TG 108 WORKSHOP: PART 2

OPTIMISATION OF RADIOLOGICAL PROTECTION IN DIGITAL RADIOLOGY TECHNIQUES FOR MEDICAL IMAGING

20 MARCH 2023 | 12:00 - 15:00 (GMT)

Fluoroscopy and Interventional Procedure Techniques

IAEA

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ICRP

DRAFT REPORT FOR CONSULTATION: DO NOT REFERENCE

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Annals of the ICRP

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Practical Aspects in Optimisation of Radiological Protection in Digital Radiography, Fluoroscopy, and CT

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3. INTERVENTIONAL AND OTHER FLUOROSCOPIC PROCEDURES

3.1. The evolution of fluoroscopic techniques

3.2. Design features of modern fluoroscopy systems relevant to patient dose and image quality

3.3. Exposure configuration and optimisation during commissioning

3.4. Establishing equipment performance and QC programme

3.5. Patient dose monitoring and dose audits

3.6. Skin dose monitoring and alert levels

3.7. Practical advice for optimal performance of fluoroscopy procedures and patient management

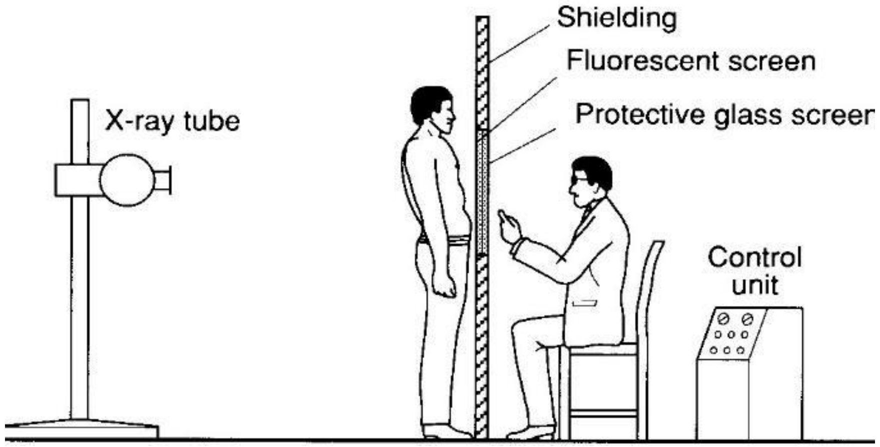
3.8. Dose management QA programme

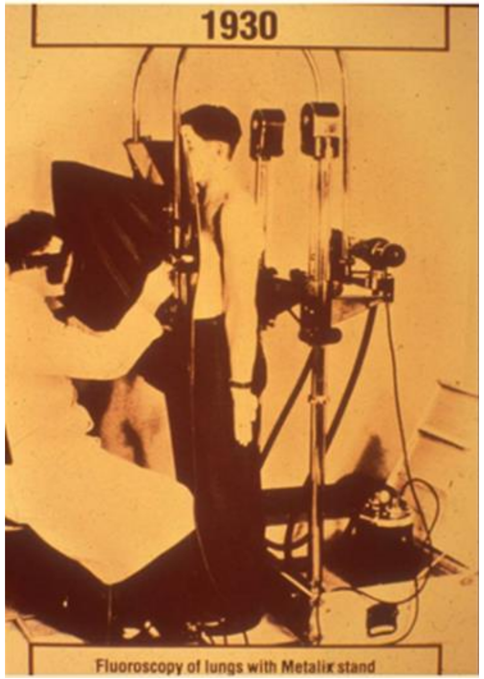
Evolution of fluoroscopic techniques

Early ages:

- Direct fluoroscopy screens
- Dark adaptation of radiologists 'eyes
- High radiation exposure to radiologists








MEDICAL PHYSICS INTERNATIONAL Journal, Special Issue, History of Medical Physics 2, 2019

Fluoroscopic Technology from 1895 to 2019 Drivers: Physics and Physiology

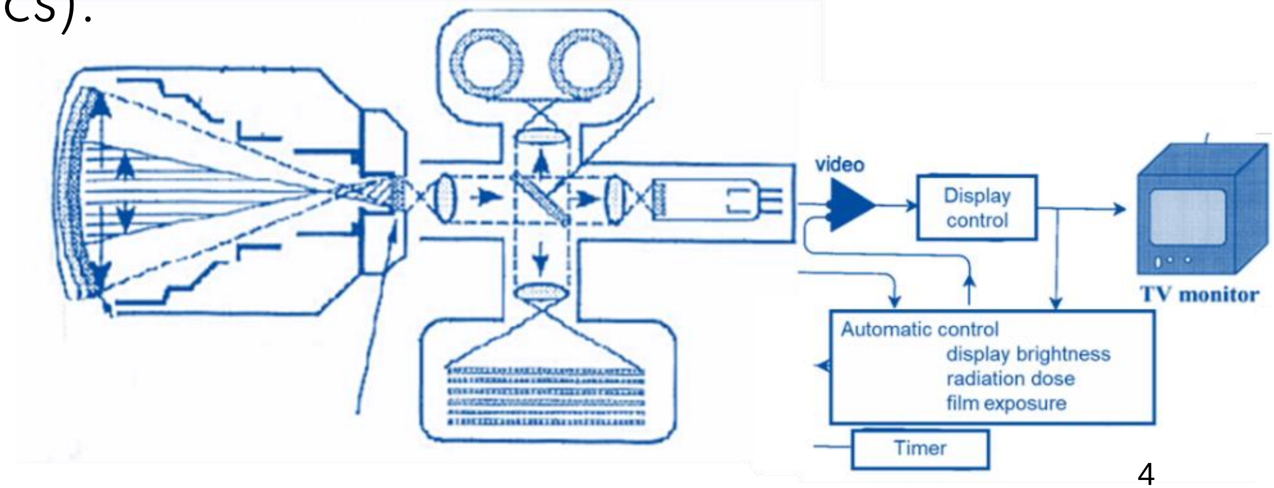
Balter, Stephen

Columbia University, Departments of Radiology and Medicine, New York, NY, USA

Evolution of fluoroscopic techniques

1950-s to 2000-s

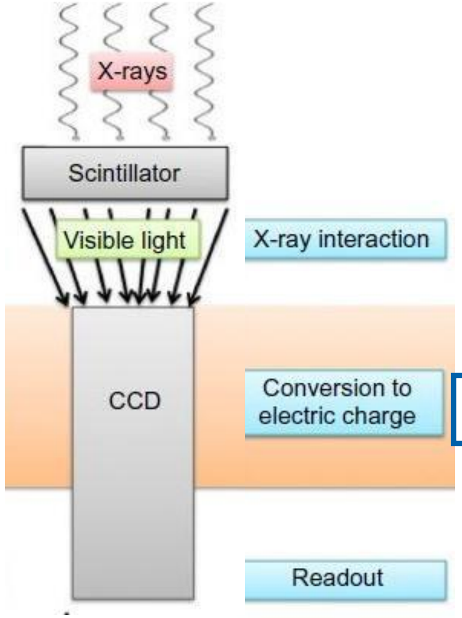
- X-ray image intensifier (II)
  -ZnCdS phosphor
  - CsI phosphor (**mid 1970-s**)
- TV camera:
  -Analog (orthicon or vidicon camera tubes)
  -Digital CCD TV camera (**1980-s**)
  -TV monitor
- Image recording (through tandem optics):
  - Film-screen
  - Spot cameras (cut or roll films)
  - Cine cameras
- Automatic control circuit
  -Automatic Brightness Control (ABC)
  -Automatic Dose Rate Control (ADRC)

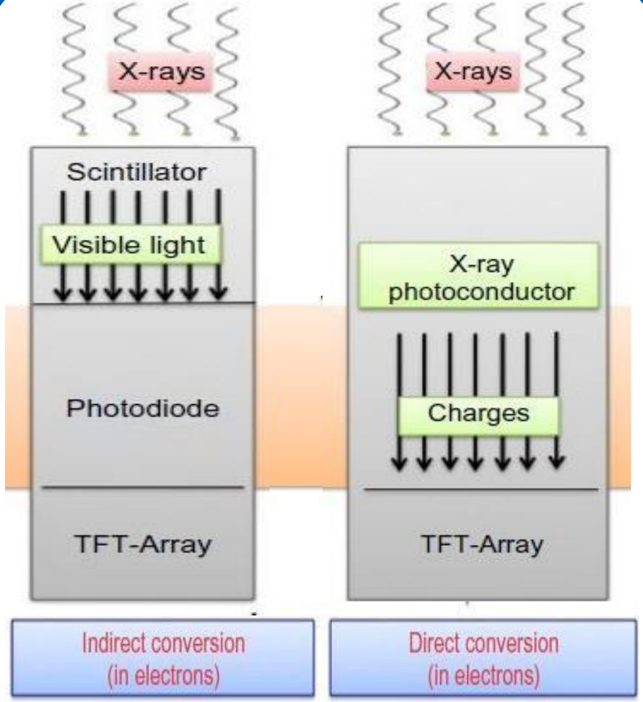


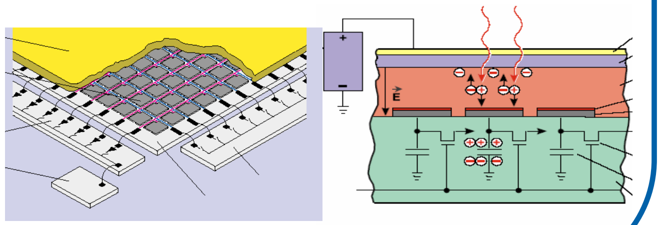
Evolution of fluoroscopic techniques

Since 2000-s

- Solid-state (flat panel, FP) detectors
  - indirect conversion
  - direct conversion
- Digital image processing

