Radiation safety

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Background

- Cath Lab is one place where ionizing radiation is abundant
- Patient :

X-ray guided procedures vs radiation-induced injuries

- Working staffs:

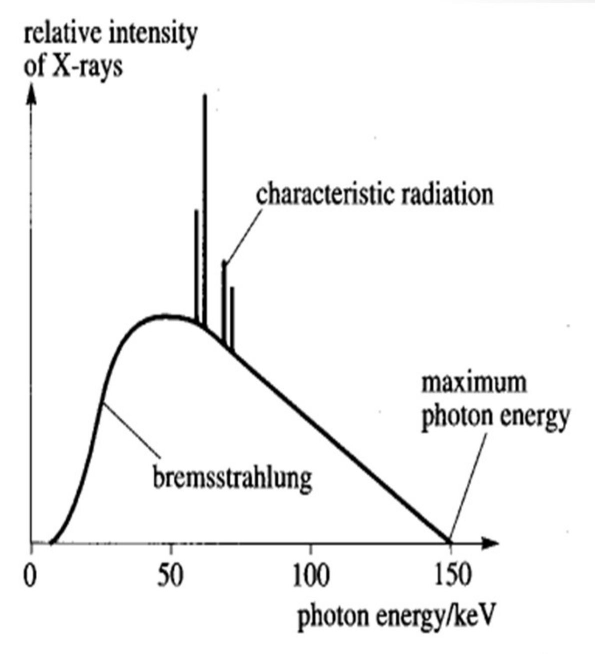
risk of radiation exposure

Aim of Radiation Protection

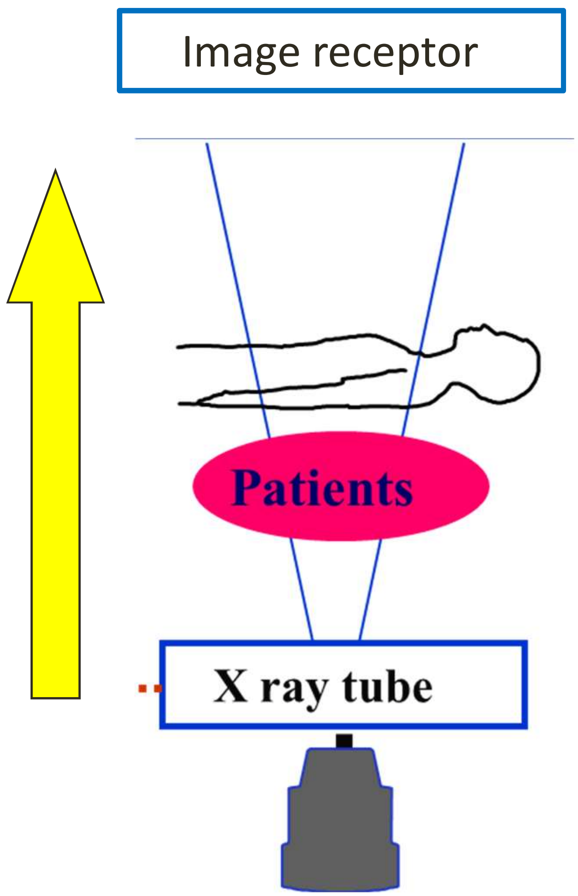
- Optimize image quality with minimal patient and clinical personnel radiation exposure.

X-ray

- Spectrum of photon energies
- The peak tube voltage (kVp) of the X-ray tube determines the maximum photon energy [keV]
- Typical X-ray tube voltages range from 60kV to 120kV

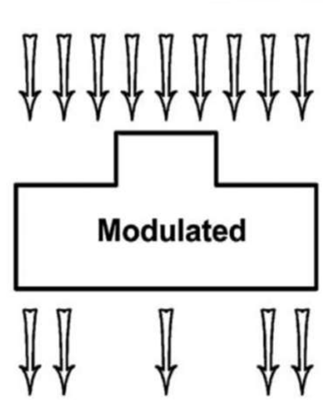


X-ray



X-ray

Differential absorption produce image

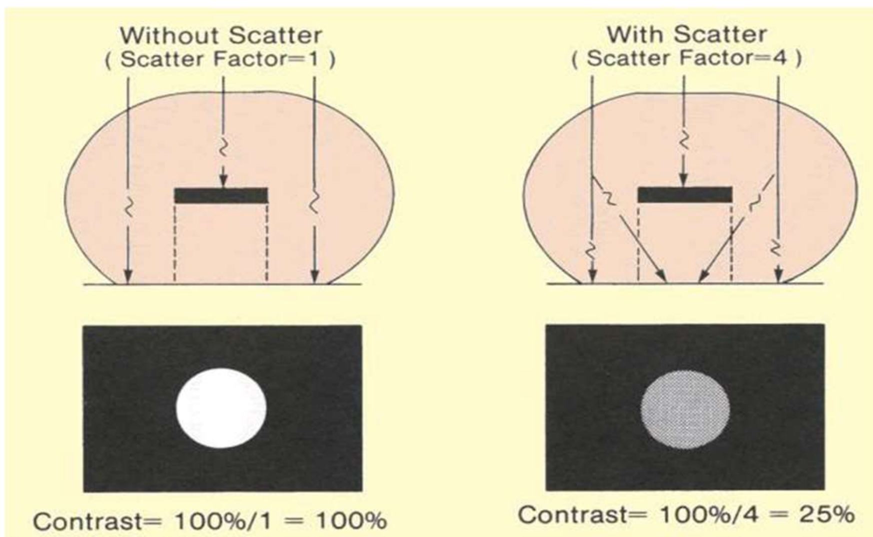


Image

- 1/ Pass through the patient
- 2/ Absorbed by tissue / iodinated contrast
- 3/ Low-energy photons have insufficient energy to penetrate tissue.
- 4/Scattered radiation:
  - X-ray photons that change their direction after interacting with patient.

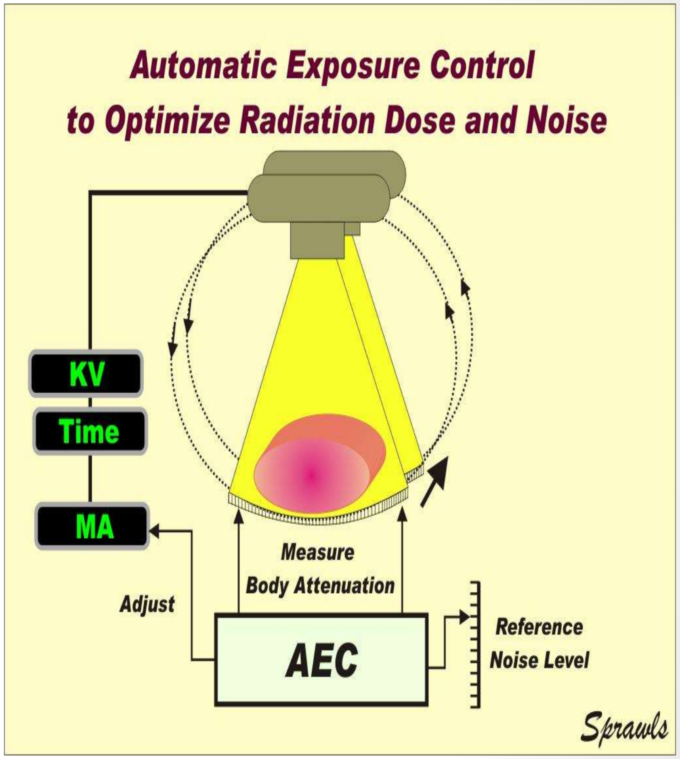
Scattered radiation

- Constitutes noise and reduces image contrast.
- Main hazard to both patient's body parts that are outside the field of X-ray beam and the cath lab staff.



