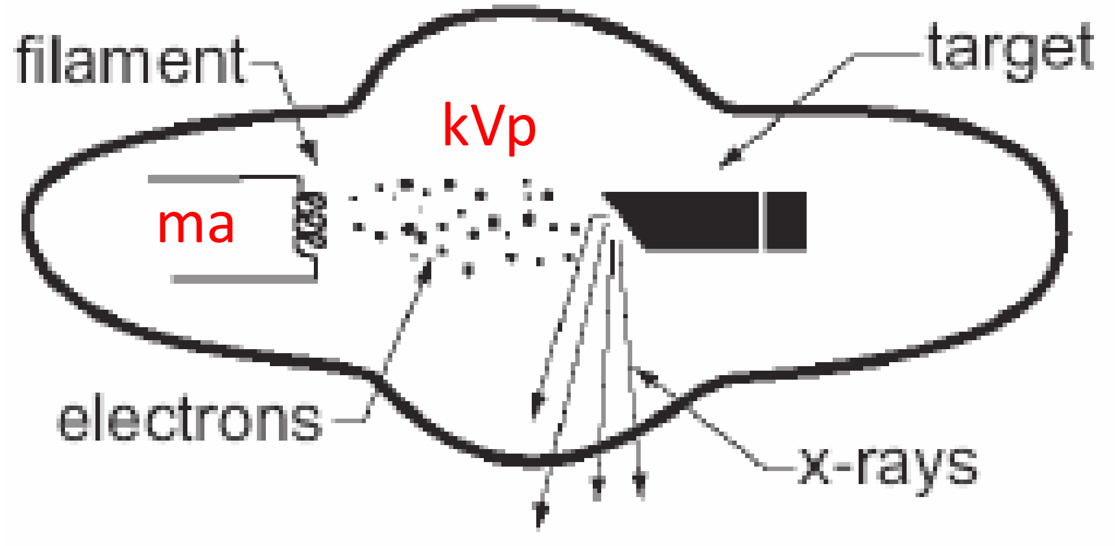
Physical Facts: X-ray production

- Heated filament(cathode) produces electrons (tube current in milliamperes ma)
- Electrons accelerated by accelerating voltage kVp to an anode (tungsten)
- Electrons interact with anode to produce x-rays
- ↑kVp produces more x-rays than ↑ma



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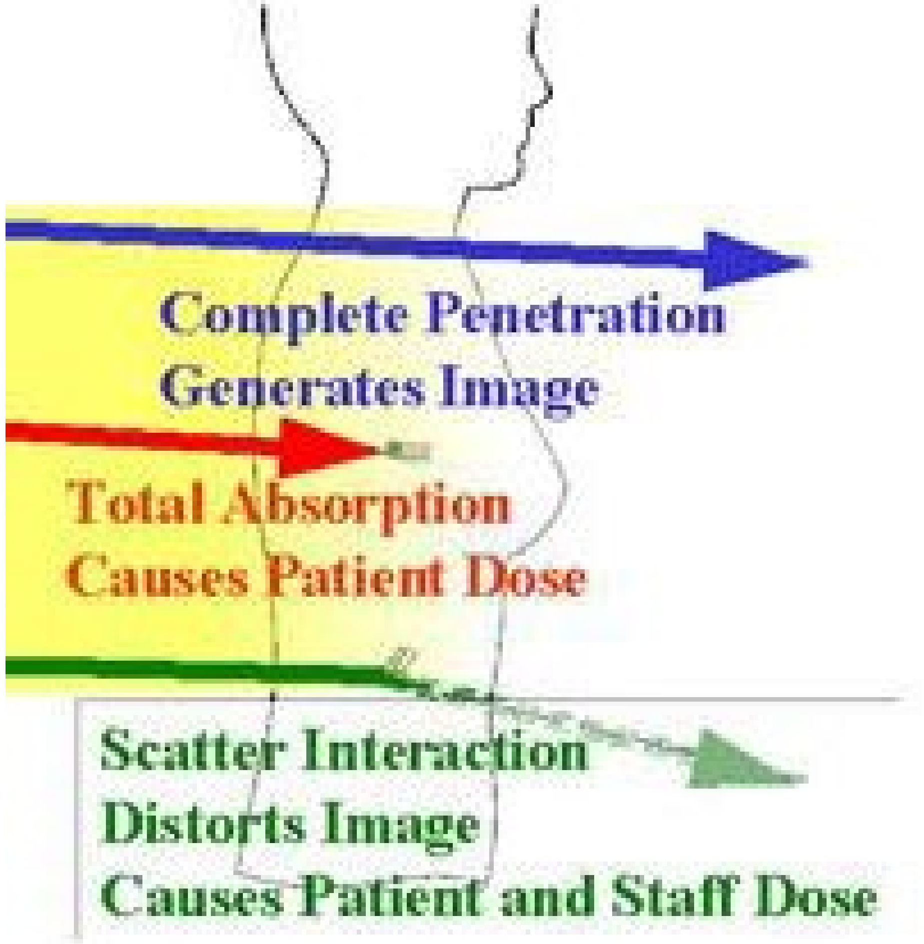
Physical Facts: Tissue Penetration



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Radiation Exposure: Measurement - Generic

- Roentgen = Quantity of x-rays required to produce an amount of ionization in air at standard temperature and pressure
  - 2.58×10^{-4} Coulombs/kilogram (C/kg) for air only
- Gray (Gy) = Energy deposit in a material
  - 1 Gray = 1 Joule/kg = 100 rad (Radiation Absorbed Dose)
  - Reflects physical effect to a material

Radiation Exposure: Measurement - Biologic

- Sievert = energy deposited in biologic material (absorbed dose x radiation quality factor – x-ray is 1)
  - was Roentgen equivalent in man - rem
  - 1 Sv = 1 Joule/kg = 100 rem = 5.5% chance of cancer

- For human tissue dose multiply Sieverts by a tissue weighting factor to determine the dose in Sieverts – effective dose equivalent (EDE)
- Entrance skin exposure (ESE) amount of radiation delivered to patient skin at point of entry of beam into patient – no adjustment factor

Radiation Exposure: Measurement - Human

- Effective dose equivalent (EDE) calculates the risk of cancer from partial vs total body irradiation in Sieverts
  - < 20 mSv low risk
  - 20 – 50 mSv high risk
  - > 50 mSv very high