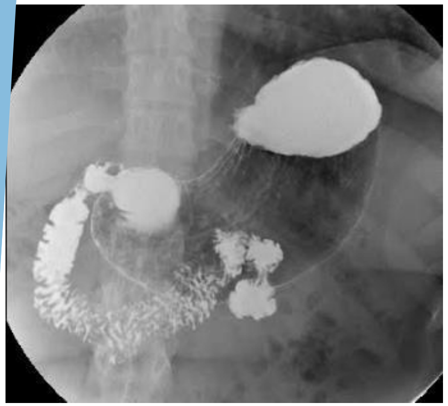






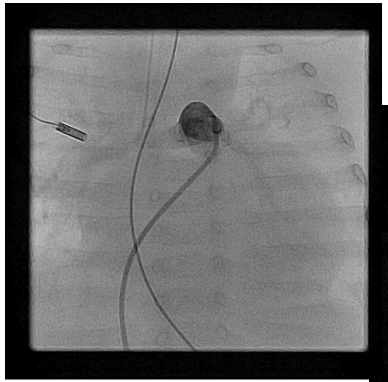
X-ray fluoroscopy

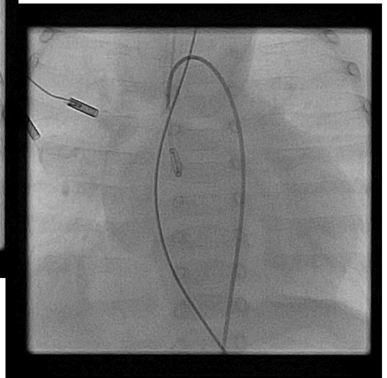
Diagnostic procedures



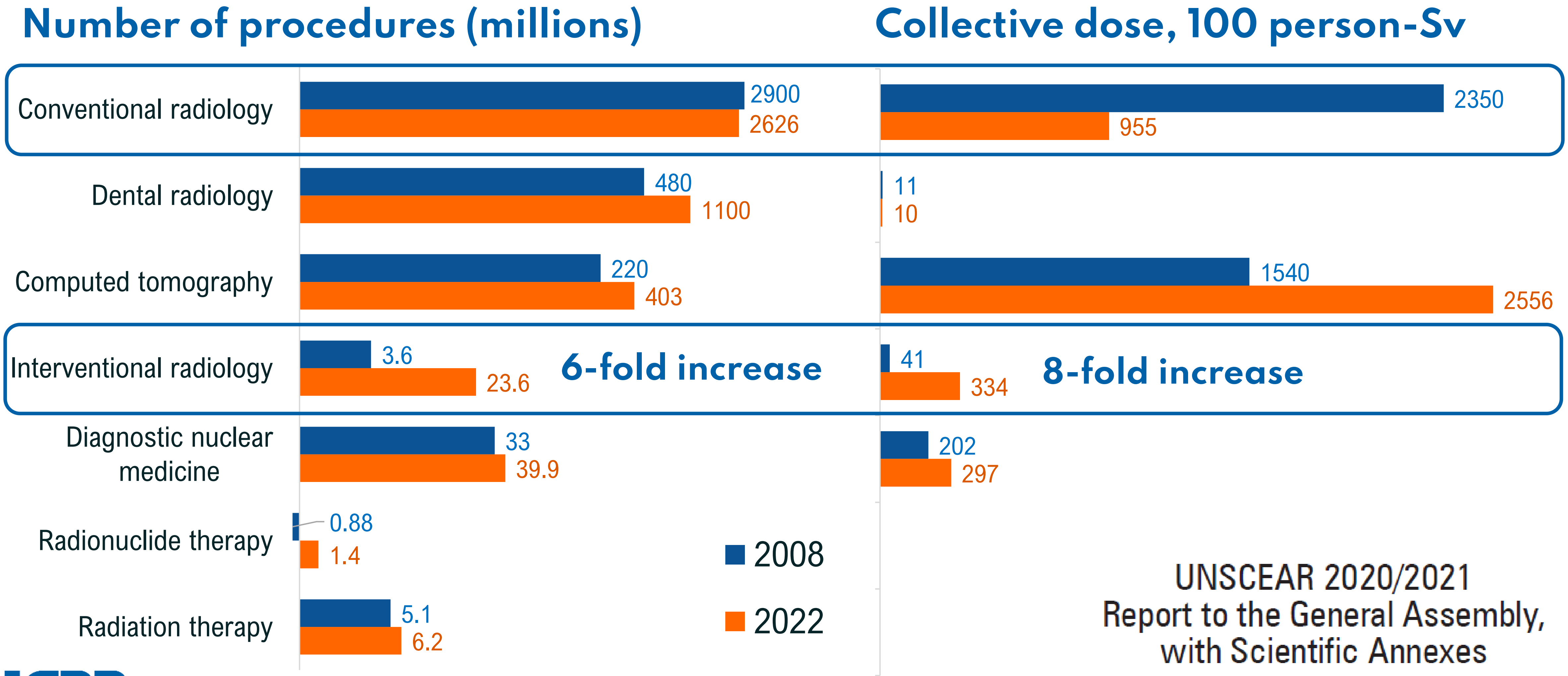
Fluoroscopy guided interventional (FGI) procedures

for navigation of instruments to perform surgical, minimally invasive and interventional procedures





Global trends in medical exposure



UNSCEAR 2020/2021
Report to the General Assembly,
with Scientific Annexes

FGI procedures

- **Increase of type and frequency of FGI procedures**:
  - Less invasive; less risky for patient; cost saving
  - Growth of embolization procedures for trauma, tumors, other oncologic procedures;
  - Increase in biopsies and vascular therapies due to the aging of the population and resultant increased prevalence of cancer and vascular disease.
- **Increase of complexity:** Requires extensive use of x-ray imaging
- **Various professional groups:** Radiologists; cardiologists, vascular surgeons, neurosurgeons, orthopaedic surgeons, urologists, gastroenterologists, …., ,
- **Variety of settings**: dedicated labs; operating theatres, hybrid rooms, …
- **Other staff in the room**: radiological technologists, anaesthesiologists, nurses

Increased importance of radiation protection training!

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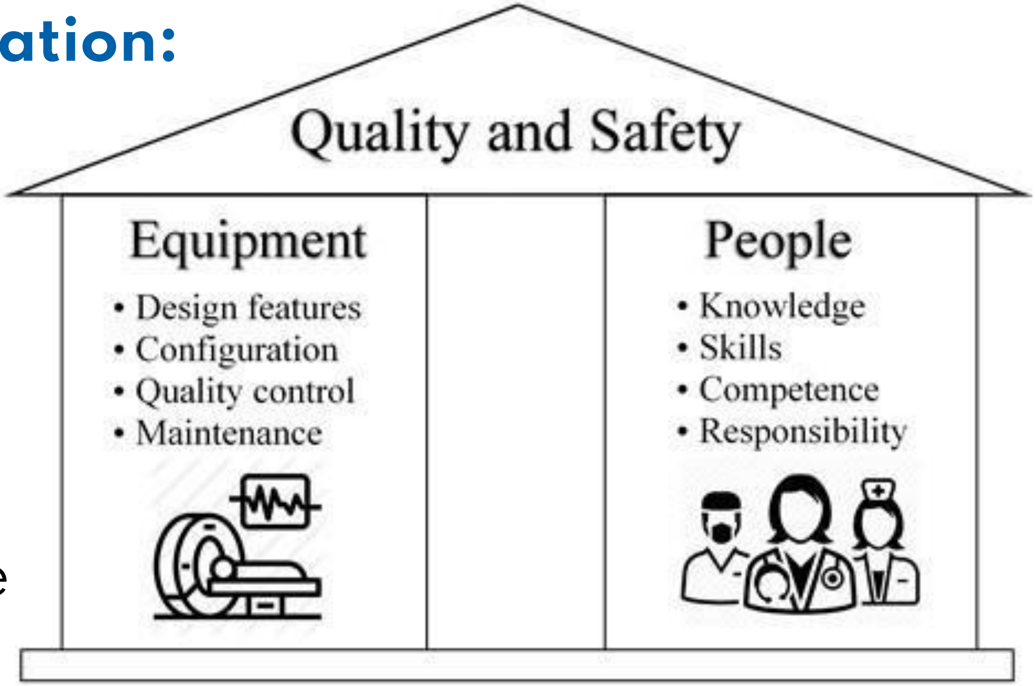
Optimisation in fluoroscopy

1) **Selection of a fluoroscopy system** with design features consistent with the intended clinical uses: multi-disciplinary team: medical physicist, radiographer and radiologist/ interventionalist).

2) **Configuration and exposure setting optimisation:** at the time of commissioning, tailored to the clinical tasks and required image quality.

3) **Comprehensive QA programme:** equipment maintenance and QC tests; reviews of common fluoroscopic procedures.

4) **Appropriate use of the equipment features and settings** by the operators, to perform the clinical task with minimum possible exposure to the patient and to the clinical team members.



Fluoroscopy equipment configuration

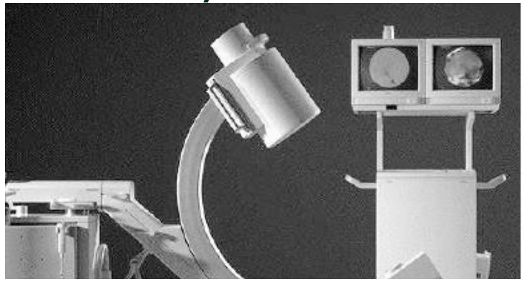
Conventional R/F systems

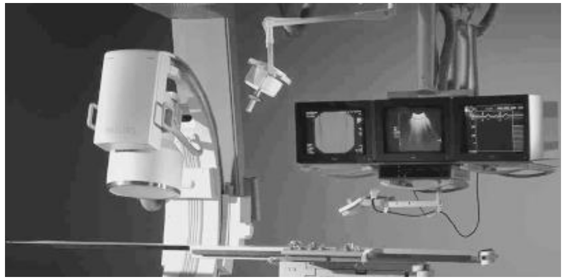
"C-arm" geometry systems

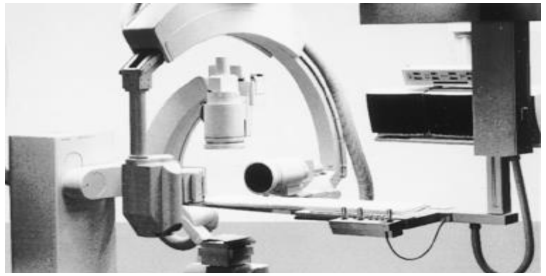
Angiography systems

Single plane

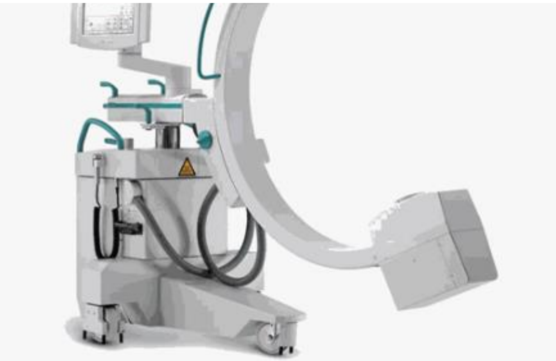
Bi-plane







Appropriate selection of the design features of a fluoroscopy system consistent with the intended clinical uses is imperative if the Dose Management QA programme is to function as intended.

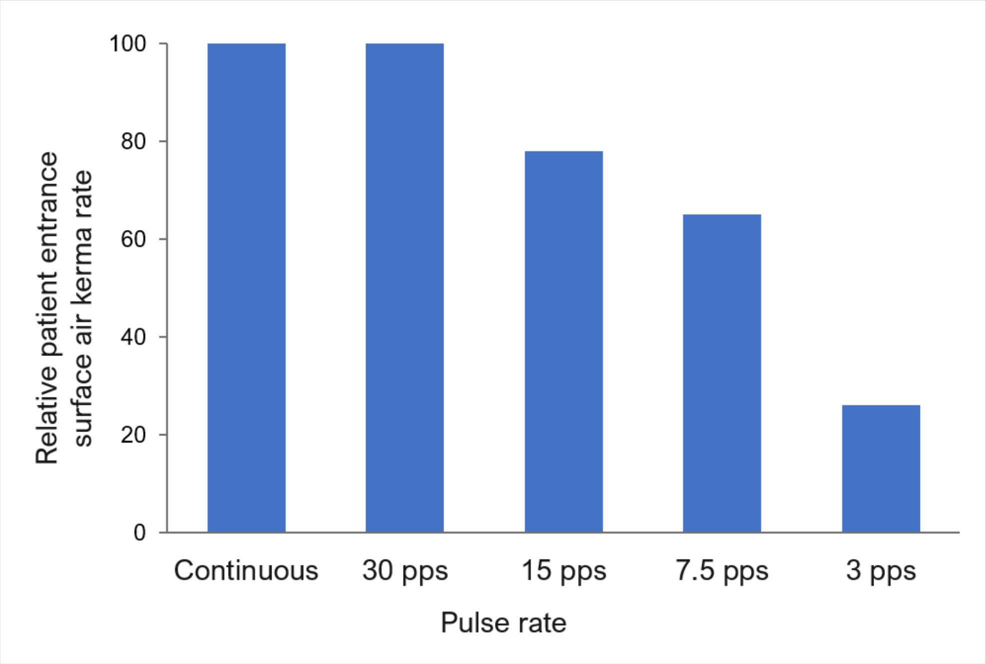


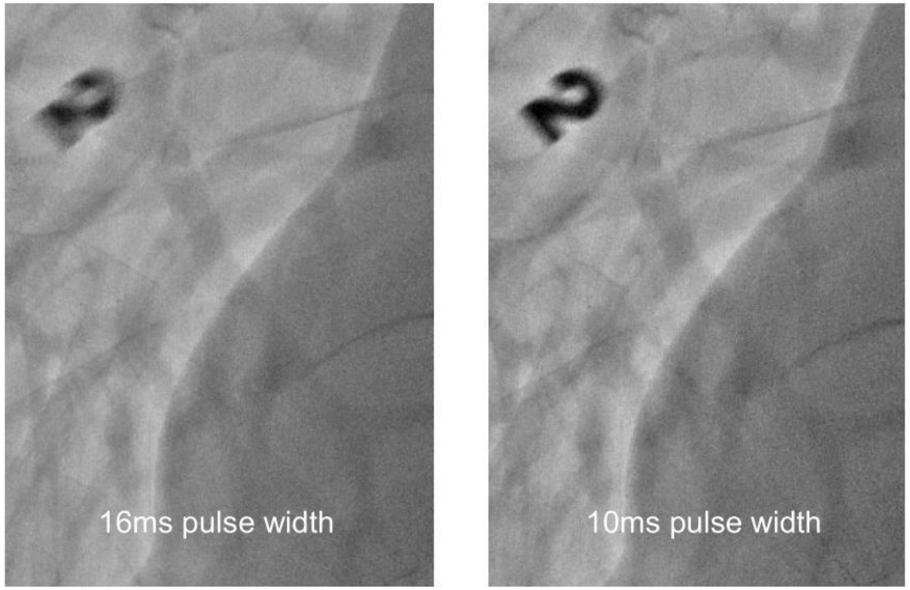
Fluoroscopy system components

- High-power generator (80-100 kW)
- High heat capacity x-ray tube
- 2-3 focal spots (0.3; 06; 0.9 mm)
- High filtration (0.2 mm - 0.9 mm)
- Image receptor (from 10-15 cm up to 40 cm)
- Automatic Dose Rate Control (ADRC)