Control of X-ray production

- Automatic dose rate (exposure) control:
  - Any drop in light detected by the image detector will triggers an increase in generator output to the level that is optimal for image production



Radiation quantities

- Radiation exposure : (Roentgen or milliroentgen)
  - Measures amount of radiation at a point in space/ air

Radiation quantities

- Absorbed dose (Gray Gy or milligray mGy)
  - Characterizes the amount of radiation deposited in tissue
  - 1 Gy = 1 joule / kg
- Equivalent dose (Sievert Sv or millisievert mSv)
  - Same energy delivered by different particles may have different effect on living cells.
  - For radiations other than X-rays, equivalent dose can be different even though the absorbed dose is equal to that of X-rays.
  - rem: unit of dose as applied to man (1 rem = 10 mSv)

Radiation quantities

- Effective dose (Sievert Sv or millisievert mSv)
  - Converts any localized absorbed or equivalent dose to a whole-body risk factor
  - Sum of the equivalent doses in all irradiated organs multiplied by the respective tissue weighting factors
  - Measures stochastic risk (allows estimation of cancer risk from non-uni-form dose delivery)

Radiation quantities

- Peak skin dose:- maximum dose anywhere on the patient's skin (gray; Gy)

- Kerma Area Product or dose-area product (KAP or DAP):
  - Dose at the center of the beam x beam area (Gycm^2)
  - Measures the total amount of radiation leaving the X-ray tube
  - Related to scatter production
  - Indicator of stocastic risk

Types of radiation injuries

- 1/ Deterministic effect

- 2/ Stochastic effect

Radiation injuries

- 1/ Deterministic effect
  - Dose dependent
  - Threshold dose depends on the time course of the radiation delivery
  - Dose fractionation (delivery over multiple sessions) changes this relationship, enabling a tissue to tolerate a greater total accumulative dose

Radiation injuries

- 1/ Deterministic effect
  - skin injury
  - hair loss
  - cataract

Radiation injuries

- Radiation induced skin injury
  - do not appear for hours to days following exposure
  - appear in cycles: begin with redness and itching that last for 1 -2 days, followed by a latent stage in which no injury is apparent. The manifest stage begins days to weeks after exposure and can represent a range of signs and symptoms.
  - Dose below 2Gy will not cause skin injury; dose above 15 Gy will cause serious injury

Radiation injuries

- Radiation induced skin injury

Table 4. Threshold Skin Entrance Doses for Different Skin Injuries

Single-Dose Effect	Threshold (Gy)	Onset
Early transient erythema	2	Hours
Main erythema	6	Approximately 10 days
Late erythema	15	Approximately 6–10 wks
Temporary epilation	3	Approximately 3 wks
Permanent epilation	7	Approximately 3 wks
Dry desquamation	14	Approximately 4 wks
Moist desquamation	18	Approximately 4 wks
Secondary ulceration	24	Greater than 6 wks
Ischemic dermal necrosis	18	Greater than 10 wks
Dermal atrophy (1st phase)	10	Greater than 14 wks
Dermal atrophy (2nd phase)	10	Greater than 1 yr
Induration (invasive fibrosis)	10	*
Telangiectasia	10	Greater than 1 yr
Late dermal necrosis	Greater than 12?	Greater than 1 yr
Skin cancer	Not known	Greater than 5 yrs

Gy = Gray. *No estimate available. Data derived from references 1,4,10–12.

Hair loss due to radiation

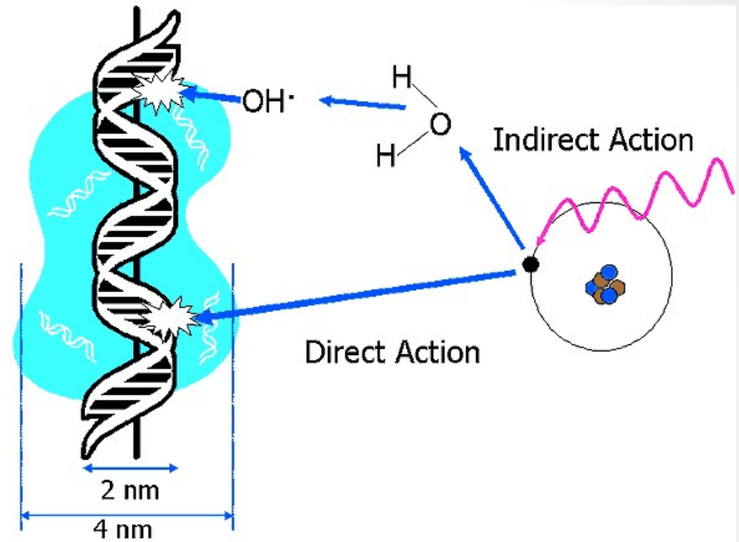
Major burn

Radiation injuries

- <u>Cataract:</u>
  - In 2011, The International Commission on Radialogical Protection (ICRP)
    - reduced lens of eye dose limit to 20 mSv per year, averaged over 5 years, with no single year exceeding 50 mSv.
    - reduced threshold dose from 2-5 Gy to 0.5 Gy for a single acute exposure

Radiation injuries

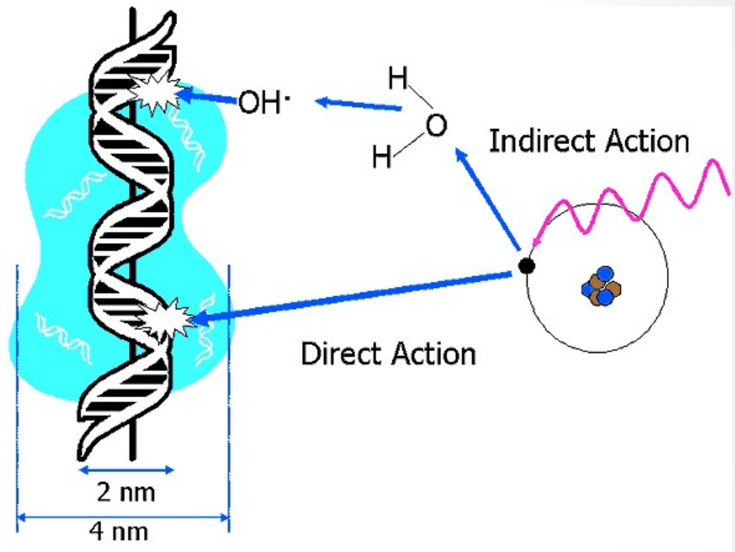
- 2/ Stochastic effect
  - Assumed no dose threshold
  - The probability of the effect increases with increasing the radiation dose
  - Genetic damage causing cancer or heritable genetic defects