Radiation Exposure: Measurement - Human

Radiograph	Effective Dose	Risk Ratio
Pelvis (AP)	0.6	1 in 33,300
Hip	0.7	1 in 28,600
Shoulder	0.01	1 in 2,000,000
Knee	0.005	1 in 4,000,000

CT Scan	Effective Dose	Risk Ratio
Pelvis	6.0	1 in 3300

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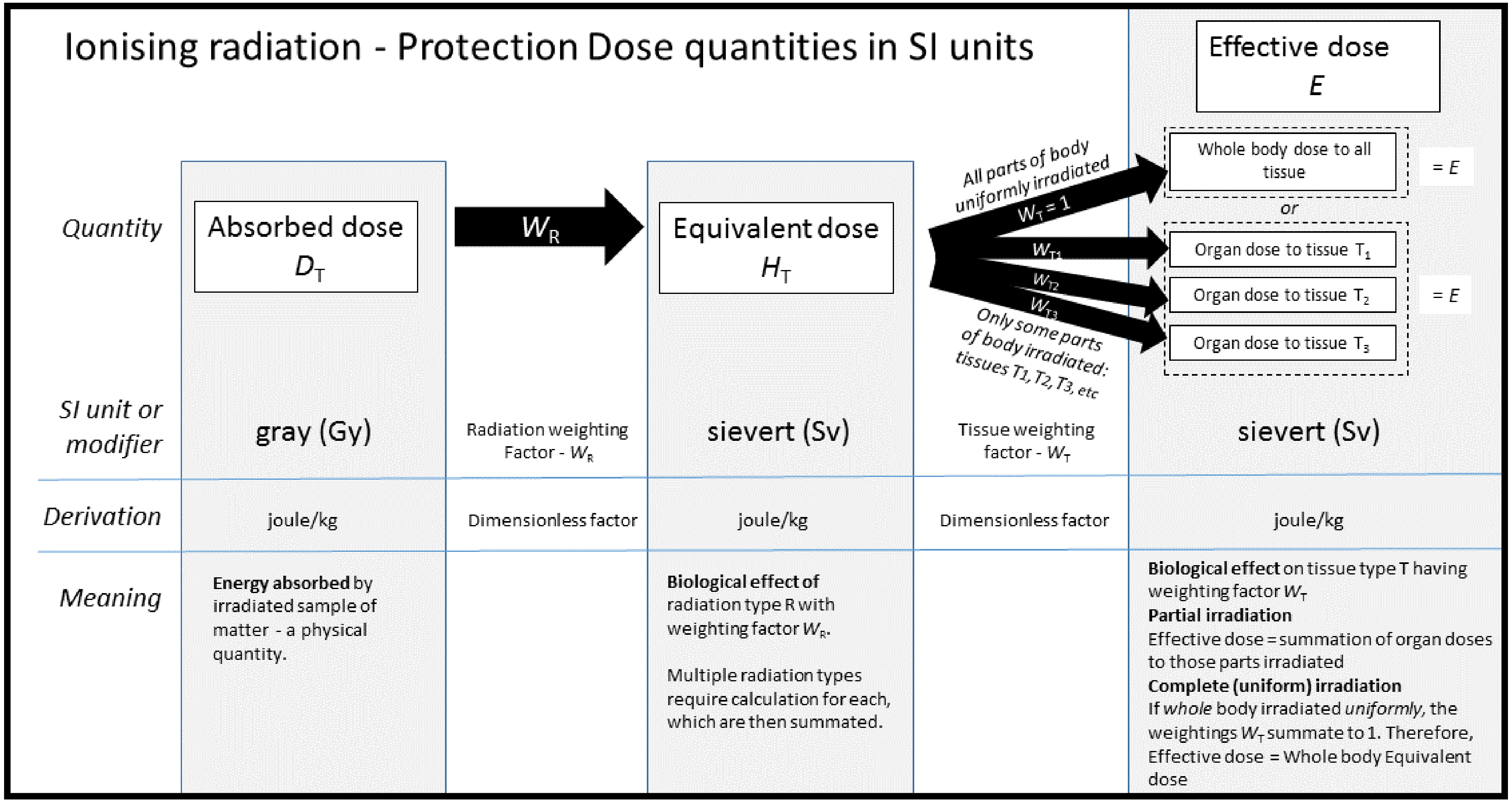
Radiation Exposure: Measurement - Human



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Ionizing radiation - Effects

- **Somatic effects**—directly related to dose - determined by dose threshold
  - Early effect: radiation sickness and death
  - Late effect: leukemia, thyroid cancer, radiation cataract
  - **Below a certain threshold, no increased risk of radiation-induced problems**

- **Stochastic effects**—not determined by dose but by chance
  - Cumulative damage, no threshold
  - Late effect, e.g., thyroid cancer, leukemia

Ionizing radiation - Effects

- Radiation sickness: 500–1000 mSv
- Radiation from nuclear bomb: 500–1000 mSv

Ionizing radiation – Effects: Background radiation

- The average person in the United States receives about 360 mrem/yr.
  = 3.6 mSv

- This dose is mostly from natural sources of radiation

Source	mSv
Inhaled (radon & its progeny)	2.00
Other internal (K-40)	0.39
Terrestrial	0.28
Cosmic	0.27
Cosmogenic	0.01
Medical X-ray	0.60
Total	~ 3.60

Ionizing radiation – Effects: Background Radiation

Normal radiation exposure

- In USA: natural cosmic radiation is
  - 0.27 mSv/year (27 mRem)

Occupational Risk

Cosmic ray in high-altitude flights: 0.001–0.01 mSv/hour

Pilots have a higher rate Acute Myeloid Leukemia (1.5 X higher)