Fluoroscopy system features

- **Pulsed fluoroscopy**
  -from 3 pps to 30 pps
  -variable pulse width
  -sharper images;
  -reduced temporal resolution
  -reduced ESAK rate





Pulse rate selection depends on imaging task: higher for rapidly moving organs (e.g. heart, especially in children)

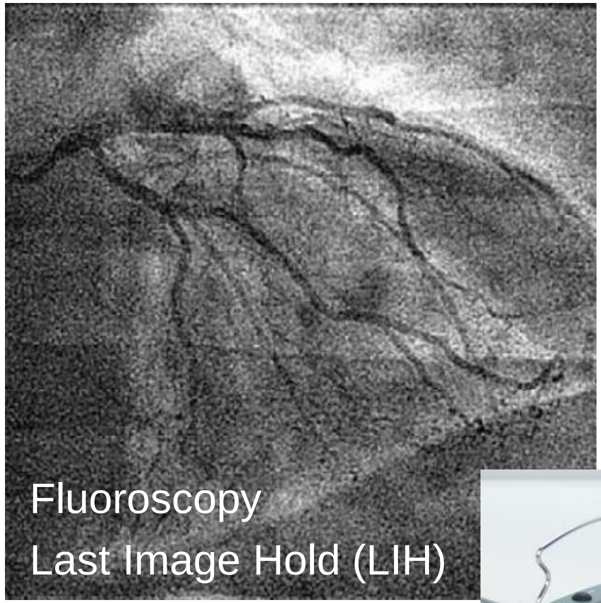
Fluoroscopy system features

- **Fluoroscopy and radiography modes**

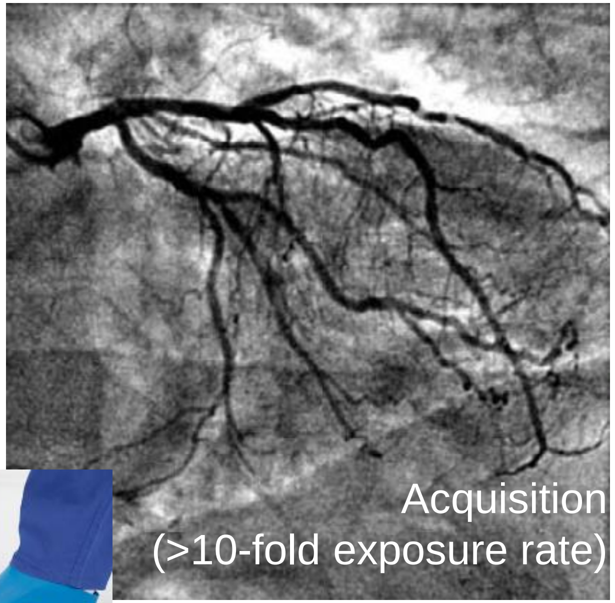
  -Fluoroscopy: pulsed (7.5-30 pps); low mA (0.5-2 mA)

  -Digital radiography: higher SNR and recording/ archiving capability: single (spot) images; number of images (acquisition); serial images ("cine") 1-5 f/s vascular, 7.5-15 f/s cardiac, higher f/s for paediatric protocols;

  -High mA (>400 mA)



Fluoroscopy
Last Image Hold (LIH)



Acquisition
(>10-fold exposure rate)

Dose saving features:

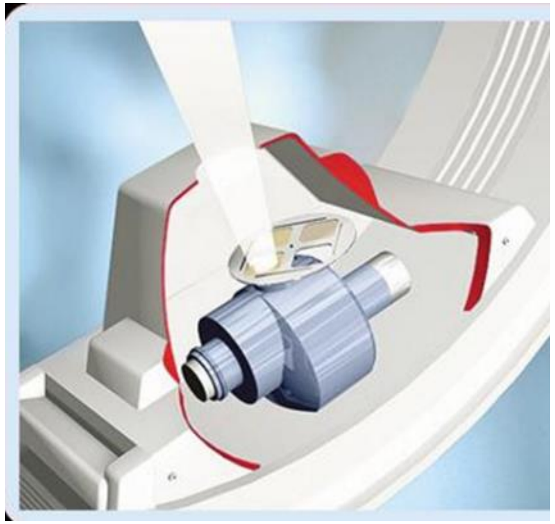
-Last Image Hold (LIH)

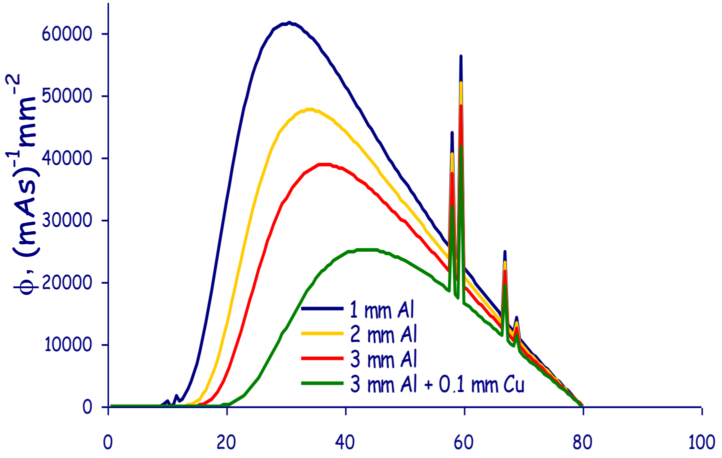
-Last Series Hold (LSH)

- Store and replay the most recent fluoroscopic-imaging sequence (at least 300 frames in modern systems)

Fluoroscopy system features

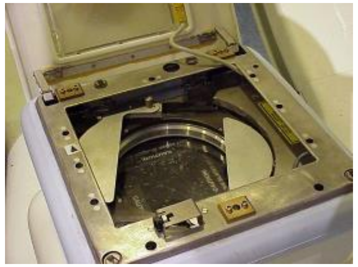
- **Beam spectrum shaping filters**
  - Al+Cu (also Au, Ta)
  - Reduce absorbed dose to skin and superficial tissues (by >70%)
  - Increase image contrast by shaping the x-ray spectrum to match the k-absorption edge of barium (33.44 keV) or iodine (33.17 keV).

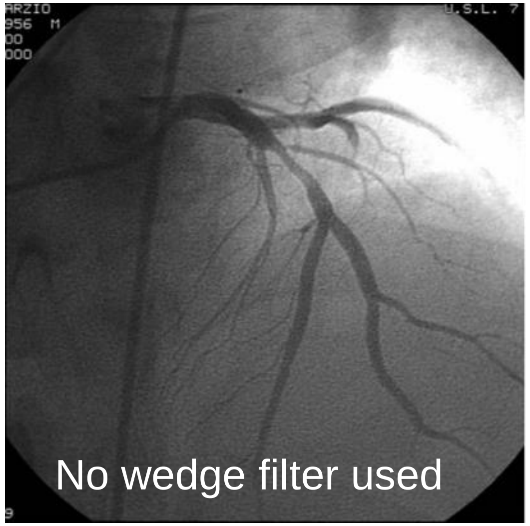




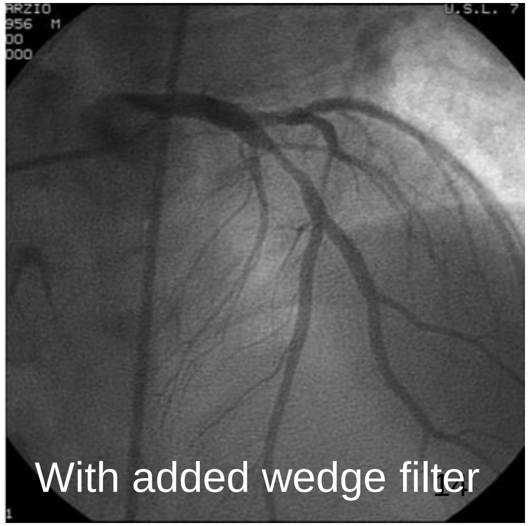
- **"Wedge" filters**

-semi-transparent to compensate for the lower object attenuation in FOV
-maintain image brightness and IQ





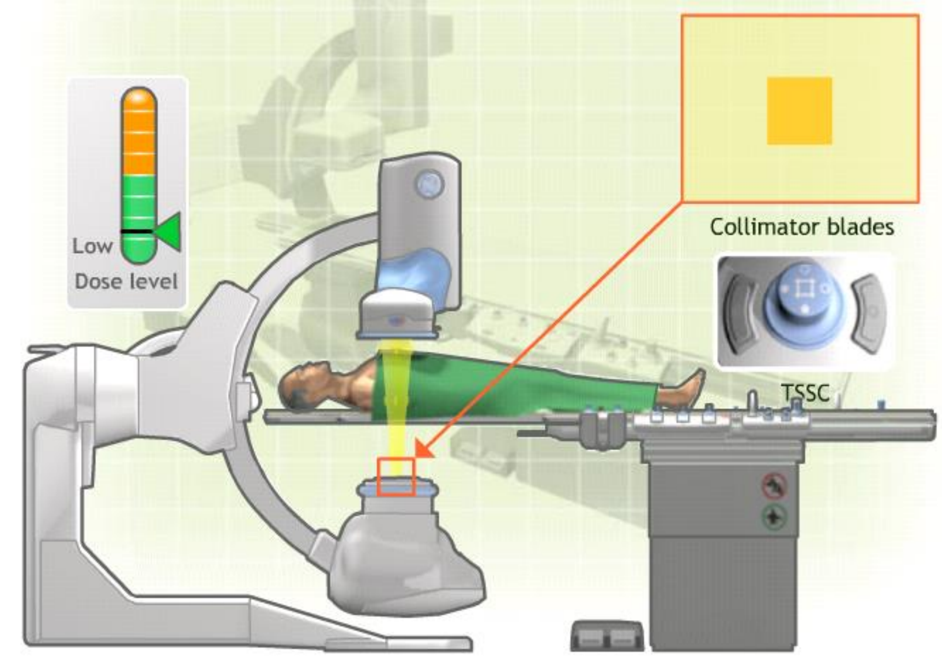
No wedge filter used

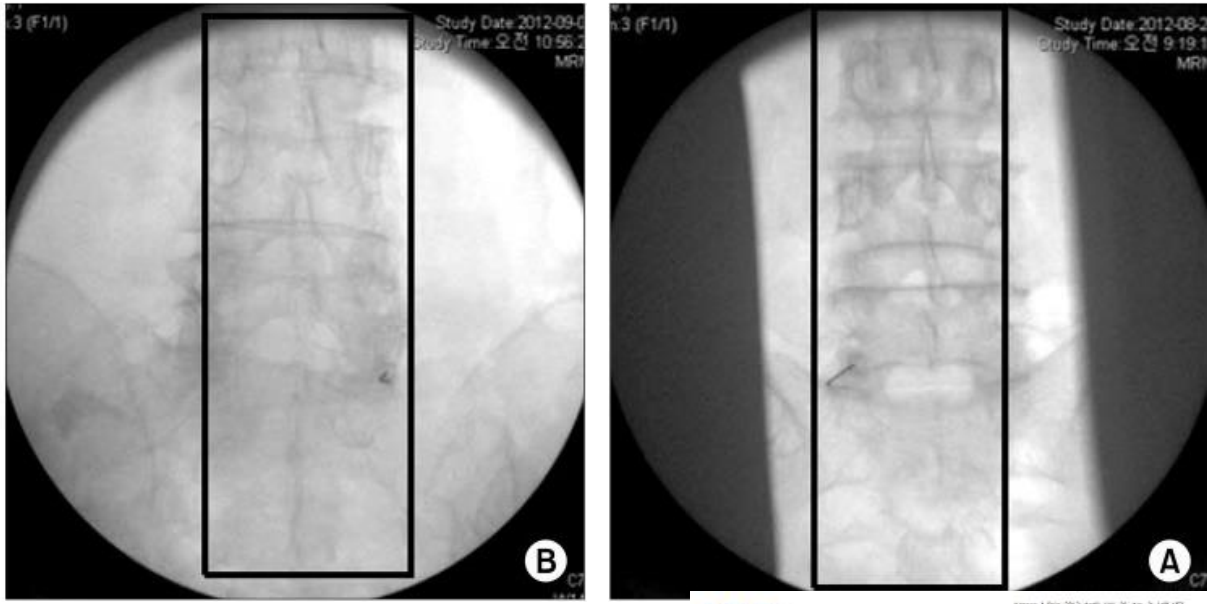


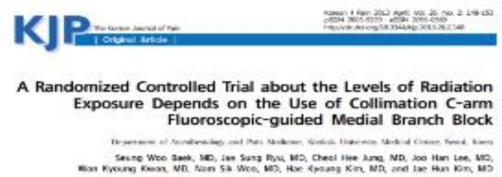
With added wedge filter

Fluoroscopy system features

- **Collimator device:**
  - Automatic collimator system to align beam to the image receptor &FOV
  - Dual-shape collimators (circular or rectangular) to modify field to the ROI
  - Limit dose to patient, reduce scatter ⇨ improve contrast, reduce staff dose