Direct and Indirect Action of Radiation in Biological Systems

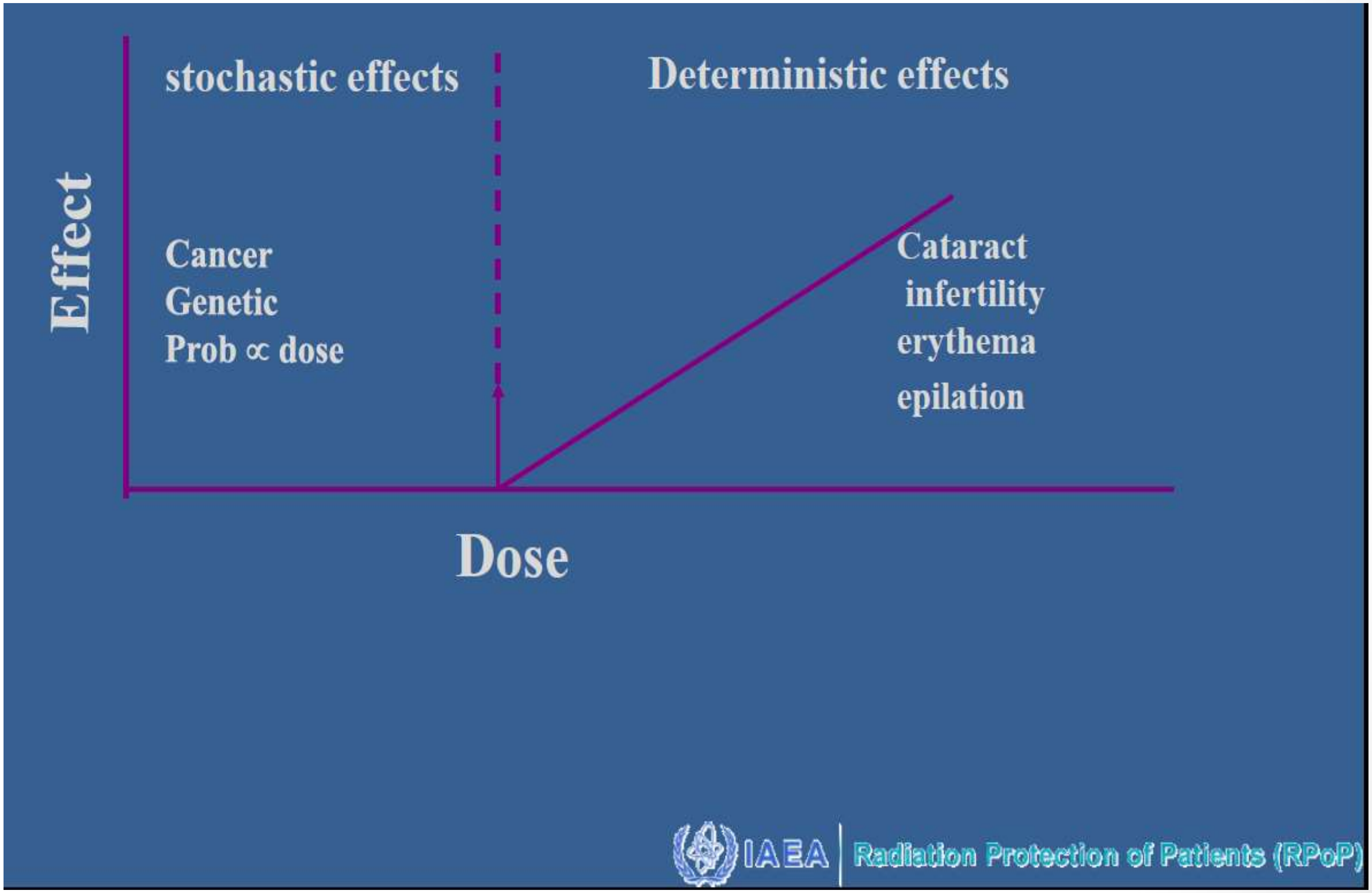
Radiation injuries

- 2/ Stochastic effect
  - Risk of fatal cancer is ~ 0.04% per rem of exposure
    - Committee on the Biological Effects of Ionizing radiations. National Academy Press, 1990.



Direct and Indirect Action of Radiation in Biological Systems

Radiation injuries



Principles of radiation protection

- 1/ Justification of practices
- 2/ Limitation of doses
- 3/ Optimization of protection

Justification of practices

- any exposure produces sufficient benefit to offset the radiation harm that it might cause.

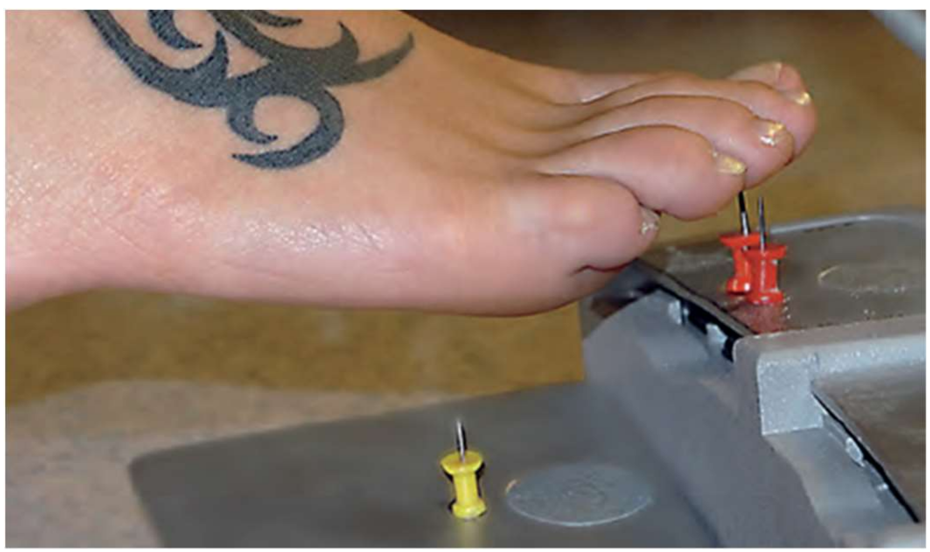
Limitation of doses

- doses should be “as low as reasonably achievable ” assuming image quality is adequate for diagnostic purposes

ALARA

Limitation of doses

- Time
  - Minimize exposure time
  - Keep fluoro times as short as possible.



Optimization of protection

Distance

- As distance from the radiation source increases, the radiation intensity decreases rapidly by the inverse square law

- Double distance from source of x rays, dose is reduced by a factor of 4

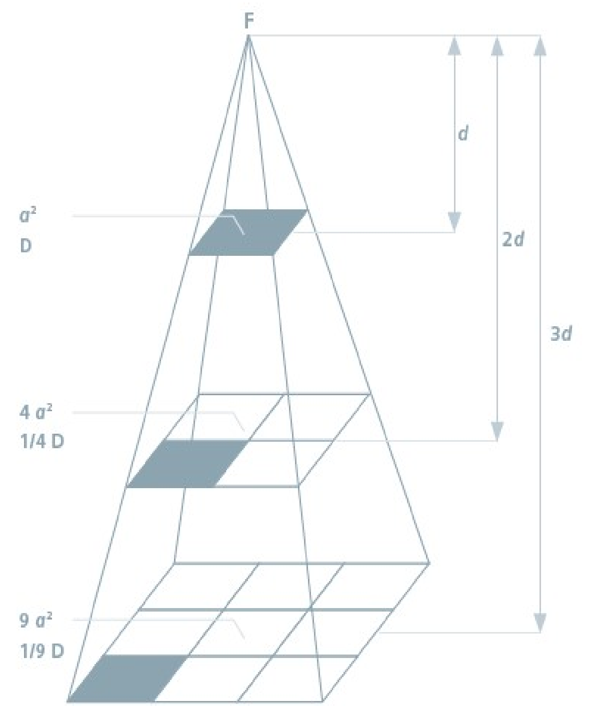
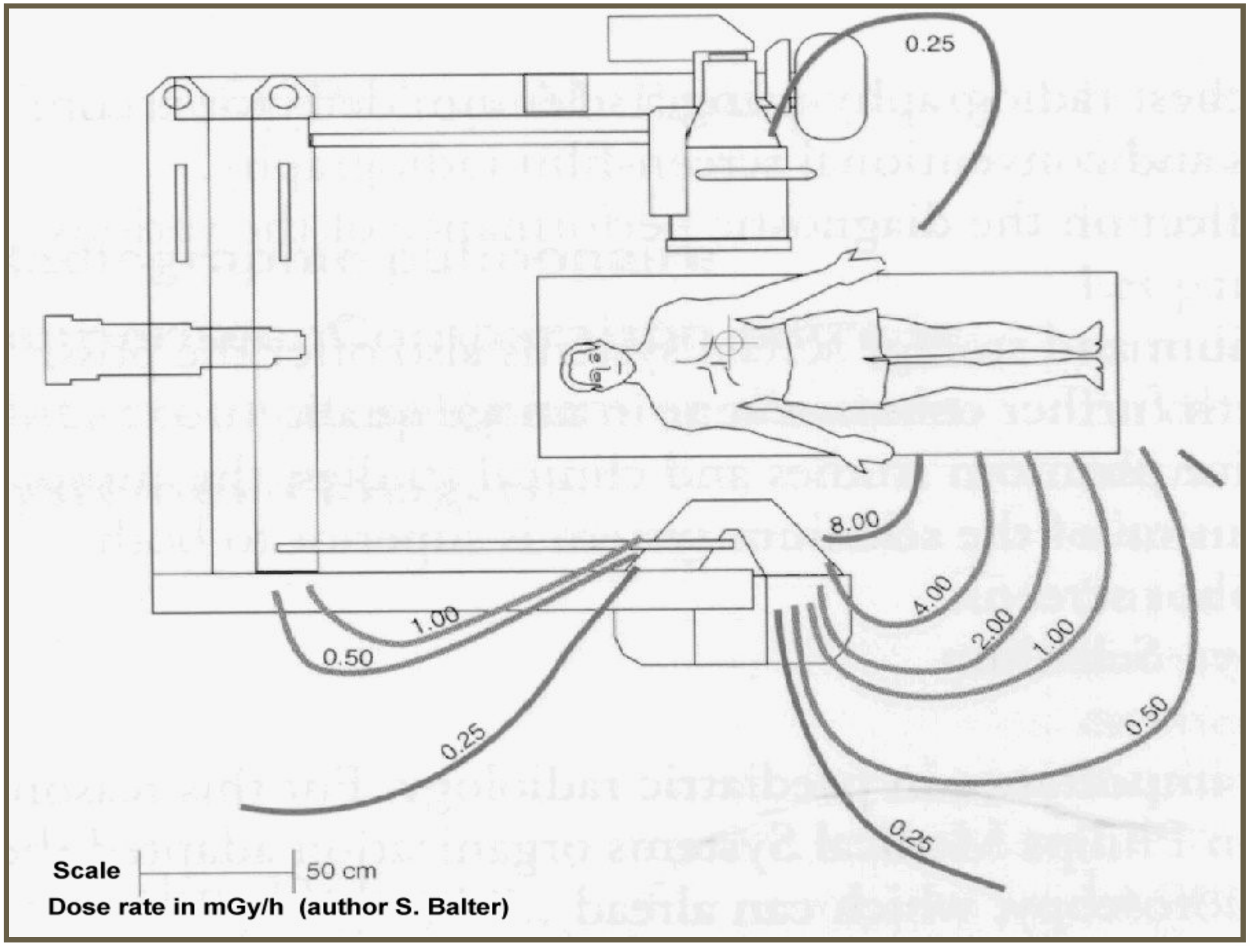


Fig. 55
Dose area product and inverse square law for radiation dose.