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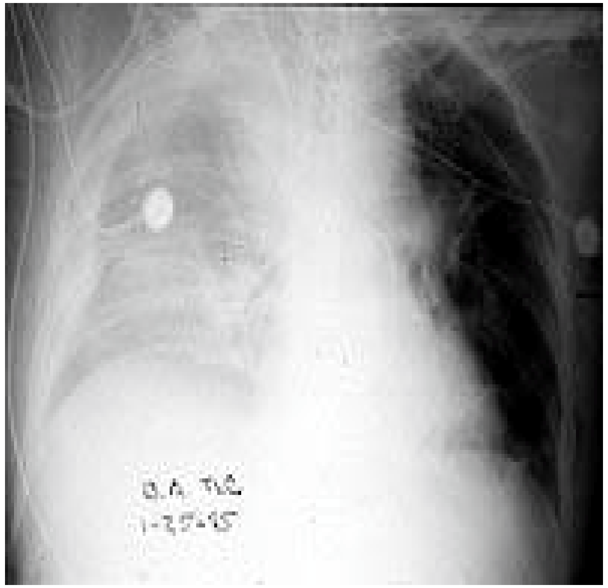
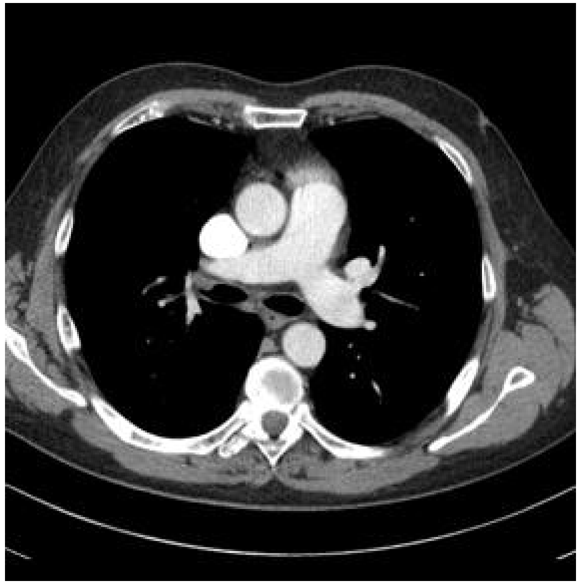
Dosage with respect to backgorund



Chest x-ray. 0.1 mSv

CT brain: 1.5 mSv



CT whole body 9.9 mSv

- CT angio 6.7 – 13 mSv

Normal environmental exposure = 3.6 mSv/year

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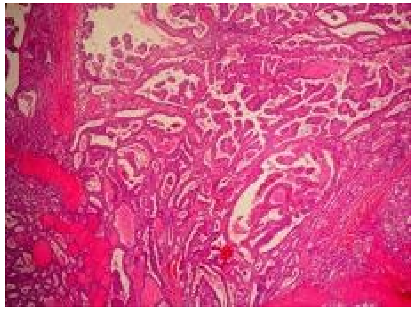
Ionizing radiation – Effects: Human Tissue

- Eyes: Most sensitive
  - 150mSv/year(radiation cataract)
  - Somatic effect - cataracts
- Thyroid: 85% of papillary carcinoma are radiation induced
  - Carcinogenic dose of radiation = 50 - 100 mSv
  - Is also a stochastic effect – no threshold
- Hands: greatest exposure risk
  - 500mSv/year
  - Only tendons and bones – more resistant to radiation



Devalla KL, Guha A, Devadoss VG (2004) The need to protect the thyroid gland during image intensifier use in orthopaedic procedures. Acta Orthop Belg; 70 (5):474–77.

Iglesias ML, Schmidt A,et.al. Arch. Endocrinol. Metab. vol.61 no.2 São Paulo Mar./Apr. 2017 Epub Feb 16, 2017

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Ionizing radiation – Effects: Human Tissue

Common orthopedic procedural dosage

	K-wire distal radius	Intramedullary nail	External fixator lumbar spine
	Average radiation dose μSv (1/1000 mSv)		
Eye	1.1 μSv	19.0 μSv	49.8 μSv
Thyroid	1.1 μSv	35.4 μSv	55.5 μSv
Hand	3.1 μSv	41.7 μSv	117.0 μSv

Safety regulation limits radiation exposure on professionals to 300–500 mSv/y

Fuchs M et al (1998) Intl Orthopedics

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Ionizing radiation – Effects: Human Tissue

Common orthopedic procedural dosage

- Systematic literature review of 34 publications concerning radiation exposure of orthopedic surgeons
- Inconsistent studies
- Highest exposure – spine surgery: 4.8mSv equivalent dose to hand
- IM nailing 0.142 mSv equivalent dose to thyroid
- Reduce exposure by 96.9% and 94.2% with thyroid collar and led apron

Matityahu A. Injury, 2017 Aug;48(8):1727-1734. doi: 10.1016/j.injury.2017.04.041. Epub 2017 Apr 21.

Ionizing radiation – Effects: Human Tissue

Common orthopedic procedural dosage

Radiation exposure with use of the mini-C-arm for routine orthopaedic imaging procedures

Regardless of position, distance, or relative duration of exposure, exposure rates resulting from the use of the mini-c-arm device were one to two orders of magnitude lower than those reported in the literature in association with the use of the large c-arm device.

Badman, Brian. J Bone Joint Surg Am. 2005 Jan;87(1):13-7. doi: 10.2106/JBJS.D.02162

Ionizing radiation – Effects: Human Tissue

Common orthopedic procedural dosage

Radiation exposure with use of the mini-C-arm for routine orthopaedic imaging procedures

“After 155 sequential fluoroscopy exposures, totaling 300.2 seconds of imaging time, only the sensor placed in a direct line with the imaging beam recorded a substantial amount of measurable radiation exposure.”

“The surgical team is exposed to minimal radiation during routine use of mini-c-arm fluoroscopy, except when they are in the direct path of the radiation beam.”

Giordano, Brian. J Bone Joint Surg Am. 2007 May;89(5):948-52. doi: 10.2106/JBJS.F.00733

Ionizing radiation – Effects: Human Tissue

Common orthopedic procedural dosage

Hand and body radiation exposure with the use of mini C-arm fluoroscopy

200 consecutive cases (50 cases per surgeon) requiring mini C-arm using badge dosimeters

The total measured radiation exposures for the (1) external whole body exposure dosimeters were 16 mrem (for shallow depth), 7 mrem (for eye depth), and less than 1 mrem (for deep depth); (2) shielded whole body badge dosimeters recorded less than 1 mrem; and (3) ring dosimeters totaled 170 mrem.

The measured whole body and hand radiation exposure received by the hand surgeon from the mini C-arm represents a minimal risk of radiation, based on the current National Council on Radiation Protection and Management standards of annual dose limits (5,000 mrem per year for whole body and 50,000 mrem per year to the extremities).