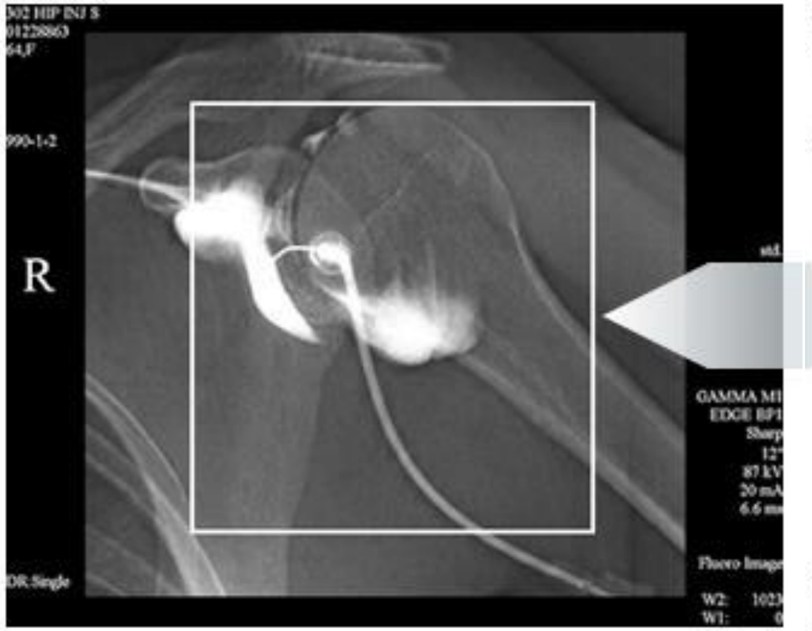

KJP

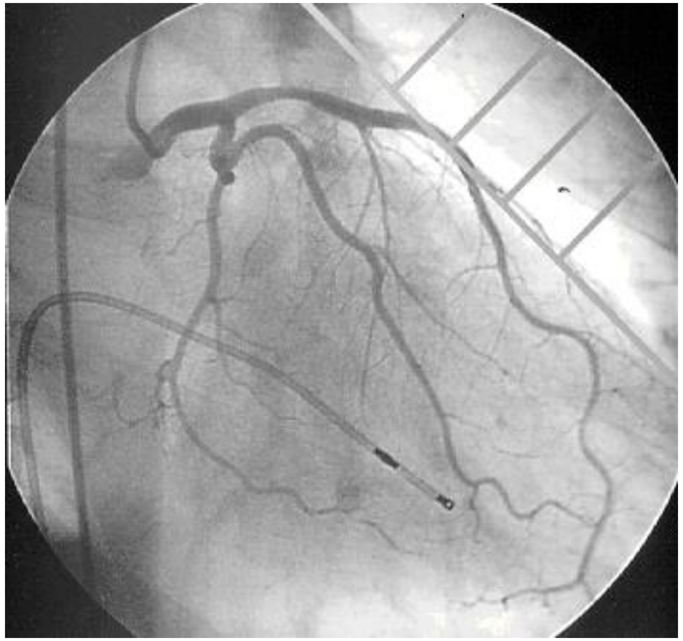
A Randomized Controlled Trial about the Levels of Radiation Exposure Depends on the Use of Collimation C-arm Fluoroscopic-guided Medial Branch Block

Seung Woo Baek, MD, Jae Sung Ryu, MD, Cheol Hee Jung, MD, Joo Han Lee, MD, Won Kyoung Kwon, MD, Nam Sik Woo, MD, Hae Kyoung Kim, MD, and Jae Hun Kim, MD

Fluoroscopy system features

- **Automatic positioning**
- **Virtual collimator** – capacity to position the collimation blades or the wedge filter in the desired position using LIH and without extra radiation for the patient ⇨ **dose saving**





Fluoroscopy system features

- **Anti-scatter grid**
  - remove the scatter radiation and improve image contrast (at increased dose)
  - should be easily removable (e.g. for children and objects <20 cm)

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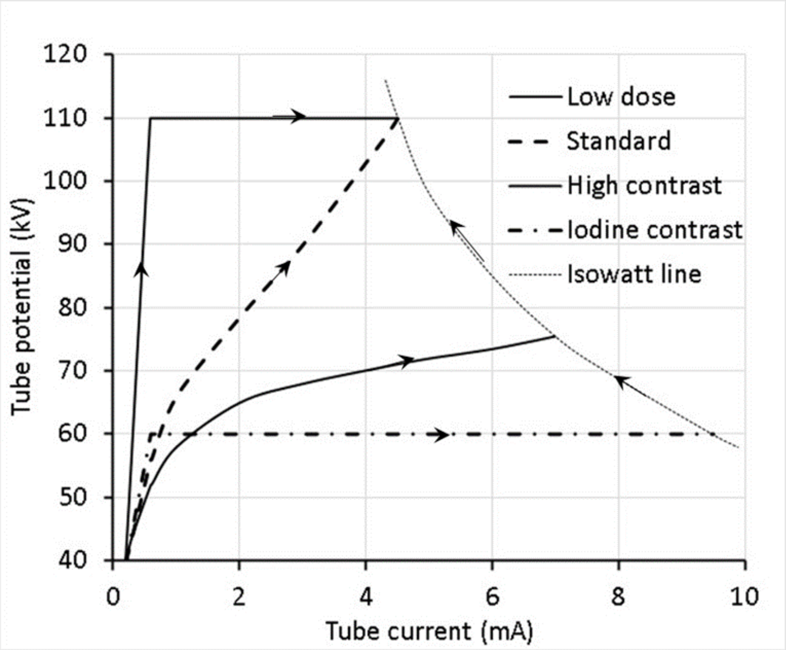
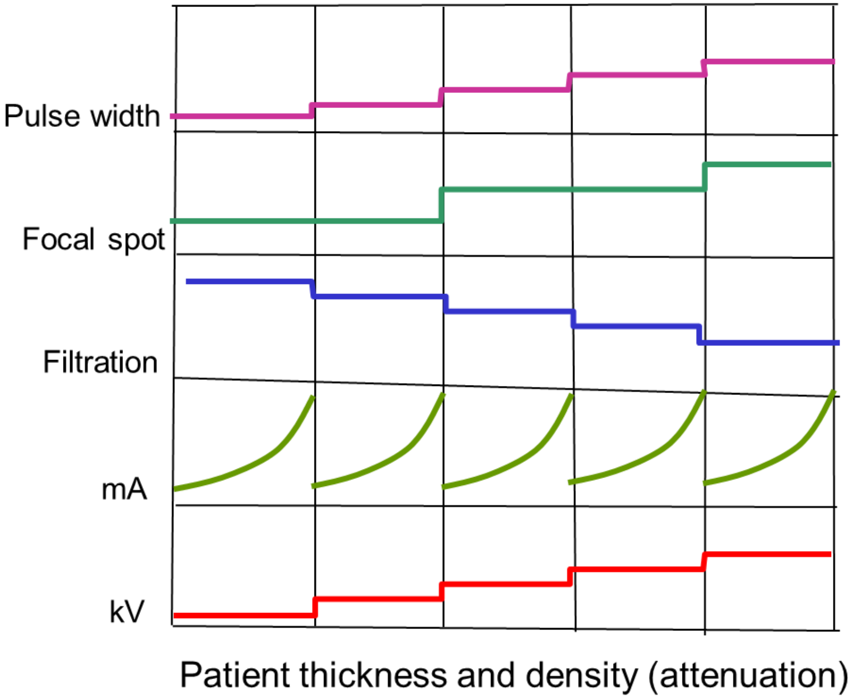
Fluoroscopy system features

- **Automatic dose rate control (ADRC):** automatically adjusts exposure parameters and IAK rate to the image receptor, to deliver a constant signal intensity at the image receptor, resulting in constant image brightness and SNR at the display despite body habitus