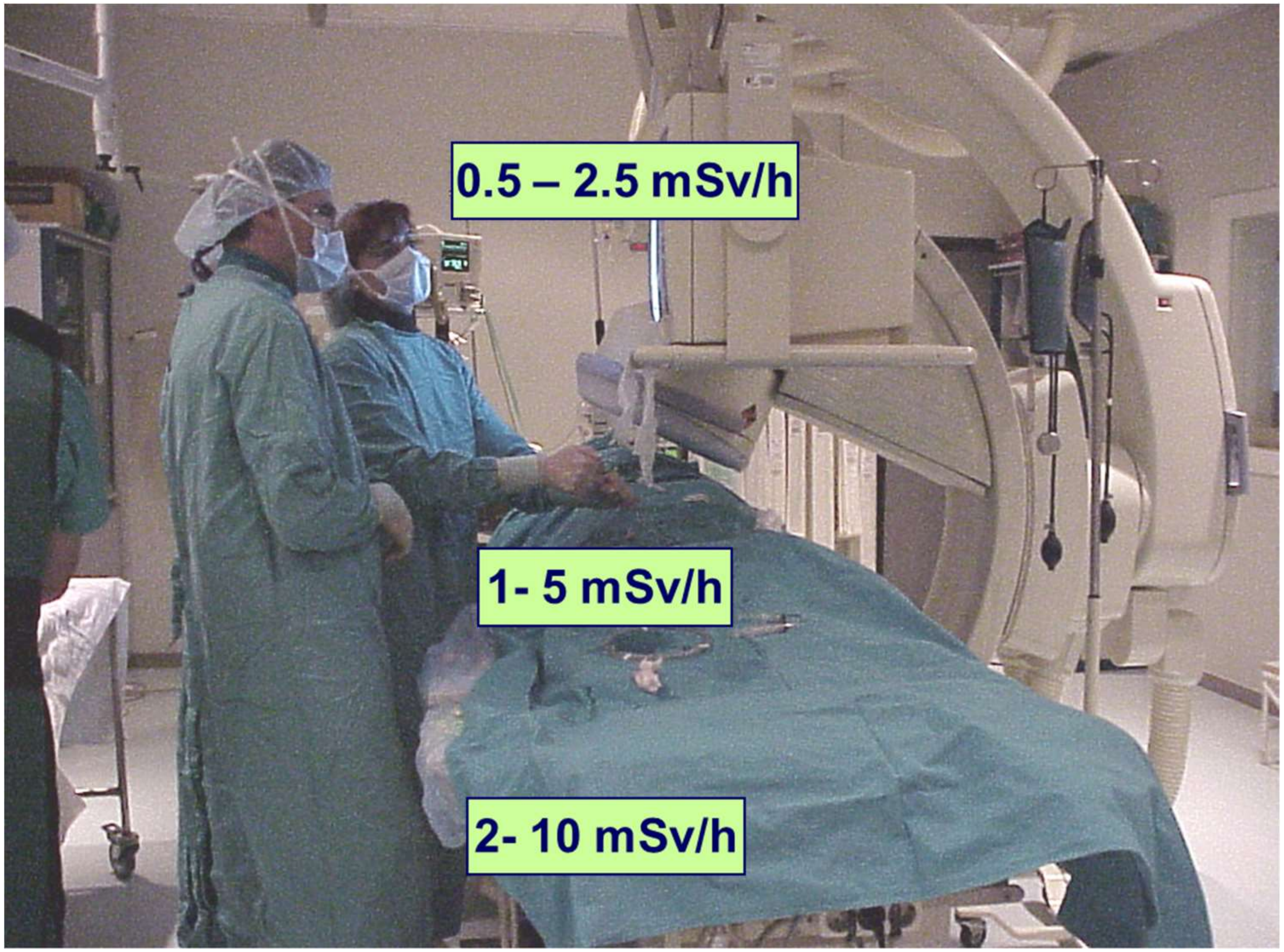
Optimization of protection



Isodose curves for scatter radiation

Reference : IAEA Training Material on Radiation Protection of Patients Cardiology
https://rpop.iaea.org/RPOP/RPoP/Content/AdditionalResources/Training/1_TrainingMaterial/Cardiology.htm

Optimization of protection



Radiation doses for scatter radiation

Reference : IAEA Training Material on Radiation Protection of Patients Cardiology
https://rpop.iaea.org/RPOP/RPoP/Content/AdditionalResources/Training/1_TrainingMaterial/Cardiology.htm

Optimization of protection

- Shielding
  - Diagnostic x-rays are easily shielded with thin sheets of lead.

Optimization of protection

- Shielding
    - Amount of protection is Lead Equivalent (LE) , measured in mmLE

Ceiling mounted shield and under-table shield

Shielding

- Lead apron
  - Any person who is required to stand within 1 m of the x-ray tube or patient when the machine is operated at tube voltages above 100kV should wear a protective apron of at least 0.35mm LE.
  - The higher the LE, the heavier the apron
  - Most are 0.25 ,0.35 and 0.5 mmLE
  - At least 0.25mmLE if X-ray up to 100kV and 0.35mmLE if above 100kV.

Shielding

- Lead apron

Table 1.6: Measured attenuation of 0.5 mm Pb and nominal 0.5 mm lead equivalent materials specified at 90 kV, but measured at 80, 90, 100 and 120 kV.

		80 kV		90 kV		100 kV		120 kV	
Material	**Layers**	**Mean**	**% CV**	**Mean**	**% CV**	**Mean**	**% CV**	**Mean**	**% CV**
0.5 mm Pb		95%		93%		92%		91%	
Starlite	3 x 0.167	96%	0.1%	94%	0.1%	91%	0.1%	85%	0.2%
Starlite	2 x 0.25	96%	0.2%	94%	0.0%	93%	0.3%	87%	0.2%
Cost Cruncher	3 x 0.167	95%	0.3%	93%	0.5%	92%	0.5%	92%	0.6%
Cost Cruncher	2 x 0.25	96%	0.2%	93%	0.2%	92%	0.3%	92%	0.3%
TrueLite	3 x 0.167	96%	0.1%	94%	0.1%	92%	0.1%	91%	0.2%
TrueLite	2 x 0.25	96%	0.2%	94%	0.3%	93%	0.3%	91%	0.4%
Prestige	3 x 0.167	96%	0.2%	95%	0.4%	92%	0.5%	87%	0.8%

Shielding

- Back pain was reported by 50-75% of interventional physicians surveyed (Klein et al, 2009)
- Options for relief:
  - One-piece apron with elastic belts :
    - to distribute much of the weight to the operator's waist
  - Two-piece apron:
    - Vest- skirt combination : 70% of the total weight onto the hips leaving only 30% of the total weight on the shoulders

Shielding

- Proper lead apron care
  - hanging aprons on designated racks with adequate hangers
  - periodic inspection for damage

Shielding

- Leaded eyewear
  - must fit properly for both protection and comfort and have additional side shielding
  - Typical lead equivalent thickness of radiation protective eyewear is 0.75mmLE ~98% attenuation

Shielding

- Thyroid collar
  - Thyroid gland is sensitive to ionizing radiation and is located fairly close to the skin.