Tuohy C. J Hand Surg Am. 2011 Apr;36(4):632-8. doi: 10.1016/j.jhsa.2010.12.022. Epub 2011 Feb 23

Ionizing radiation – Effects: Human Tissue

Common orthopedic procedural dosage
The female orthopedic Surgeon

Female U.S. surgeons in urology, plastics, and orthopedics were identified using national directories and mailed surveys to collect information on occupational and medical history, including cancer diagnoses. Standardized prevalence ratios (SPRs) and 95% CIs were calculated by dividing the observed number of cancers among female surgeons in each specialty by the expected number, based on the gender-specific, age-specific, and race-specific cancer prevalence statistics in the general U.S.

For female orthopedic surgeons, a **significantly greater than expected prevalence** of any cancer (SPR, 1.85; 95% CI, 1.19–2.76) and breast cancer (SPR, 2.90; 95% CI, 1.66–4.71) were observed.

Chou L. Womens Health Issues Sep-Oct 2015;25(5):476-81. doi: 10.1016/j.whi.2015.05.005. Epub 2015 Aug 8

Ionizing Radiation Protection

ALARA is the goal

- As low as reasonable achievable

Two areas of concern

A. Diagnostic

B. Procedural

Ionizing Radiation Protection: Diagnostic Usage

- Limit the number of x-rays to the minimum required
  - Evaluate every order – Do I really need?
  - E.g. post op x-rays if have C arm images, what do you really need for fracture follow-up x-rays
- Role of CT scanning
  - Appropriate timing – after reductions
  - Post op – is it justified: reduction, implant position, learning
  - Newer techniques: multi planar fluoroscopy

Ionizing Radiation Protection: Procedural Usage

How to protect the patient, staff and surgeon

- Operator's position
- X-ray tube position
- Protection measures

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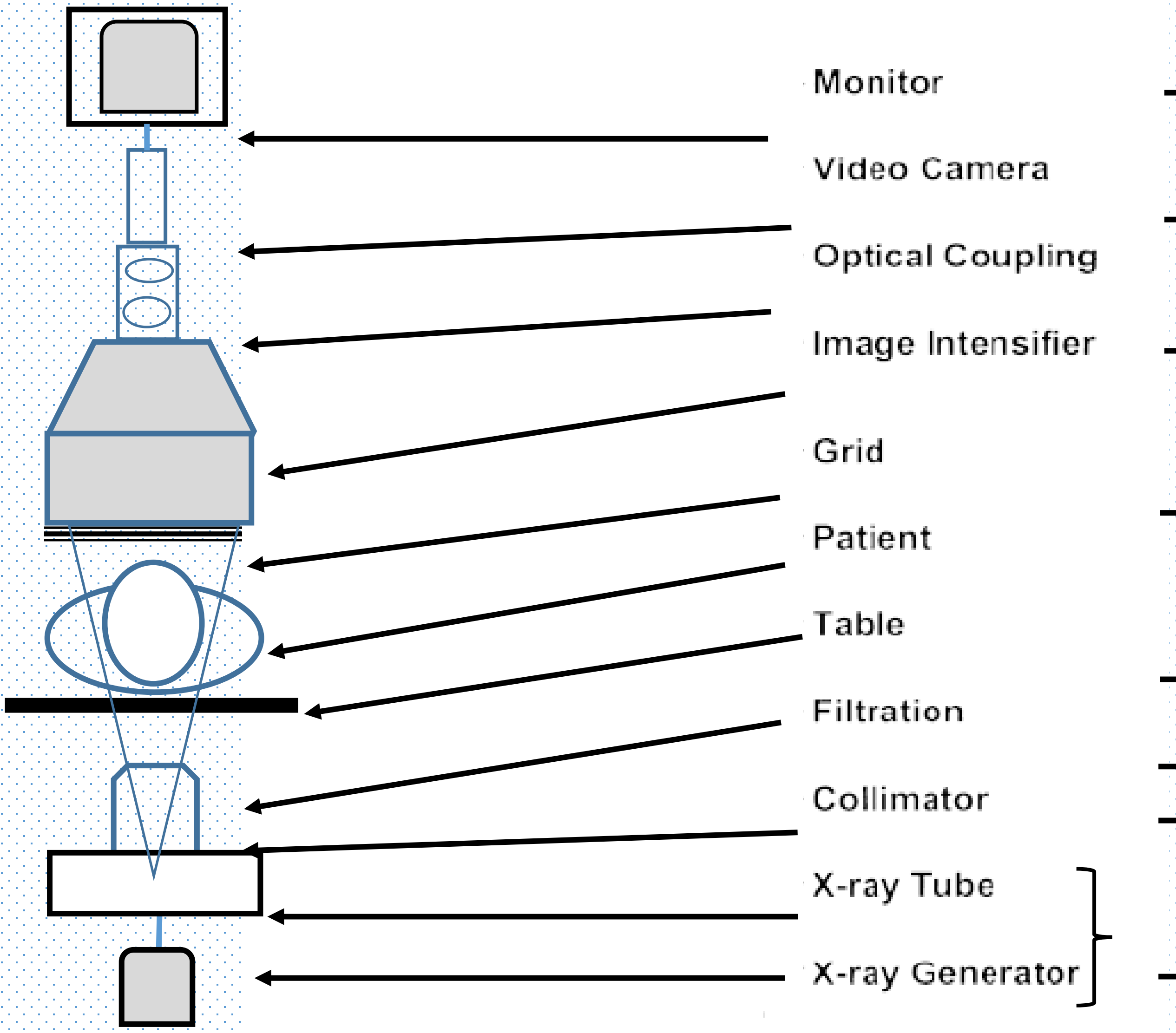
Fluoroscope - how it works



Show picture

Takes image from intensifier

Makes x-rays into image

Gets rids of scatter

Radiolucent, carbon fiber

Gets rid of unwanted x-rays

Shutter blades to define beam

Produces x-rays (ma and kVp)

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Ionizing Radiation Protection: Procedural Usage

The Importance of Distance and Direction

- Radiation exposure inverse-square law
  - double your distance from x-ray source, you reduce the exposure rate by a factor of four.
- 1 meter away from patient at 90^{o} to the beam = 0.1% of patient's exposure
- 2 meters – decreased even more by 1/4th