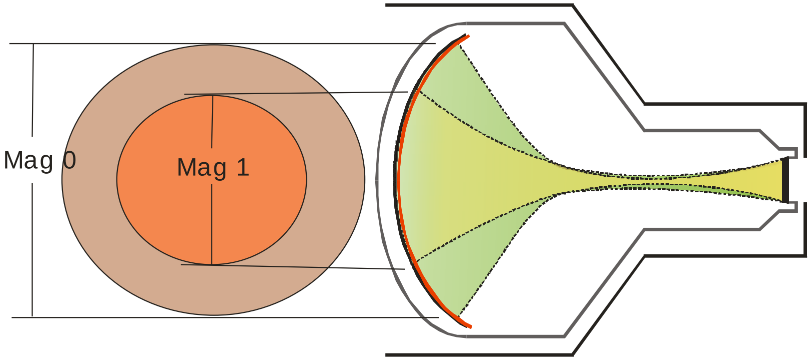


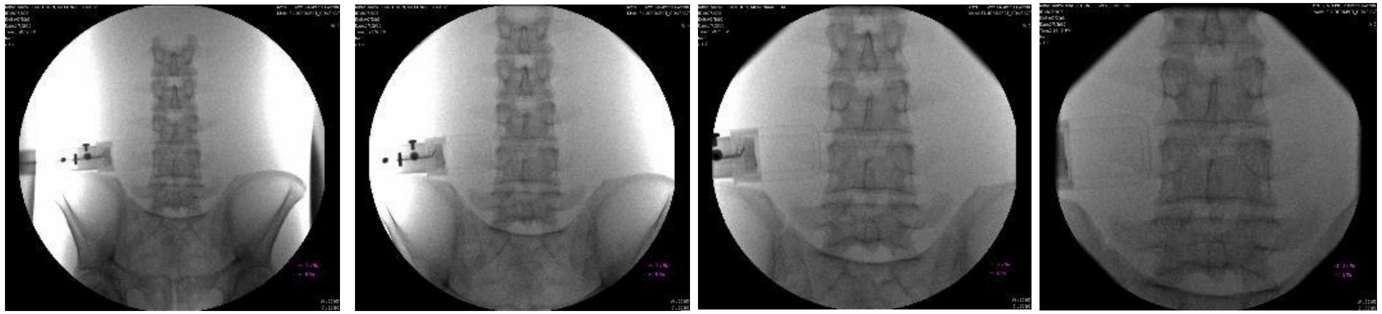


Operator-selectable fluoroscopy modes using different logics

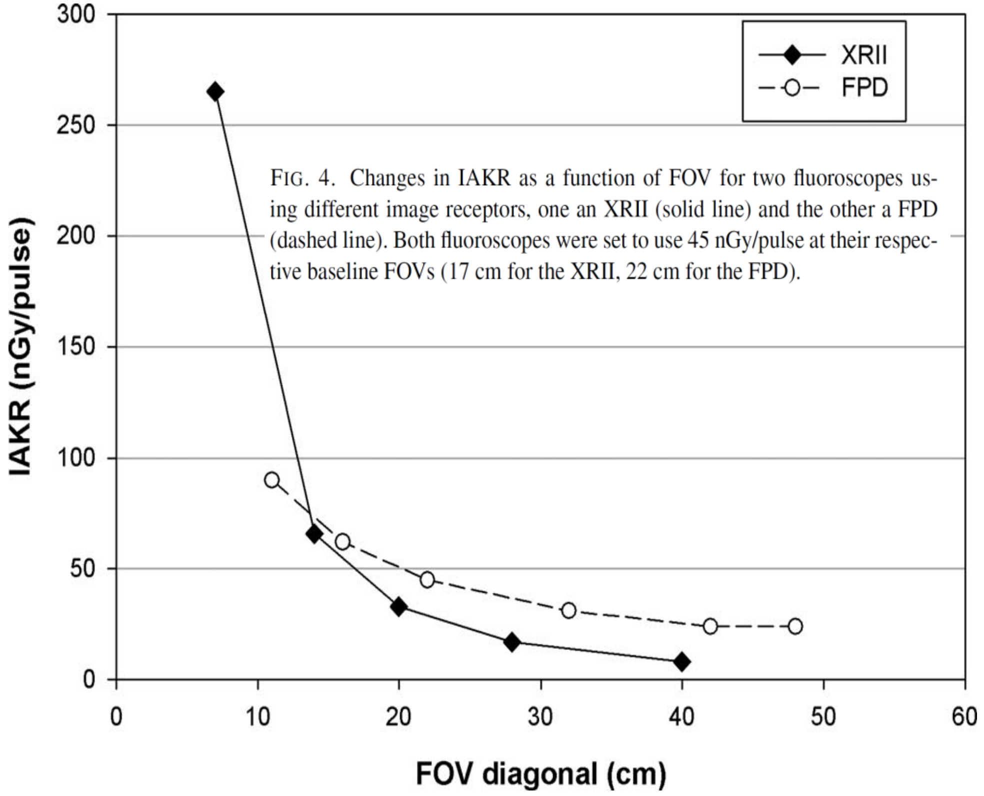
Fluoroscopy system features

- **Electronic magnification (“zoom”; “mag”)**





40 cm FOV,	33 cm FOV,	23 cm FOV,	17 cm FOV,
1 dose unit	1.46 dose units	3.0 dose units	5.5 dose units

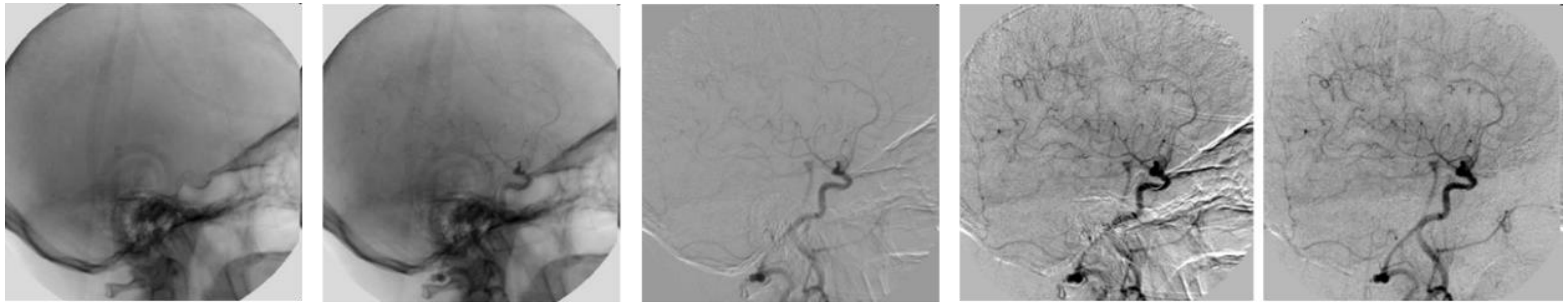


Jones et al., Medical imaging using ionizing radiation: Optimization of dose and image quality in fluoroscopy, Med Phys 2014

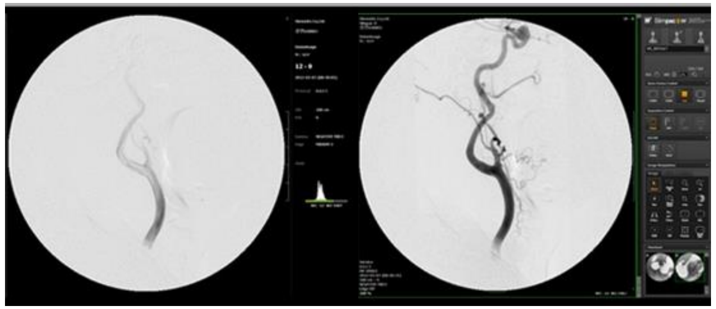
The actual relationship of IAK rate and FOV is vendor dependent and should be checked at commissioning

Fluoroscopy system features

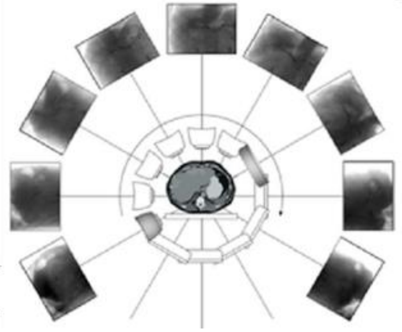
- **Digital subtraction angiography (DSA):** improve visualization of fine vessels by removing of the background tissue

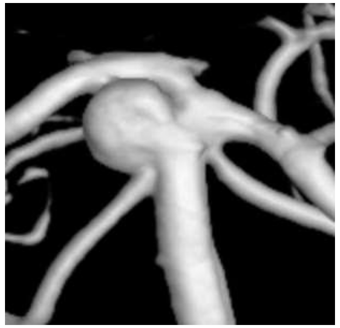


- **Road mapping:** facilitates placement of catheters and wires in small vessels and complex vasculature



- **Rotational angiography (CBCT):** to map vascular anatomy, plan complex interventions; Increasingly used to guide surgical interventions

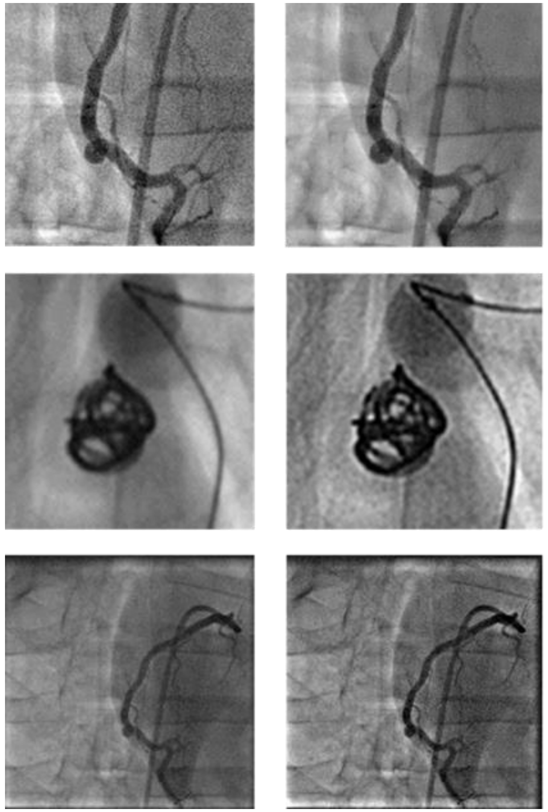




Fluoroscopy system features

- **Image processing algorithms:**
  fast image enhancement and increased perceptibility of clinically important information: Automatic and operator-controlled

  - Spatial noise reduction (averaging with neighboring pixels);
  - Temporal noise reduction (averaging with previous frames);
  - Edge enhancement,
  - Contrast enhancement

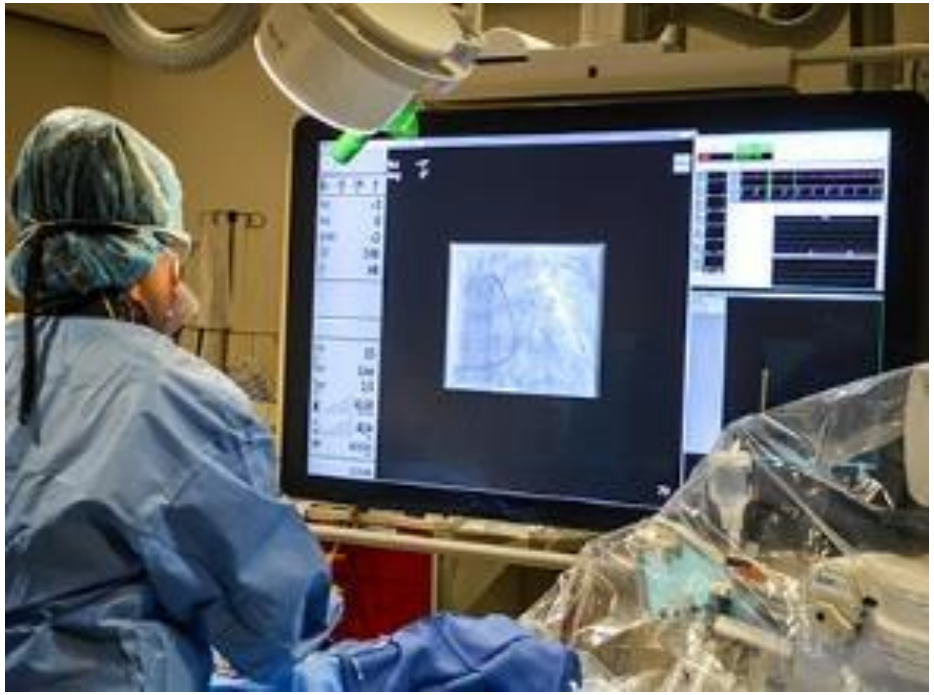


Courtesy A. Trianni

Fluoroscopy system features

- **Image display monitors:**
  -important role in the visual perception of the images
  -indirect impact on the patient and consequently staff dose

Large (e.g.60'') monitor: reduced need for magnification mode ⇨ **lower patient/staff dose**



Images from S. Balter, Medical Physics International, 2019

System configuration

- **Vendor pre-configured examination and patient specific technical sets**
  - Set of exposure technique factors:

    beam filters for fluoroscopy and radiography; focal spot size, pulse rate for fluoroscopy mode; frame rate for radiography mode, DSA and CBCT modes, maximum pulse width, dose to the image receptor, ADRC algorithm and parameters to be changed by AEC
  - Set of image processing parameters:

    spatial noise reduction; temporal noise reduction; automatic live motion compensation; edge enhancement, contrast enhancement, and other vendor-specific parameters.