Shielding

- Upper and lower body radiation protection
  - Ceiling suspended or mounted shield - typically equivalent to 1mmLE
  - Under-table shield
    - (a) large enough (not normally less than 45cm wide and 45cm long)
    - (b) made of protective material having lead equivalence of not less than 0.5mm
  - Reduces staff exposure to scattered radiation by 99%

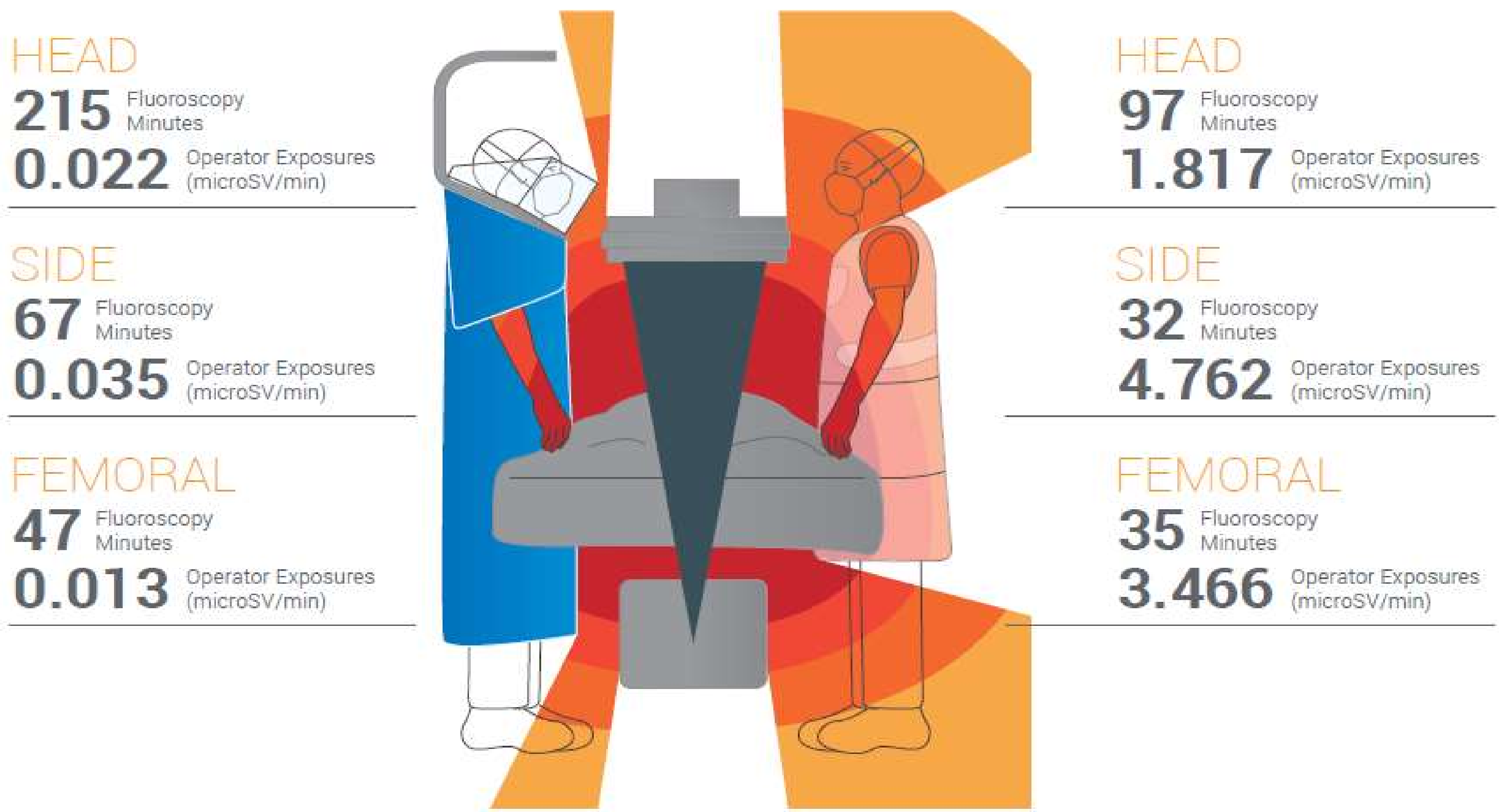
Shielding

- Suspended personal radiation protection system
  - Body shield with 1.00mmLE lining

Shielding

Suspended personal radiation protection system

Conventional lead shield

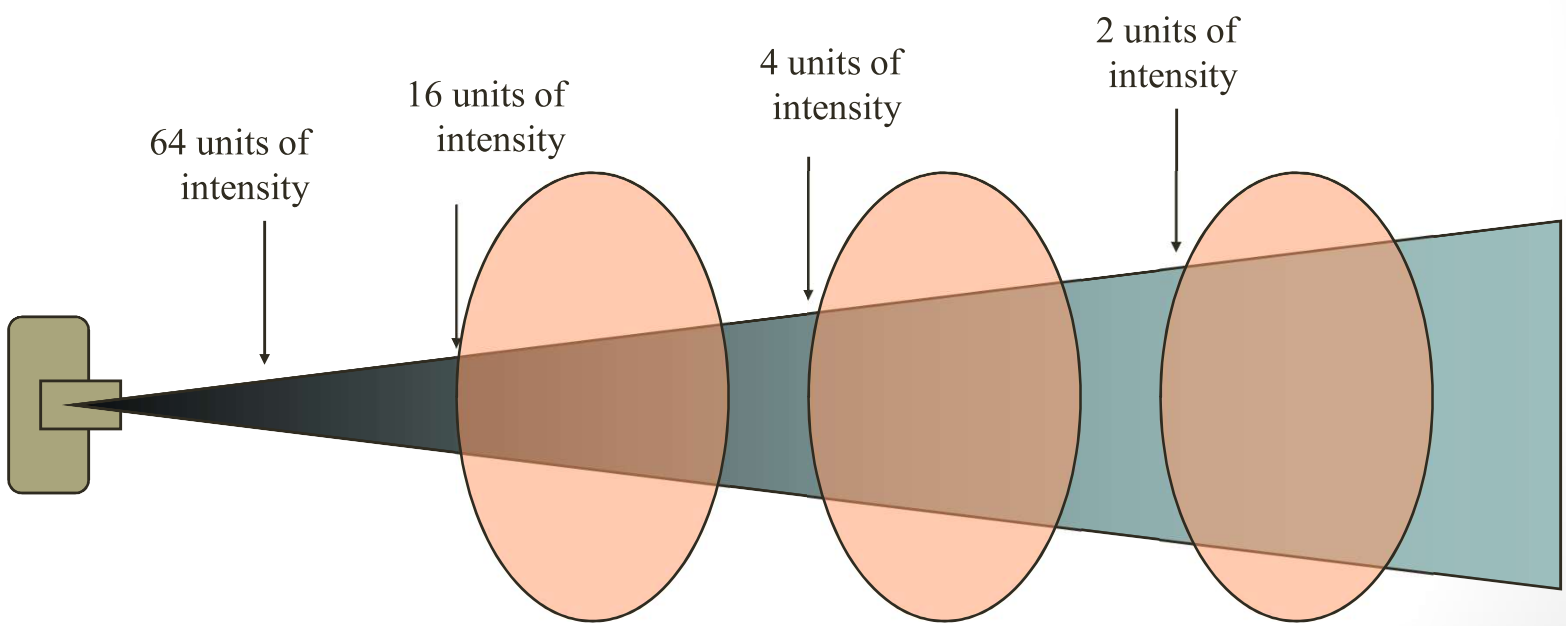


Strategies to reduce X-ray

- Keep all body parts out of the field of view at all times
- Keep table height as high as comfortable possible for the operator
- Vary the imaging beam angle to minimize exposure to any one skin area
- Keep patient's extremities out of the beam
- Minimize use of cine or use lower framing rates and store X-ray fluoroscopy when appropriate
- Minimize use of steep angles of X-ray beam
- Minimize use of magnification modes
- Minimize frame rate of fluoroscopy and cine
- Keep the image receptor close to the patient
- Utilize collimation to the fullest extent possible
- Monitor radiation dose in real time to assess patient risk/benefit during the procedure
- Use of wedge filter