Bushberg – The Essential Physics of Medical Imaging Williams and Wilkins 1994

Ionizing Radiation Protection: Procedural Usage

OR Staff Doses

Distance	Radiation effect (mrem/min)
• In direct beam	4000 mrem, 40 mSv
• Surgeon 1 ft away	20 mrems to whole body 29 mrem to hands
• Assistant 2 ft away	6 whole body mrems 10 mrem hands
• Scrub 3 ft	0
• Anesthesia	0

Mehlman et al J. Ortho Trauma 1997;11: 392-398

Ionizing Radiation Protection: Procedural Usage

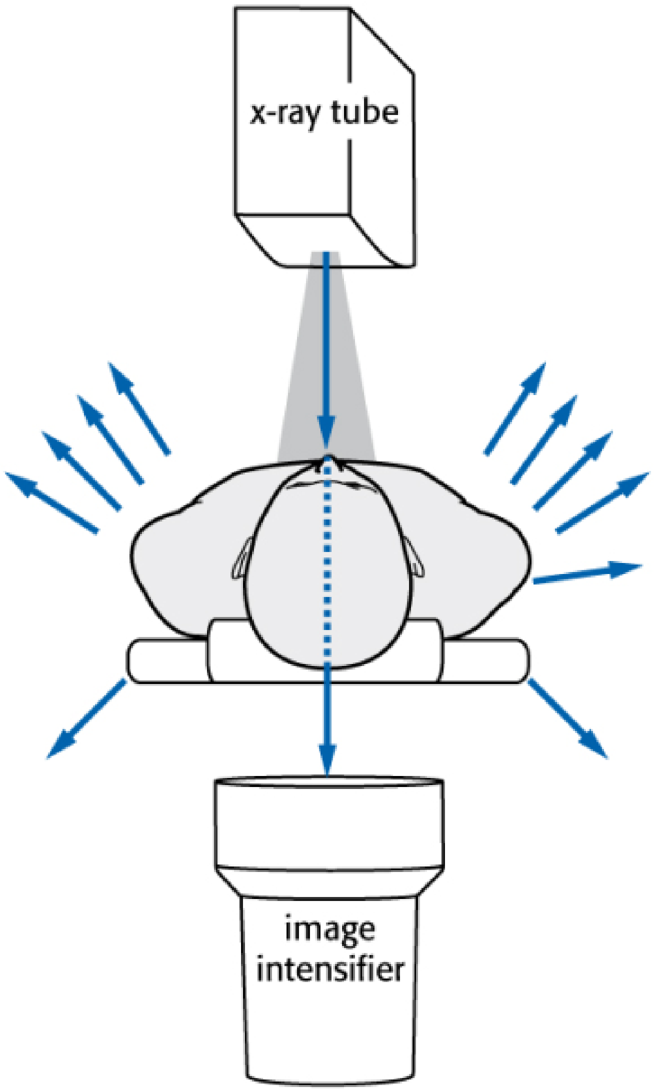
Absorption and scatter

For every 1000 photons

- ~100 - 200 are scattered
- ~ 20 reach the image detector
- Rest are absorbed (= radiation dose) by the patient

Radiation scatter is mainly directed toward the source

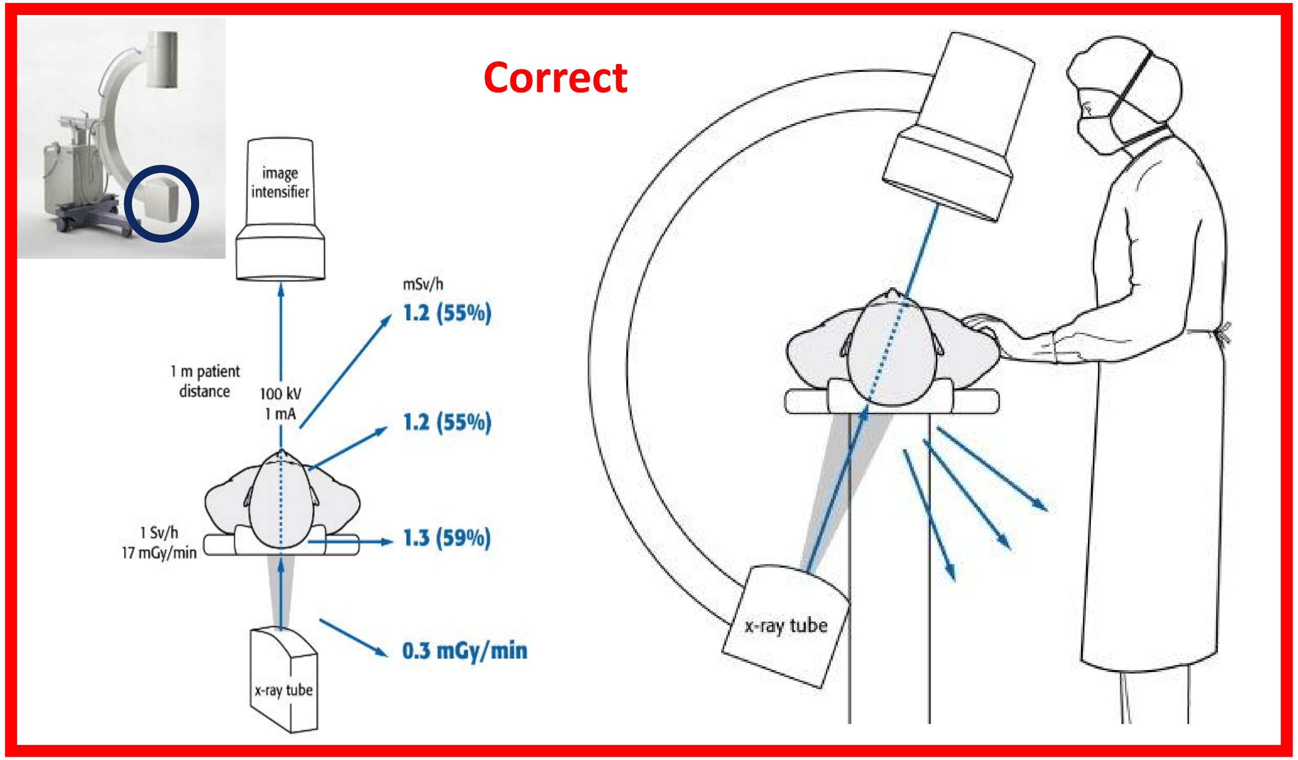
The main source of radiation during fluoroscopy is scattered radiation from the patient