- **Adjustable to the local practice and user preferences**
  - vendor representative (application specialist) or a local super user,
  - in collaboration with the hospital medical physicists and experienced representatives of the clinical staff

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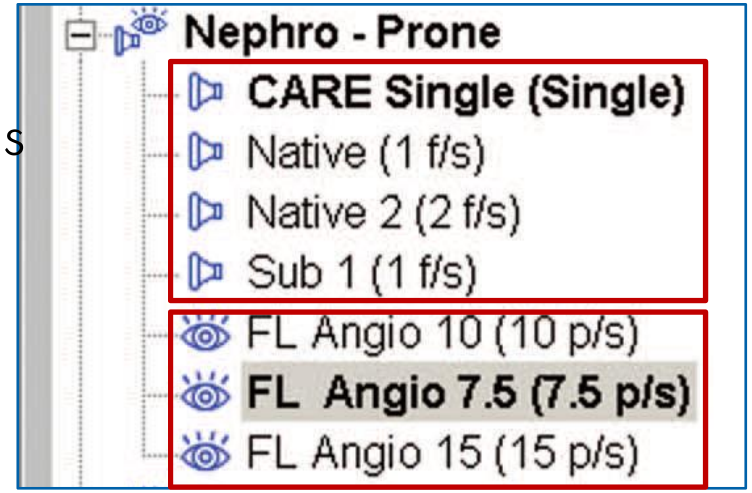
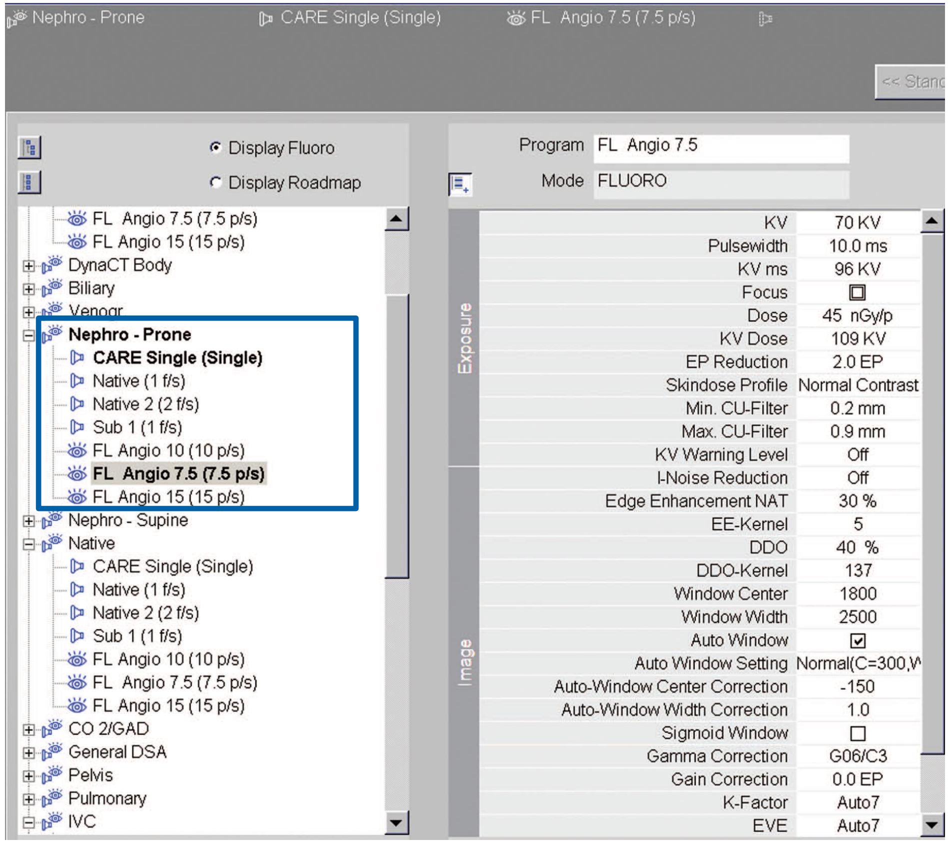
System configuration

- **Protocol configuration and optimisation**
  -Includes proper adjustment of settings customised to the required image quality and dose saving needs for the clinical task.
  -cardiac, neuro, vascular, pediatric,
  -fluoroscopy, cine, DSA, Road mapping, CBCT

Example:
Nephrostomy exam pre-sets
(Siemens interface)





Jones et al., Medical imaging using ionizing radiation: Optimization of dose and image quality in fluoroscopy, Med Phys 2014

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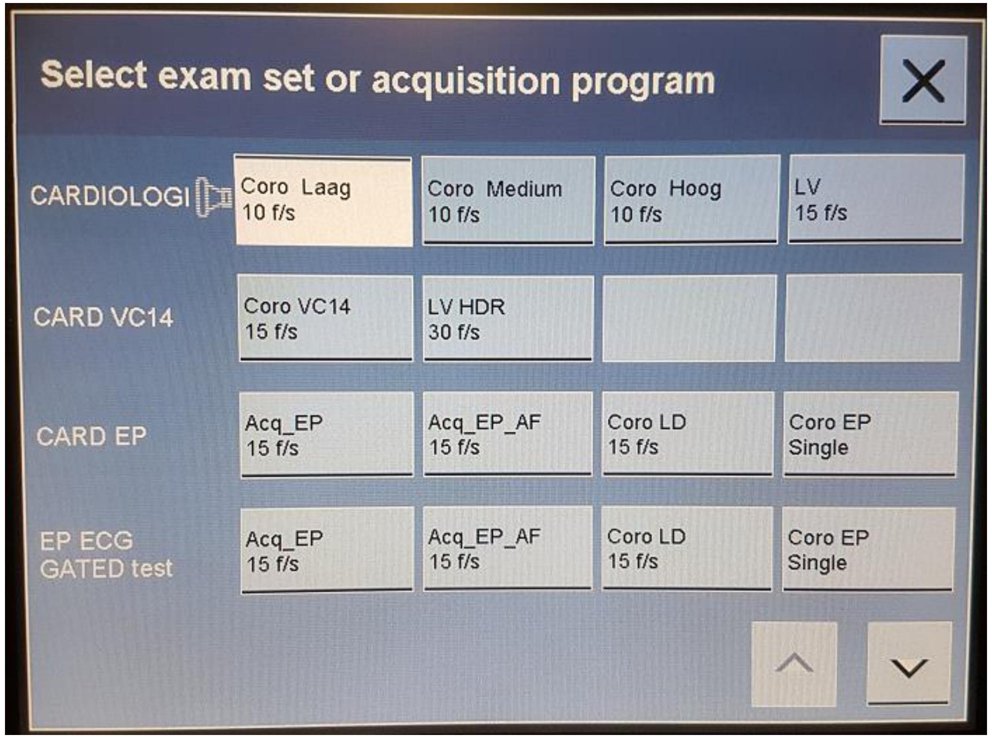
System configuration

- **Protocol configuration and optimisation**
  -Includes proper adjustment of settings customised to the required image quality and dose saving needs for the clinical task.

! **Requires clear understanding of the system features, functions, programme architecture, as well as the clinical requirements and operators' preferences.**



System commissioning

- **Equipment commissioning**
  - Confirmation of equipment function,
  - Checking acceptable values have been set for the default acquisition programmes
  - Establishing baseline values of equipment performance in terms of image quality and dose parameters, using standard phantoms and test objects, and representing a range of patient sizes

  Performed by medical physicists

  Necessary adjustments made in collaboration with the equipment vendor representative and clinical staff.

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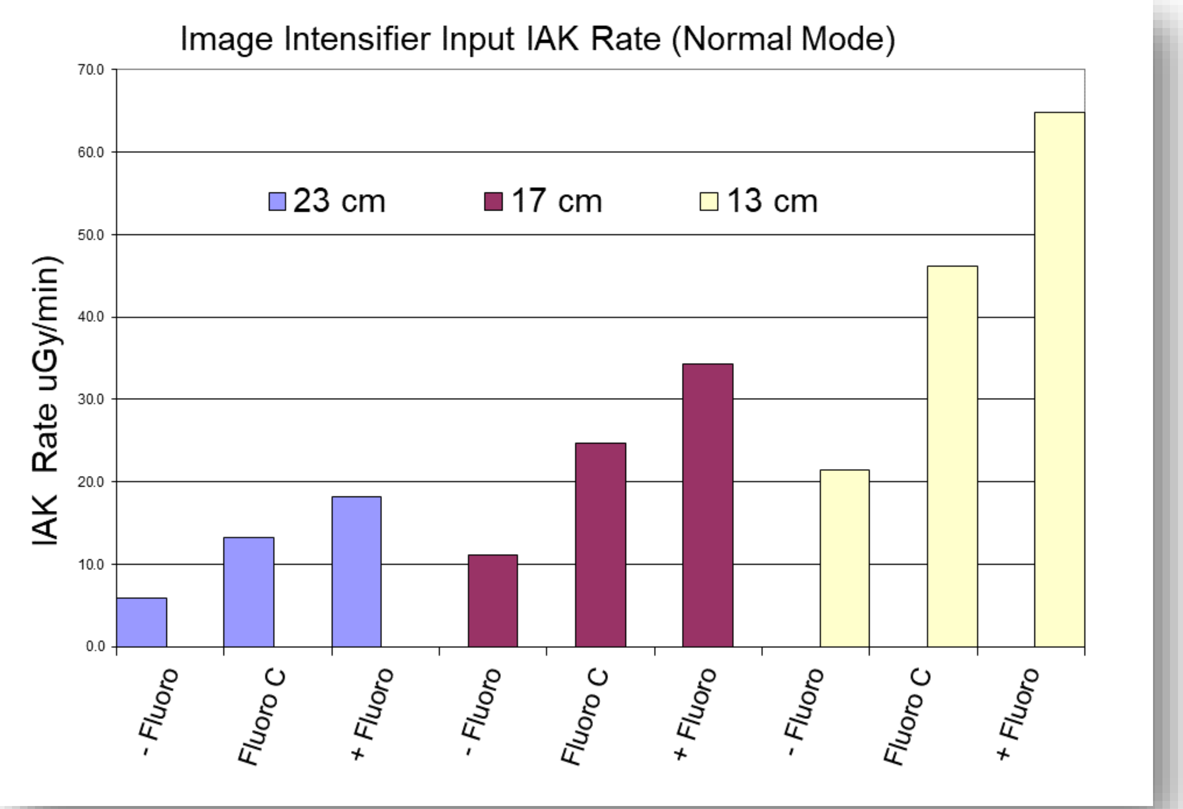
System commissioning

- **Testing and adjustment of ADRC settings for different modes and anatomical/clinical programmes**
  - Setting baseline values of the IAK rate at the image receptor
    - in fluoroscopy and radiography
    - for different dose modes,
    - for different pulse rates
    - for different FOVs



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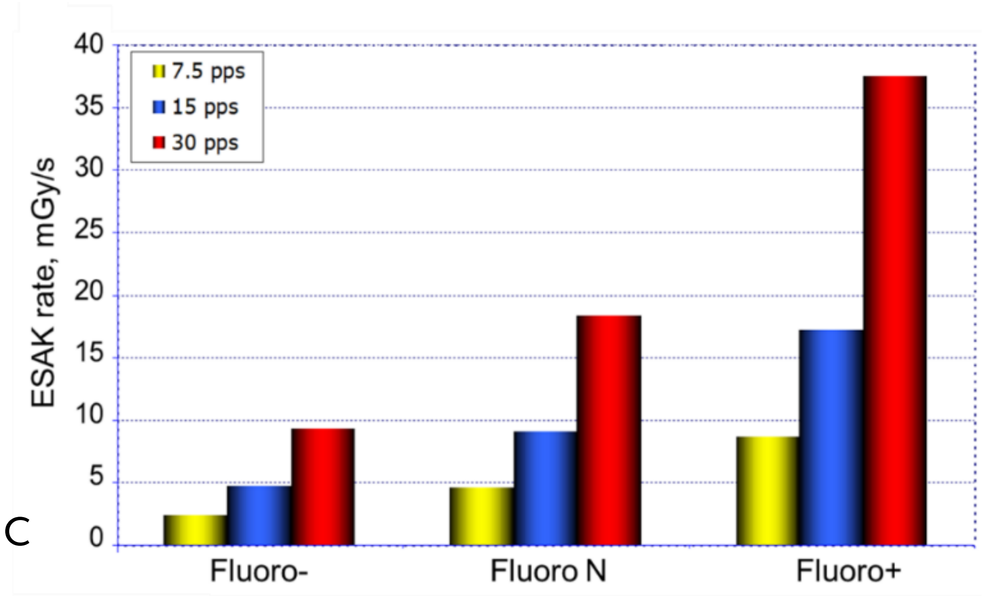
System commissioning

- **Testing and adjustment of ADRC settings for different modes and anatomical/clinical programmes**
  - Setting baseline values of the patient's ESAK rate
  - Compliance with regulatory limits

    Examples:
    U.S. FDA: nominal limits:
    88 mGy/min for normal fluoroscopy mode
    176 mGy/min high-dose control mode

    Europe, EC RP 162: suspension level
    100 mGy/min for normal fluoroscopy mode
    2 mGy/frame for normal digital fluorographic acquisition mode
    0.2 mGy/frame for the cardiac mode



QC programme

- To evaluate performance of all exposure modes relating to selection of options that are optimal for specific imaging tasks