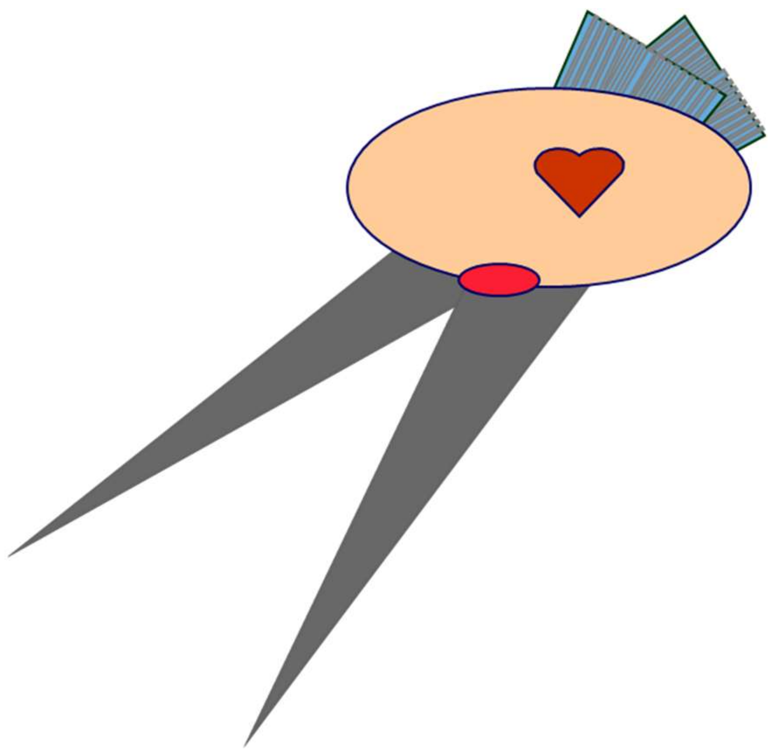
Keep table height as high as comfortable possible for the operator

- To minimize patient's skin dose by keeping the X ray tube at the practicable maximum distance from the patient



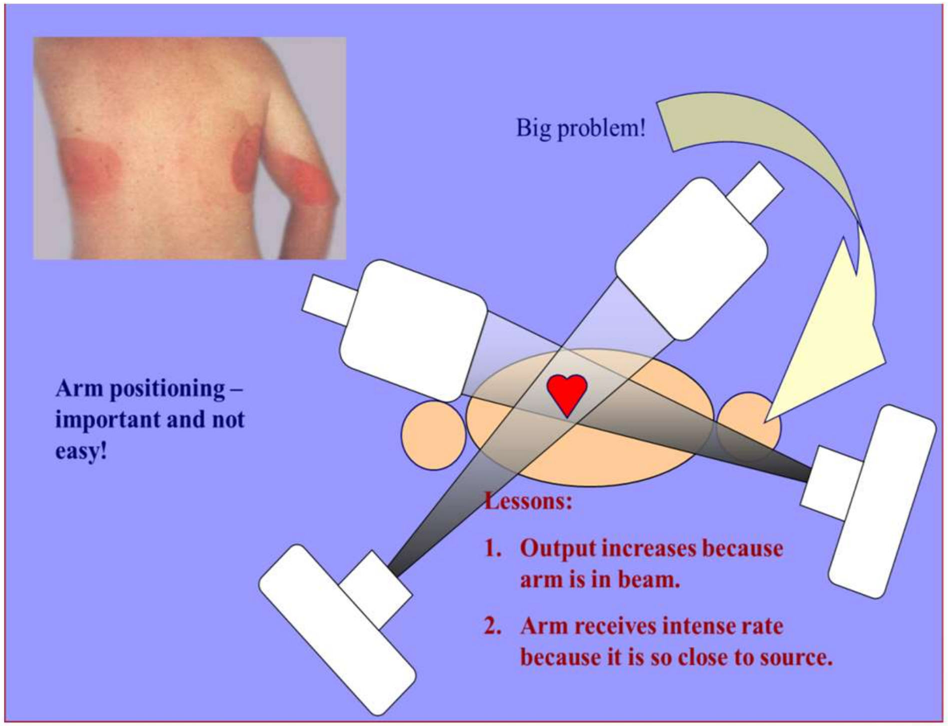
Vary the imaging beam angle to minimize exposure to any one skin area

- Reorientation of beam can minimize patient's skin dose
- Overlapping area (red area) remaining after reorientation are still at high risk. Good collimation reduces the overlap area.



Keep patient's extremities out of the beam

- If extremities are in the field of view, automatic dose rate controls will increased X-ray tube output to compensate for the increased tissue thickness



Minimize use of cine or use lower framing rates and store X-ray fluoroscopy when appropriate

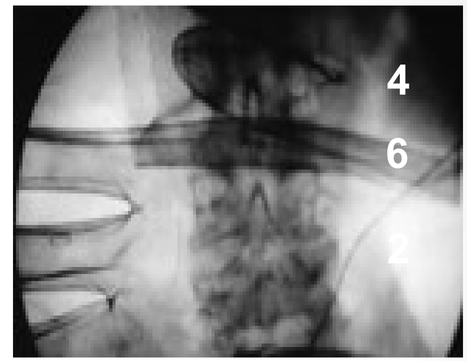
- Cine acquisition dose rate is significantly greater than fluoroscopy

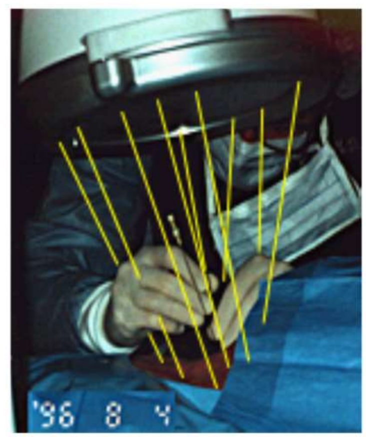
- From low fluoroscopy to cine, radiation / scatter dose rate could increase in a factor of 10-15

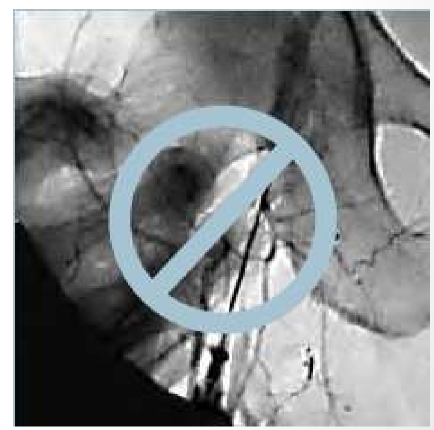
Keep all body parts out of the field of view at all times

- No bony fingers! Workers should never see their own body parts on the X-ray monitor.
  - Clinical necessity?
  - Improper tools?
  - Poor Work Habits

- Chronic overexposure of the operators' hands is a significant hazard.







Minimize use of steep angles of X-ray beam

- Increase in patient's thickness of about 3 cm results in twice the entrance dose for a constant detector entrance dose.

[This rule of thumb is based on the assumption that tissue absorbs radiation in a similar manner as water and that a certain quality of beam is applied.]

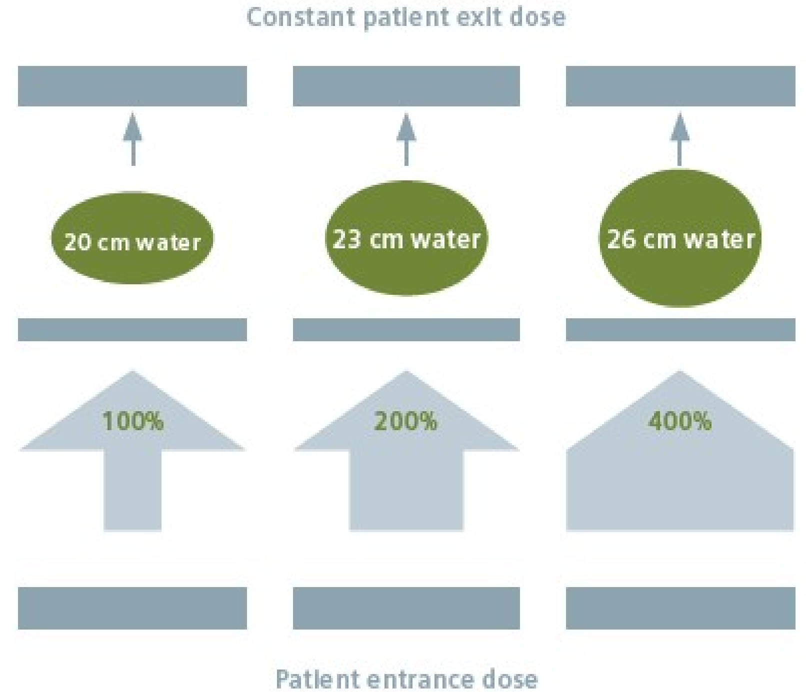


Fig. 53
Patient entrance dose depends on patient thickness to achieve the same patient exit dose.