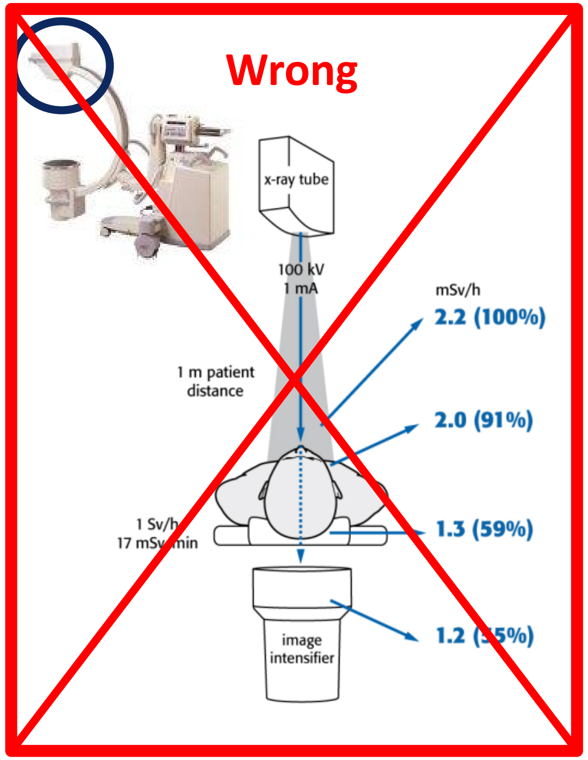


Ionizing Radiation Protection: Procedural Usage

X-ray tube position

- The patient is always between the x-ray generator and the operator
- Scatter is directed away from the operator





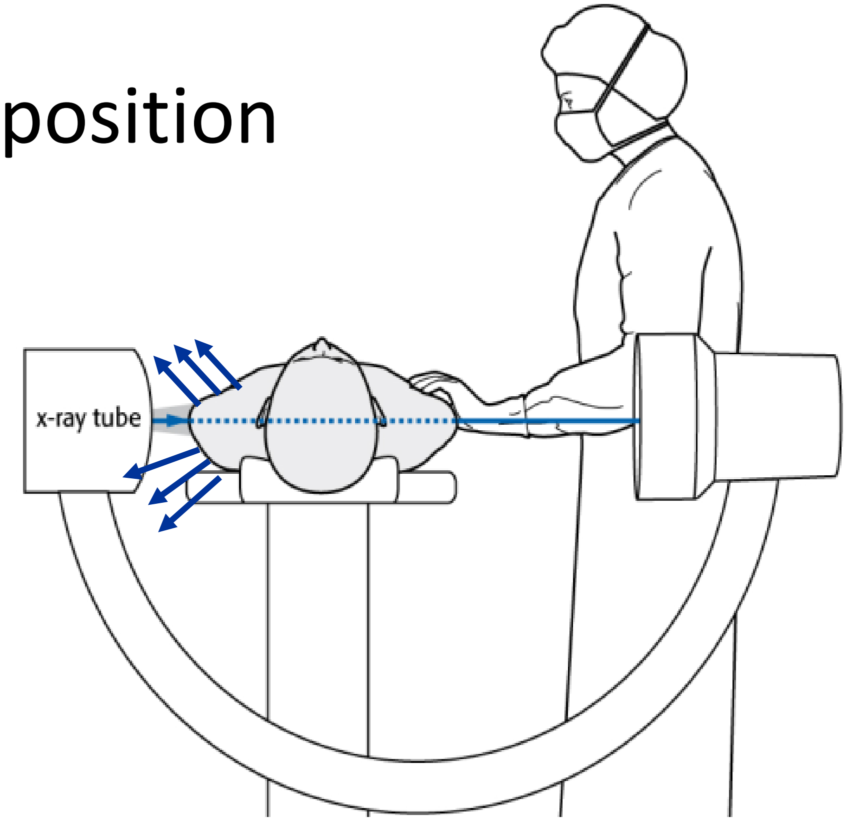
Ionizing Radiation Protection: Procedural Usage

X-ray tube position – patient between generator and operator

- Scattered dose is higher at the x-ray tube side

Lateral C arm position

Staff should stay clear of the x-ray tube area



Stand on the intensifier side

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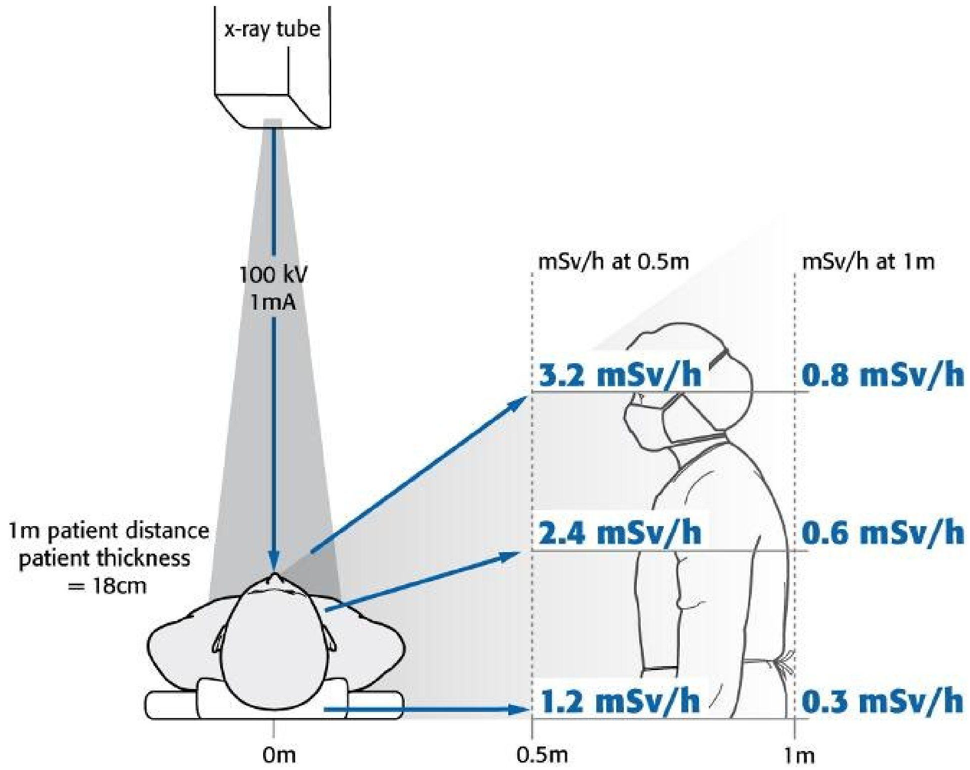
Ionizing Radiation Protection: Procedural Usage