Elements of QC programme	Parameters to be measured
X-ray source assembly	Accuracy and reproducibility of the tube voltage Half- value- layer (HVL) Reproducibility and linearity of the tube output Tube leakage
Collimation and radiation field alignment	Alignment and collimation of the radiation field to the image receptor
ADRC settings and performance	IAK rate at the image receptor and patient ESAK rate for most commonly used modes and programmes
Integrated radiation dose displays	Verification of calibration of KAP meter Verification of displayed KAP and reference air kerma Correction factors for use with RDSR when function is available
Image quality	Noise level Low contrast detectability High contrast detectability Image distortion and artefacts
Cone Beam CT (CBCT) mode if available	Dose parameters Geometry characteristics Image quality

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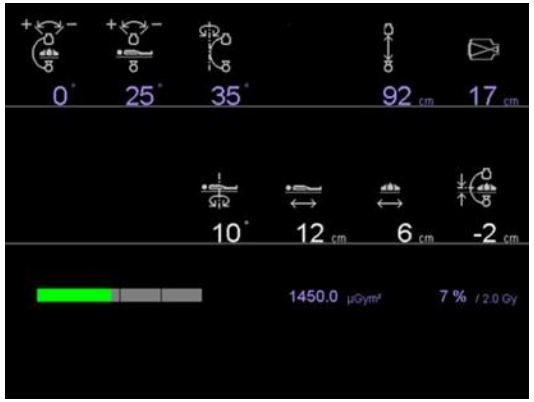
QC programme

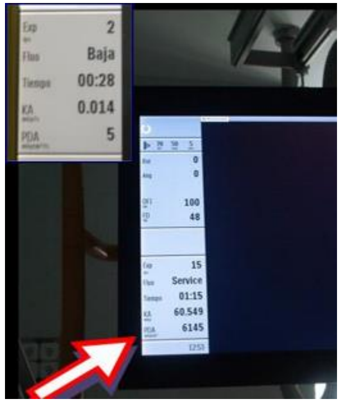
- **QC developments**
  - More realistic test objects (task-based model observer evaluations of system imaging performance)
  - User Quality Control Mode (UQCM) for interventional procedures

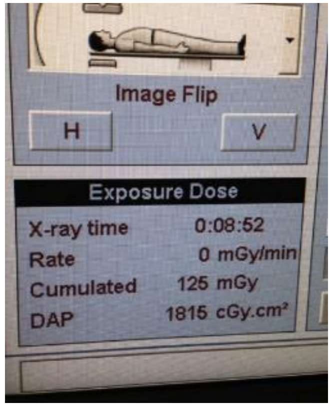
more comprehensive physical tests in routine QC

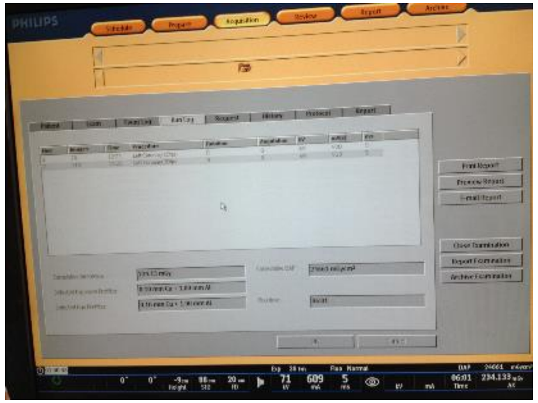
Dose monitoring

- **Dose index display** (IEC 60601-2-43)
  - Reference air kerma $K_{a,r}$ rate and cumulated reference air kerma $CK_{a,r}$;
  - Air kerma area product P_{KA} (KAP) rate and cumulated KAP









- **Dose index export**
  - Export of their cumulated values at the end of procedure in a proper digital format to the procedure report: DICOM RDSR; PRDSR

DICOM 2005, DICOM 2009, IEC 60601-2-43; IEC 61910-1

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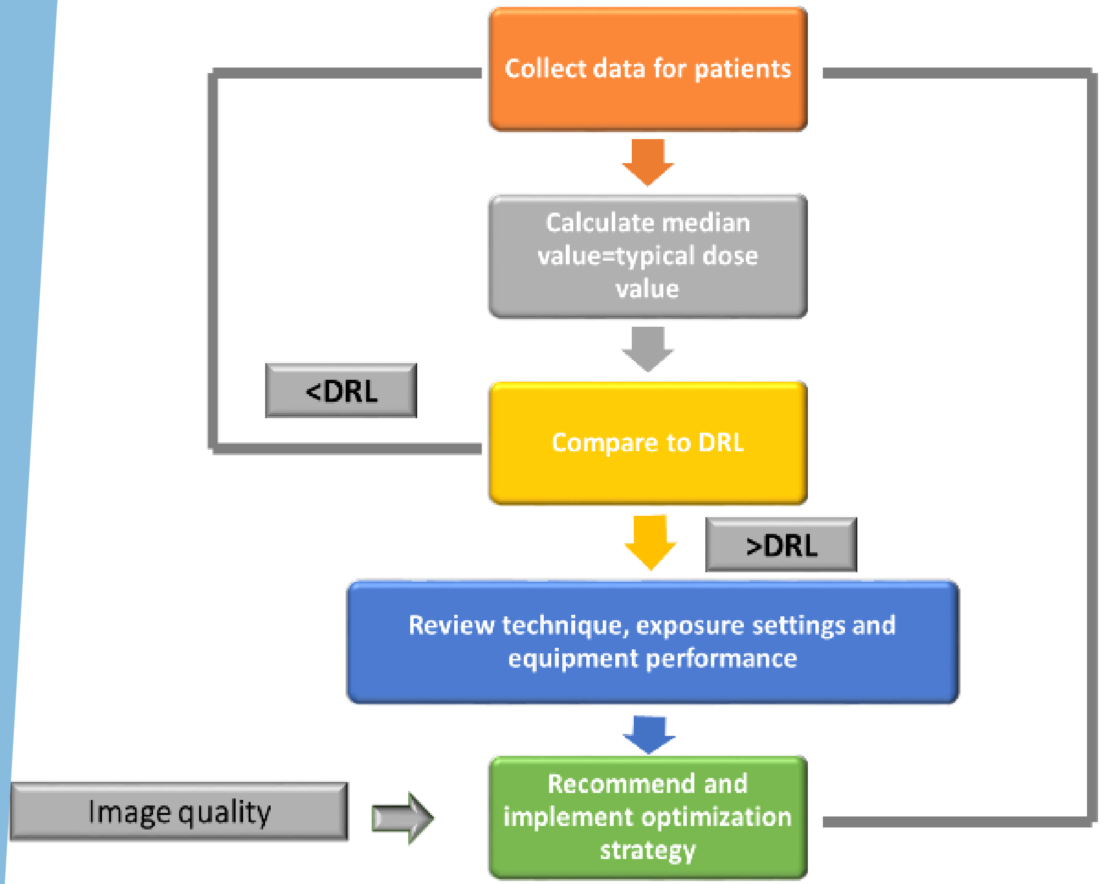
DRLs and patient dose audits

- **Setting and using Diagnostic Reference Levels for optimization**



Challenges for FGI procedures:

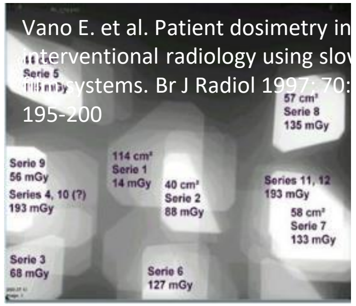
- Therapeutic, not diagnostic procedures
- Vary by severity, complexity and site
- Wide distribution of doses for a given procedure

ICRP Publication 135 recommends:

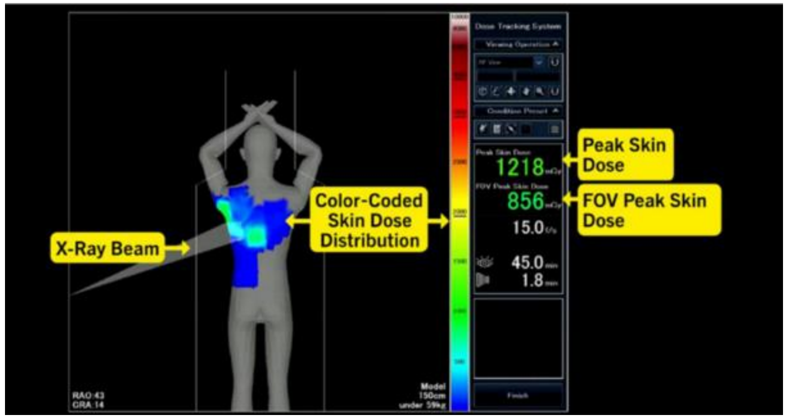
- Keeping the term DRL for FGI procedures
- KAP, reference air kerma, fluoroscopy time and number of radiographic images
- At least 30 patients for diagnostic fluoroscopy and more (all) patients for FGI procedures
- Determine DRLs based on procedure complexity (*Balter et al., 2008; IAEA, 2009*) or utilise the concept of Advisory Data sets (*Miller et al, 2012*).

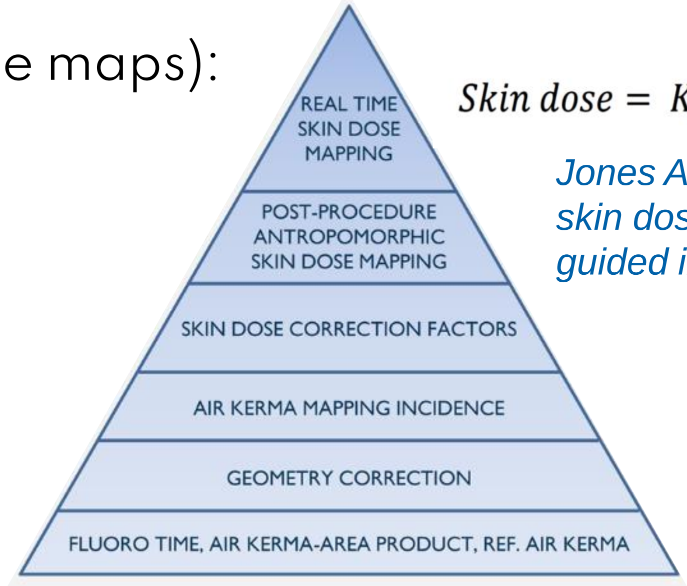
Skin dose monitoring and alert levels

- **Dose monitoring for management of tissue reactions**
  - Skin dose distribution and Peak skin dose (PSD)
    - Measured



- Calculated (color-coded skin dose maps): post-procedure or real time





$$Skin\ dose = K_{a,r} \times CF \times Att \times BSF \times \left(\frac{d_{ref}}{d_{perp}}\right)^2 \times f_{skin}$$

Jones AK and Pasciak A; Calculating the peak skin dose resulting from fluoroscopically guided interventions. Part I: Methods; 2011

Courtesy A. Trianni

Skin dose monitoring and alert levels

- **Dose monitoring throughout a complex FGI procedure:**
  - Automatic alerts, or notification by a designated staff member

Dose parameter	First notification level	Subsequent notification level (increments)
Peak skin dose	2 Gy	0.5 Gy
Cumulated incident air kerma at the interventional reference point	3 Gy	1 Gy
Cumulated air kerma area product	300 Gy cm^{2*}	100 Gy cm^{2*}
Fluoroscopy time	30 min	15 min

Stecker MS, et al. Guidelines for patient radiation dose management. J Vasc Interv Radiol. 2009 Jul;20(7 Suppl): S263-73.