Minimize use of steep angles of X-ray beam

- When the angle of the X-ray beam increase (steeper angles) , the length of the X-ray beam become longer, resulting in a higher entrance dose.

- Minimize use of steep angles of X-ray beam decrease doses

(True values may differ significantly since the body is not really a homogeneous ellipsoid but consists of bones, organs, etc)

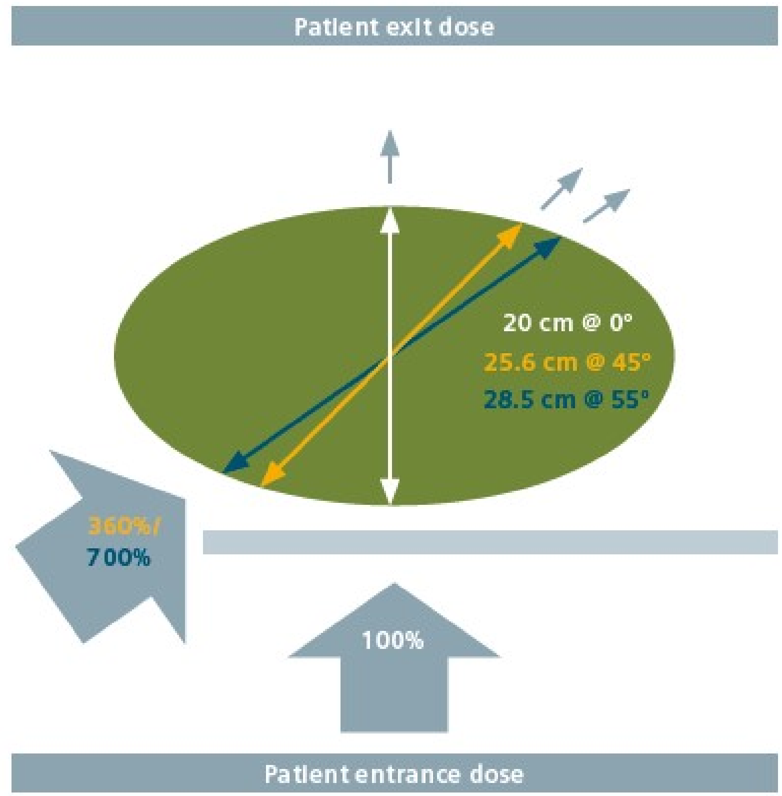
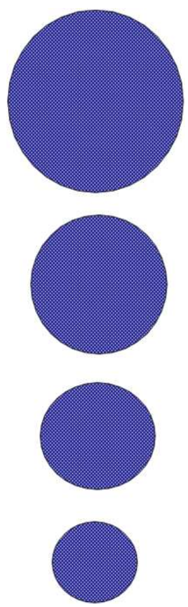


Fig. 54
Simplified model showing the effect on patient entrance dose when the projection is angulated.

Minimize use of magnification mode

- In general, for image intensifier as the degree of electronic magnification of the image increases, the dose rate often increases.



Field of view or magnified mode	Relative patient's entrance dose for some unit
12" (32 cm)	100
9" (22 cm)	200
6" (16 cm)	300
4.5" (11 cm)	400

Minimize frame rate of fluoroscopy and cine

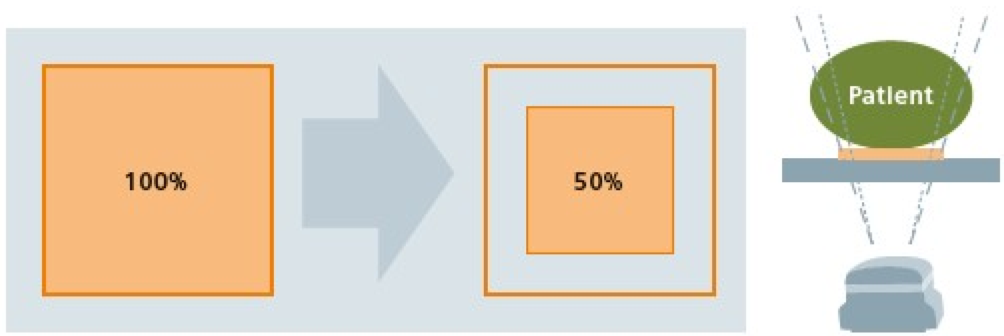
- Typical X-ray pulse rates are 30, 15, 7.5 pulses per second
- Higher pulse rates provide greater temporal resolution at the price of a greater X-ray exposure

Utilize collimation to the fullest extent possible

- 1/ Reduce amount of scatter radiation (reduces DAP) due to reduce size of X-ray field

- 2/ Reduce radiation exposure (stochastic risk) to other patient body parts

- 3/ Reduces potential overlap of fields when beam is reoriented



Keep the image receptor close to the patient

- According to the quadratic law and a constant requested dose at the detector, a greater distance between the source and the imager (SID, source-image distance) increases radiation entrance rate and thus the patient entrance dose (skin dose) and amount of scatter.

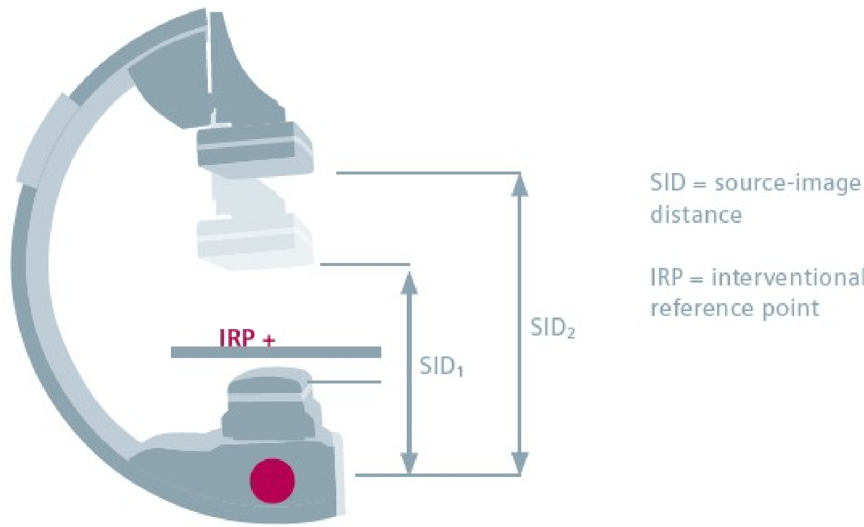
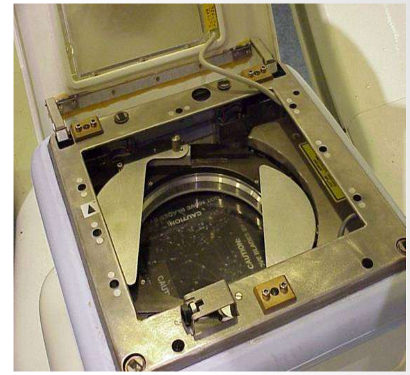


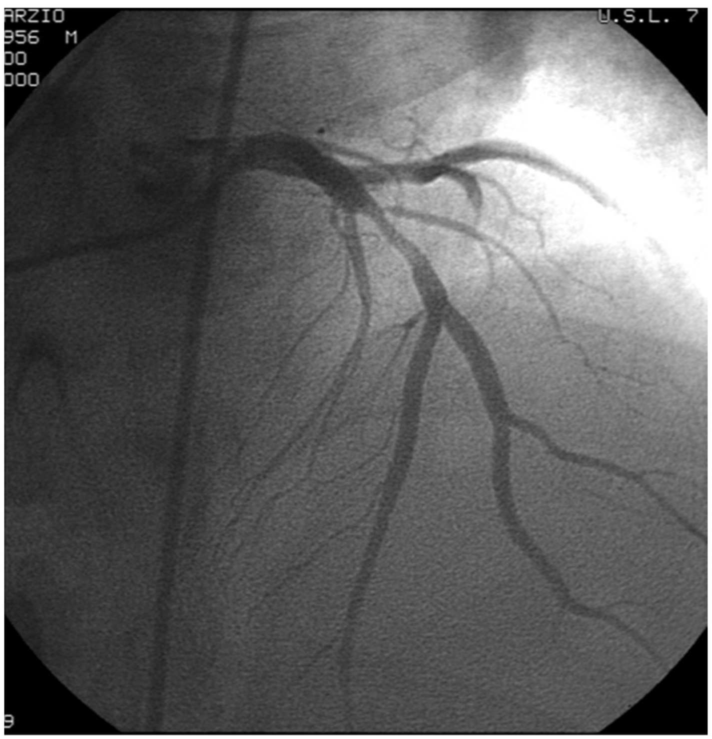
Fig. 56
C-arm, two different SIDs, constant table height, location of the IRP.