X-ray tube position and operator distance



Double the distance and decrease the dose by 75%

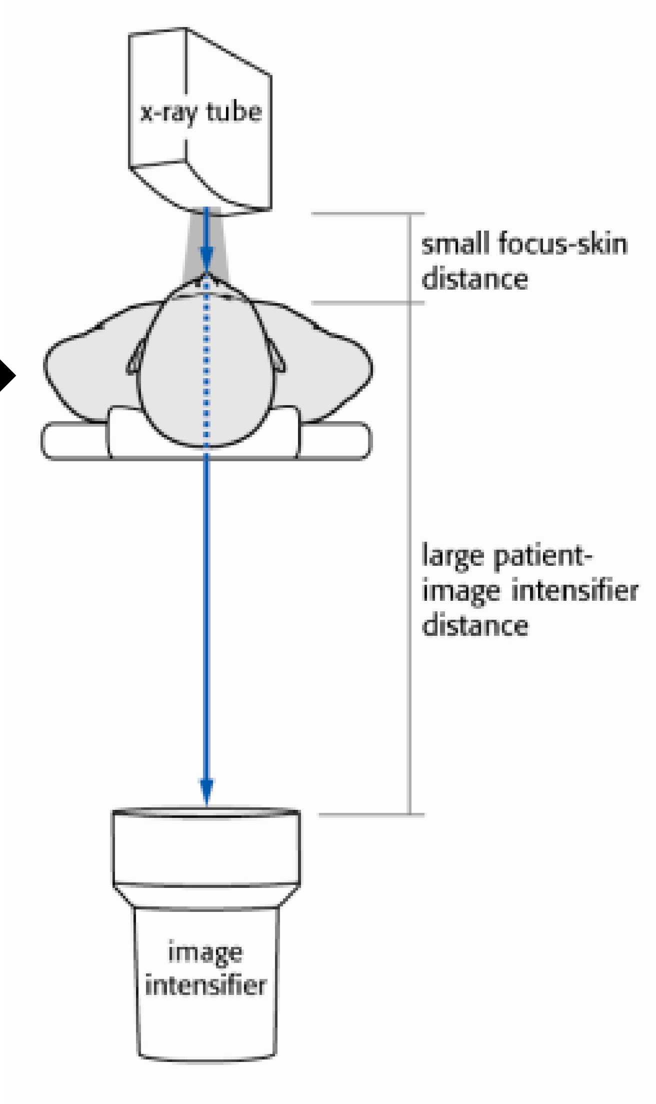
Scatter-dose rate is lower when distance between patient and surgeon increases

Ionizing Radiation Protection: Procedural Usage

X-ray tube position - height

Scatter dose will **increase** if:

- X-ray tube–skin distance is short
- More magnification
- Occurs with bigger patients



Reduce scatter: place patient close to image intensifier and **far from x-ray tube**

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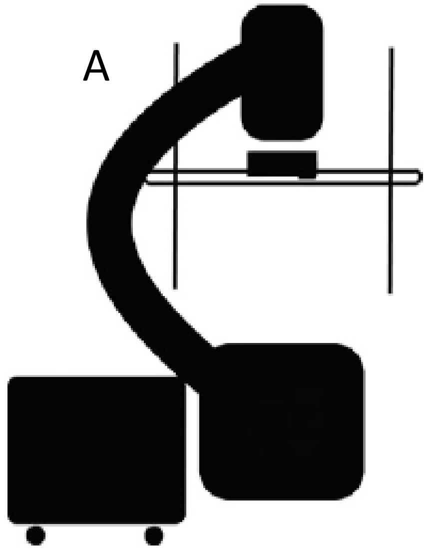
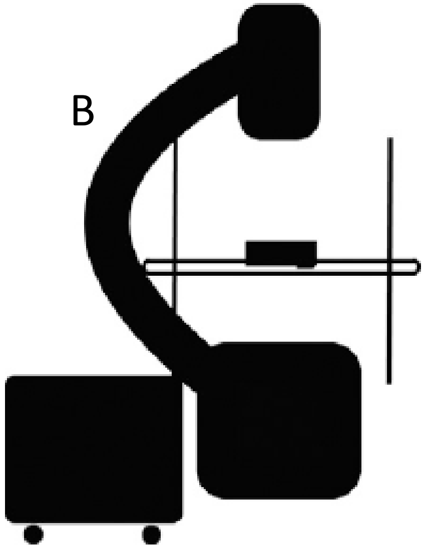
Ionizing Radiation Protection: Procedural Usage

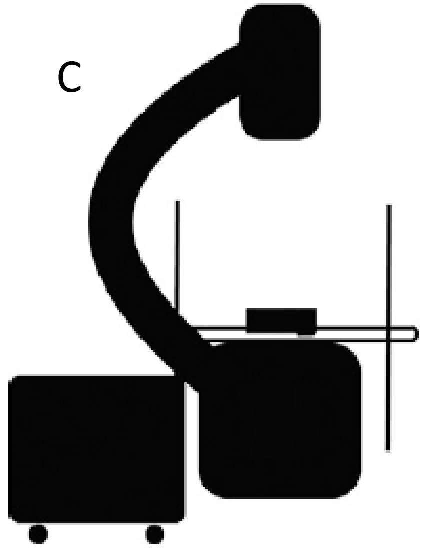
X-ray tube position - height



Worst generator close to
Patient and maximizes scatter



Midway position which
lessen scatter



Best position with
generator as far away
from patient as possible
to decrease scatter
as much as possible

Ionizing Radiation Protection: Procedural Usage

Factors : Patient

As patient size increases skin dose and scattered radiation increases

Protective devices and a safe distance necessary from large size patients

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Ionizing Radiation Protection: Procedural Usage

Factors affecting patient doses

Intensifier diameter	Relative patient entrance dose
32 cm (12 in)	Dose 100
22 cm (9 in)	Dose 150
16 cm (6 in)	**Dose 200**
11 cm (4.5 in)	**Dose 300**

A smaller image intensifier diameter can increase patient entrance dose

Magnification increases the dose with locking nails!