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Skin dose monitoring and alert levels

- **After a complex procedure: dose recording and patient follow-up**

IAEA trigger levels to detect clinically relevant tissue reactions (2022)

Dose indicators listed in order of their value for the likelihood of tissue reactions

Peak skin dose ($D_{skin,max}$)	**3 Gy**
Reference air kerma (Cumulative dose) ($K_{a,r}$)	**5 Gy**
Air kerma-area product (dose-area product) (P_{KA})	500 $Gy.cm^2$
Fluoroscopy time	60 min
Multiple fluoroscopy-guided interventional procedures within 1 month	

https://www.iaea.org/resources/rpop/resources/safety-in-fgi-procedures

Optimal procedure performance

Optimal procedure performance

- **Before the procedure (especially a complex FGI)**
  - Review patient medical and radiation history, including previous images
  - Standard policy for assessing pregnancy
  - Standard checklist to identify patient at higher risk for skin injury (BMI>30, sensitive skin; patient with recent FGI procedure
  - Guidelines on methods for reducing risk of skin injury
  - Guidelines for performing FGI procedures during pregnancy
  - Written form to educate patient and obtain consent

Box 3.6. Example of language for informed consent for radiation risks before a scheduled complex and potentially high dose interventional procedure (adapted from Stecker et al. (2009))

You have been scheduled for an interventional [fluoroscopy-guided] procedure. This involves the use of x-rays for imaging during the procedure and documenting the results. Because of the nature of the planned procedure, it is possible that we will have to use significant amounts of radiation. Potential radiation risks to you include:

- A slightly elevated risk of cancer later in life, not starting until several years after the procedure. This risk is very low in comparison to the normal incidence of human cancer.
- Depending on the complexity of the procedure, a substantial amount of radiation may occasionally need to be used. This could carry a risk of temporary skin injury or hair loss, but any more severe radiation effect is very unlikely.

You (or your family) will be advised if substantial amounts of radiation were used during the procedure. If this has occurred, you will be given written instructions requesting that a family member checks the area of skin irradiated during the next 30 days for any redness or other sign of injury.

Sign and date here______________ witness (physician)______________ date_____

Optimal procedure performance

- **During the procedure**
  - **Clearly pre-defined responsibilities of all team members**
    - Main operator – primary responsibility for the procedure outcome and for the patient and staff safety
    - Operation of equipment control: dedicated or a physician (operator or other)
    - Proper positioning of the protection screens: nurse or radiographer
    - Monitoring dose factors and notifying the operator if alerts are reached.
    - All other functions… .
  - **Patient cooperation/ immobilisation**
  - **Pre-procedure time-out**

Well trained team on methods for dose reduction for patient and staff

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Optimal procedure performance

- **After the procedure**
  - **Produce radiation dose report and archive in the departmental and patient medical records**
    - Dose monitoring software facilitates the process
  - **Patient follow-up procedure for high dose procedures**
    - Standard form to record information
    - Patient discharge instructions
    - Follow up approximately 30 days post procedure

Box 3.8 Example of post-procedure patient discharge instructions for high dose interventional procedures (adapted from Stecker et al. (2009))

X-Ray usage - one of these two boxes is checked as part of the discharge instruction process:

- Your procedure was completed without the use of substantial amounts of x-rays. No special follow-up is needed because radiation side effects are highly unlikely.
- Your procedure required the use of substantial amounts of x-rays. Radiation side-effects are unlikely but possible. Please have a family member or carer inspect your (back/neck/scalp/…..) 30 days from today, for signs of skin redness or rash . Please call ####### and tell us whether or not anything is seen.

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IAEA resources

Home / Resources / Radiation Protection of Patients / Resources / Databases and Learning Systems

Safety in Radiological Procedures (SAFRAD)

Resources

- RPOP Home
- International Safety Standards
- Publications
- Posters and leaflets
- Bonn Call for Action platform
- Smart Card
- Recurrent imaging
- RELID Study
- Training material
- Webinars
- Online Training
- Databases and Learning Systems
  - SAFRON
  - SAFRAD
  - ISEMIR-IC

SAFRAD (SAFety in RADiological procedures) is a voluntary reporting system aiming to sustain a database of comprehensive data such as patient's dose report and other relevant data when these patients are submitted to defined trigger levels or events in fluoroscopically-guided diagnostic and interventional procedures. The primary objective of the system is educational. It is believed that going through the process of SAFRAD itself results in safety and quality of service.

All data furnished by participants (hospitals, regulators) will remain accessible to the participant. The participant will have access periodically to analysed results. The IAEA will publish overall summary reports of SAFRAD data from time to time. SAFRAD will not supply identifiable data to any governmental authority or other third party.

» Introduction to the project
» How to use SAFRAD
» Guidelines and forms

How to use SAFRAD

Overview

SAFRAD website provides you with on-line forms to be filled in order to

Related resources

- Access SAFRAD
- SAFRAD new triggers

Guidelines and forms

Download:

- Guidelines for the interventionalist
- Guidelines for the treating physician
- Instructions for the coordinator
- Patient information leaflet
- Patient data collection form

https://www.iaea.org/resources/rpop/resources/databases-and-learning-systems/safrad

IAEA resources

- **IAEA training material**

Cardiology

Lectures →

Lectures (Russian) →

Lectures:

01. Why talk about radiation protection in cardiology?
02. Talking about radiation dose
03. What radiation effects are possible? (besides skin injuries)
04. X ray production and angiography equipment
05. Patient dose management: Part 1-2
06. Standards and guidance
07. Occupational exposure and protective devices
08. Image quality in cardiac angiography
09. Optimization of radiation protection in cardiology
10. Radiation protection in paedriatic interventional cardiology
11. Cardiac CT - radiation doses, dose management and practical issues
12. Examples of Good & Bad Practice (physical factors): Part 1-2

Doctors using fluoroscopy outside radiology

Lectures →

Lectures (in Spanish) →

Lectures:

- 01. Overview of radiation protection
- 02. Understanding radiation units
- 03. What can radiation do?
- 04. Anatomy of fluoroscopy & CT Fluoroscopy Equipment
- 05. How do I reduce my radiation risk?
- 06A. Radiation protection for patients in orthopaedic surgery
- 06B. Radiation Exposure in Gastroenterology
- 06C. Other medical specialties that use fluoroscopy
- 07. International standards and recommendations

Diagnostic and interventional radiology

Lectures →

Exercises →

Lectures (in Spanish) →

Exercises (in Spanish) →

Lectures (in Russian) →

Exercises (in Russian) →

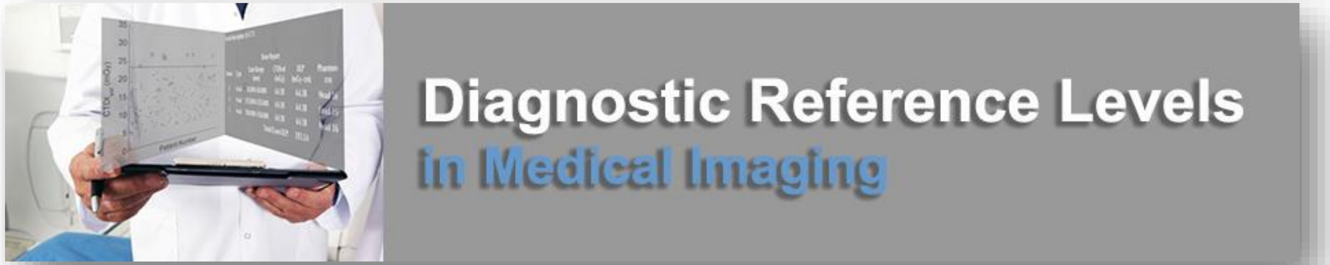
https://www.iaea.org/resources/rpop/resources/training-material

IAEA resources

- **E-learning**

- 13 short practical tutorials, 4-8 minutes each with interactive videos
- To learn effect of various factors on patient and staff dose

Based on 6 webinars prior 2019



13 modules
Module on fluoscopy&FGI procedures

https://www.iaea.org/resources/rpop/resources/online-training

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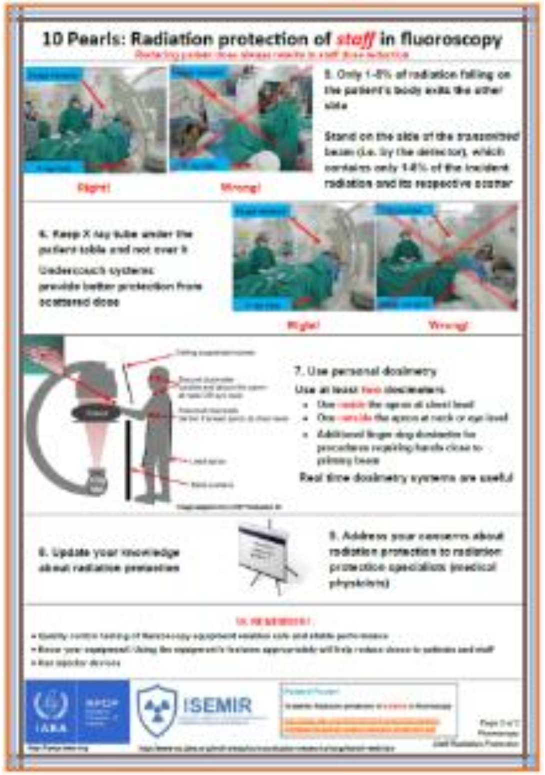
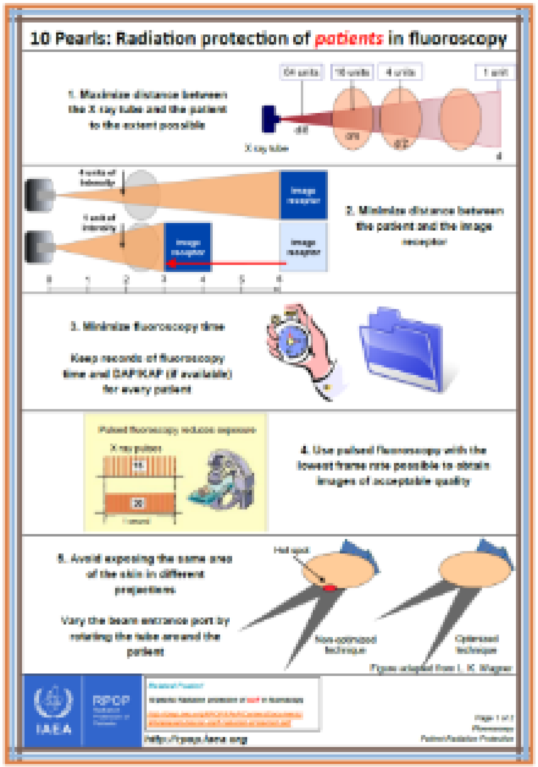
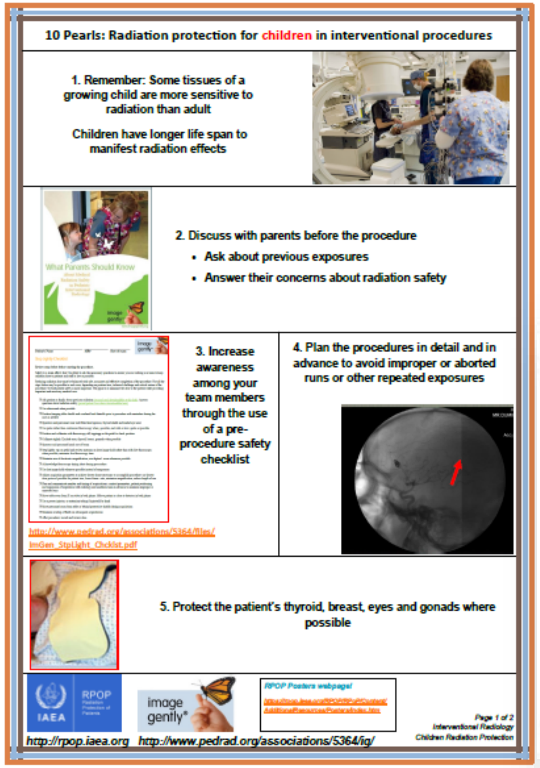
IAEA resources

- **Posters**

"Ten pearls" posters to remind staff on approaches to optimize procedures







Available in 30 languages

https://www.iaea.org/resources/rpop/resources/posters-and-leaflets

Summary: QA programme

The complexity of the Dose Management QA programme and the level of performance and optimisation will depend on the arrangements that are in place for each of the aspects:

- professional skills and collaboration;
- methodology and technology,
- organisational processes and documentation.

Summary: QA programme

- Equipment selection
- Facility design
- Equipment maintenance
- QC tests
- Image quality and procedure evaluation
- Availability of radiological protection tools, dosimeters and their use
- Availability of adequate personnel and their responsibilities
- Patient and staff dose monitoring and dose audit
- Clinical follow-up for high patient radiation doses
- Reporting and QA for unintended or accidental exposures
- Training in radiological protection (initial and continuing), including training in ethics, teamwork, safety culture, communication

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