Raising SID from 105 cm (= SID 1) to 120 cm (= SID 2) increases patient entrance dose (i.e. the dose at the IRP) by approximately 30%.

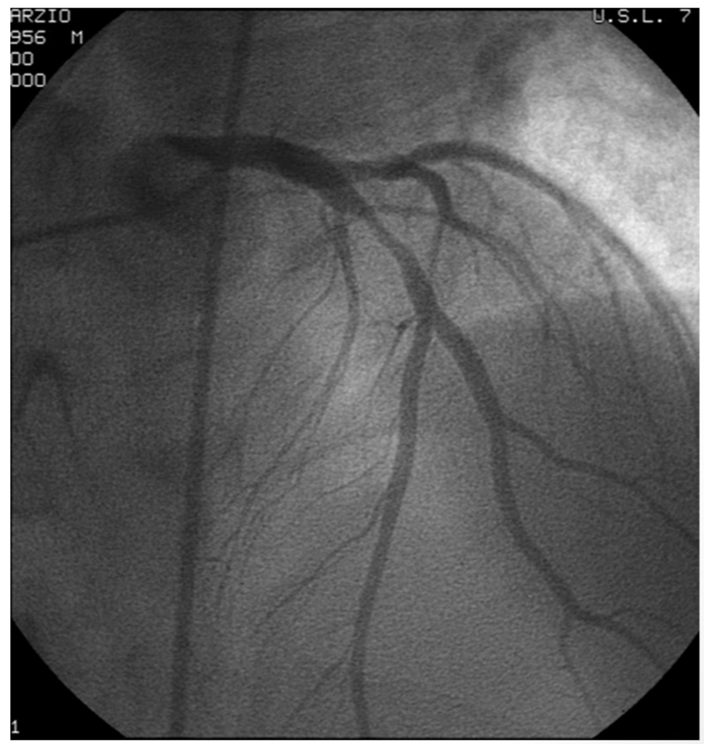
Use of wedge filter



- A portion of poorly penetrating/ low-energy X-rays are removed from the beam
- Save skin dose and improve image quality.



Without wedge filter



With wedge filter

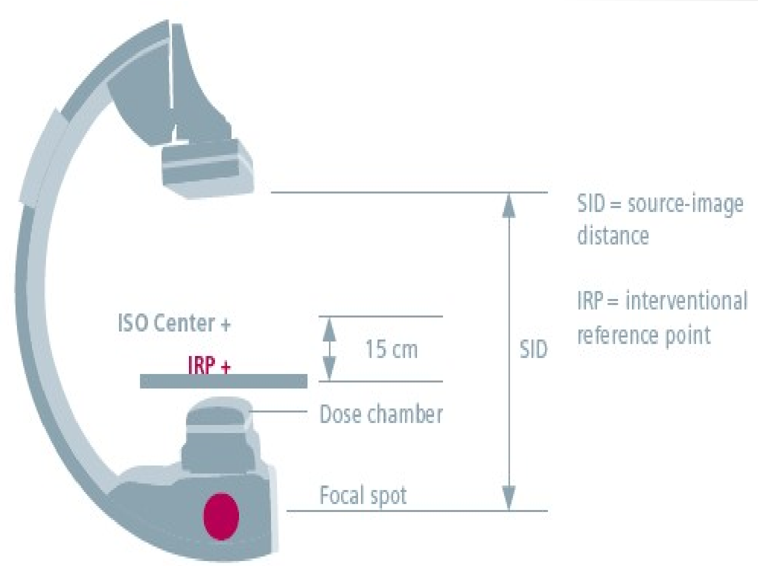
Dose monitoring

- 1/ Patients
  - i/ Cumulative dose (Air Kerma) at the Interventional reference point (IRP):
  - ii/ Dose-area product (μGym^2)
  - iii/ Fluoroscopic time (min): does not include cine
- 2/ Working staffs
  - Radiation dosimetry

Dose monitoring

- Interventional reference point (IRP) is 15cm beneath the isocenter and is assumed to be the skin entrance point

- Cumulative dose at IRP (mGy)
    - an indicator of cumulative skin dose
    - measure of patient's deterministic risk (though is not the true peak skin dose).
    - Patients who receive an cumulative dose greater than 4 Gy should be advised that they might develop a skin rash, along with instruction on what to do in the event that one is observed



Dose monitoring

- Dose-area product (μGym^2)
  - Surrogate measurement for the entire amount of energy delivered to the patient by the beam
  - Measure patient's stochastic risk

Dose monitoring

- <u>Fluoroscopy time</u>
  - Weak correlation with DAP
  - Used in quality assurance
    - for comparison between operators, centres, procedures
    - for the evaluation of protocol optimization
    - to evaluate operator skill

Dose monitoring

- Reports on radiation dose:
  - 1/ Fluroscopic time (min),
  - 2/ Total air kerma at IRP (Gy)
  - 3/ Air kerma-area product (Gy cm2)
- No regulatory dose limits exist for patients (physicians are expected to use only what is necessary for medical purposes)

Dose monitoring

- Operator should be notified during the procedure when cumulative dose is in excess of 3Gy and then every 1 Gy thereafter

- Patient notification, chart documentation, and communication with the primary care provider should routinely occur following procedures with radiation dose levels exceeding total air kerma at IRP of 5 Gy

Dose monitoring

- 2/ Radiation dosimetry
  - For those with exposure greater than 10% of the annual limit.
  - Department of Health :
    - Single dosimeter (worn at chest or waist height)
  - ICRP :
    - Two dosimeters (one under the protective garment , usually at waist height, second outside any protective garment at the collar)
      - Assess apron attenuation
      - Better estimation of operator effective dose

Dose monitoring

- 2/ Radiation dosimetry
  - Dosimeter is normally worn for 1 month then returned for dose assessment and replaced with new ones.
  - Should wear all the time at work.
  - Prevent dosimeter, while not being worn, from being exposed to ionizing radiation or heat

Dose limit

- Annual dose limited stipulated in radiation ordinance (Hong Kong)

Organs	Dose Limits Occupational	Public
Whole body	20mSv in any calendar year	1mSv
Abdomen of a woman with reproductive capacity	5 mSv in any consecutive 3 months interval	---------
Abdomen of a pregnant woman	1mSv from declaration to delivery and intake radionuclides is limited to 1/20 ALI	---------
Lens of the eye	150mSv	15mSv
Skin, average over $1cm^2$	500mSv	50mSv
Other individual organs	500mSv	---------

In 2011, ICRP reduced lens of eye dose limit to 20 mSv per year, averaged over 5 years, with no single year exceeding 50 mSv.

Dose limit

- Typical annual whole body doses for an interventional cardiologist are up to 0.2 - 9mSv (assuming workload of 1000 procedures per year) Kim et al, 2008

- The risk of cancer from doses at or below the occupational limits is considered acceptably low.

- The risk at low doses is so low that scientific investigation has never conclusively demonstrated that there is or is not a slight risk.

Pregnant staff

- Radiation risks are most significant during organogenesis and in the early fetal period somewhat less in the 2nd trimester and least in the third trimester
- The ICRP recommends less than 1.0 mSv total fetal exposure during an entire pregnancy
- Pregnant medical radiation workers may work in a radiation environment as long as there is reasonable assurance that the fetal dose can be kept below 1 mGy during the pregnancy.
- 1 mGy is approximately the dose that all persons receive annually from natural background radiation.

Source of information

1. Radiation Health Unit , Department of Health
2. International Commission on Radiological Protection (ICRP)
3. International atomic electronic agency (IAEA)
4. National Council on Radiation Protection (NCRP)
5. Charles E , Radiation Safety Program for the Cardiac Catheterization Laboratory
6. ACCF/AHA/HRS/SCAI clinical competence statement
7. Centers for Disease Control and Prevention
8. Raza,SMS, THE CATH LAB – SAFETY AND PRECAUTIONS
9. Radiation Management for Interventional Fluoroscopy Staff Safety
10. Michael J. Bohan, Fluoroscopic Radiation Safety, Patient and Occupational Safety
11. Siemens, Guide to Right Dose
12. CFI Medical