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Ionizing Radiation Protection: Procedural Usage

Dose Reduction Aids

- Integrated lasers on both x-ray tube and image intensifier
- Allows easier positioning of beam on patient without using radiation
- Reduce radiation exposure

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Ionizing Radiation Protection: Procedural Usage

Dose Reduction Aids

- Virtual patient anatomy selection ensure correct dose is given to corresponding body area

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Ionizing Radiation Protection: Procedural Usage

Dose Reduction Aids: Acquiring the image

- Avoid foot pedal use – tendency to over radiate
- Technologist takes image shot
- Pulse acquisition - a short **pulse** of x-rays at the beginning of each frame and manipulated in image intensifier to produce image

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Ionizing Radiation Protection: Procedural Usage

Dose Reduction Aids: Acquiring the image

- Selectable dose rate according to patient size
  - Image quality feeds back to x-ray generator to determine the minimal dose for the best image
- “Hold and save” allows last image to be saved to second screen for assessment and planning next step
- Appropriate technique for selected procedure

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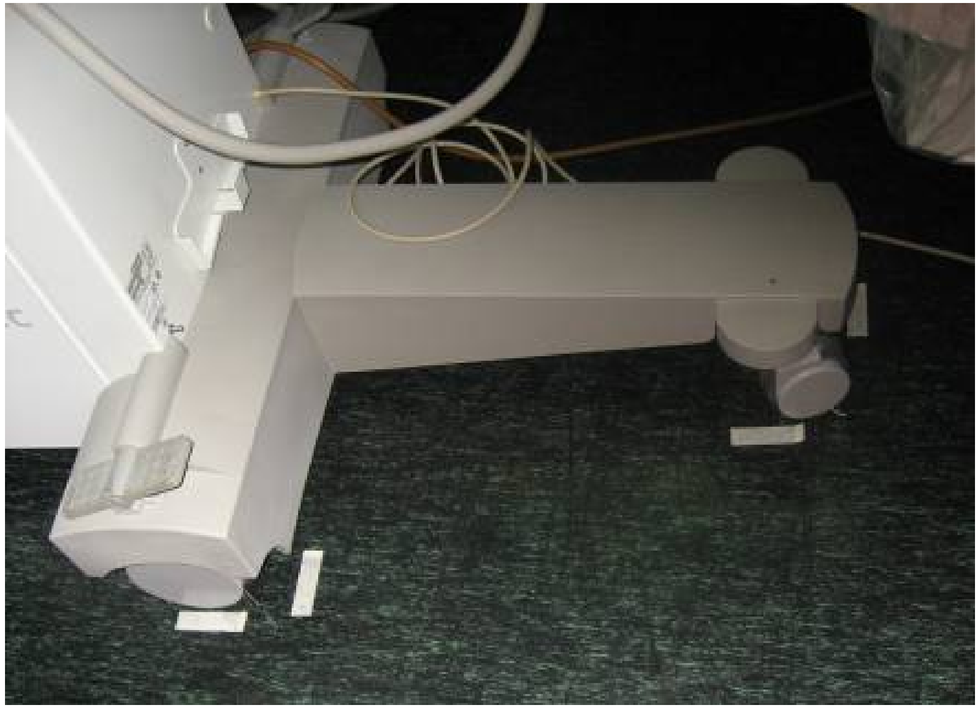
Ionizing Radiation Protection: Procedural Usage

Clinical C-arm application

- Landmarks (floor, body)
  - Set up C arm prior to draping for ideal position
  - Mark the floor with tape so technologist knows where machine goes.
  - especially important if personnel changes



Ionizing Radiation Protection: Procedural Usage

Practical radiation protection: Personal Devices

Eyeglasses
0.15 mm lead-equivalent goggles provide 70% attenuation of radiographic beam

Thyroid collar
2.5-fold decrease

Apron
AP: 16-fold decrease
lateral: 4-fold decrease

Gloves
60–64% protection at 52–58 KV

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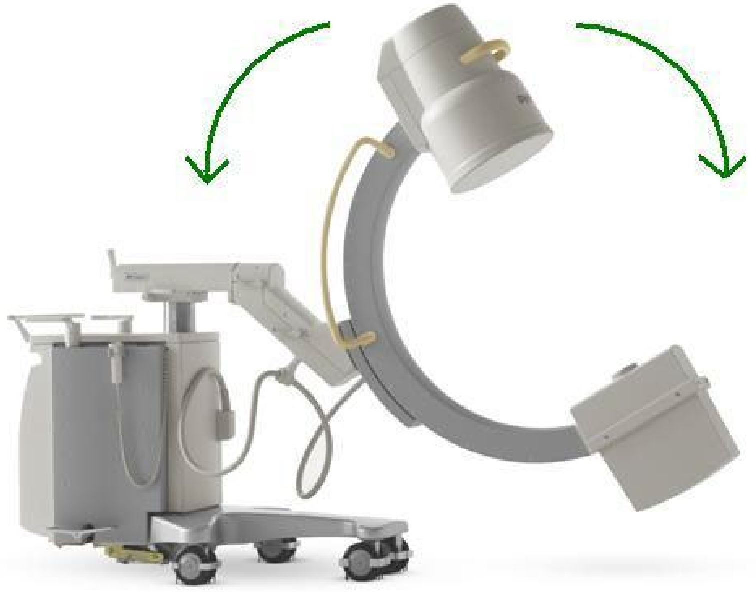
Ionizing Radiation Protection: Procedural Usage

Precise Defined Communications

C arm Position

Cant - angle cephalad or caudad



C over - moves in plane of C arm used to get AP lateral and oblique

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Ionizing Radiation Protection: Procedural Usage Summary

Fluoroscopy radiation hazard can be reduced by:

- C-arm orientation
  - Positioning x-ray tube underneath the patient
  - Lateral view: stay away from x-ray tube
  - Keep x-ray tube at maximal distance to the patient
  - Keep image intensifier close to the patient
  - Do not overuse magnification
- Keeping your hands out of the beam!
- **ALARA**

Take Home Points

- Ionizing radiation is dangerous – patient and surgical team
- Diagnostically - think before order – what do I really need
- Understand and practice the methods of decreasing the does in the operating room