Steps To Manage Radiation Dose and Possible Tissue Effects After a Fluoroscopic Procedure
The goal of this module is to inform the medical imaging team member about factors that affect the child's radiation dose during the procedure and offer suggestions for providing appropriate care after the examination. The module discusses relationships of radiation doses, air kerma and kerma area product (KAP) to tissue effects and stochastic risks. To predict the probability of tissue effects or stochastic risks after the completion of the examination, the module provides methods to estimate cumulative skin dose or peak skin dose. Finally, this module explains the documentation of radiation dose estimates and care of the child in an effort to improve quality and safety for the pediatric patient.
Authors:

Keith J. Strauss, MSc, FAAPM, FACR
Cincinnati Children’s Hospital Medical Center

Marilyn J. Goske, MD, FACR, FAAP
Cincinnati Children’s Hospital Medical Center

Tracy Herrmann, MEd, R.T. (R)
University of Cincinnati, Blue Ash College
Learning Objectives:
1. Describe radiation dose index quantities displayed on the fluoroscope used to quantify radiation production during an examination.
2. Discuss the fundamental steps required to estimate patient doses from displayed radiation dose indices.
3. Identify institutional team efforts that properly manage appropriate follow-up for patients who have received large radiation doses.

After completion of this module the participant will be able to:

1) Describe radiation dose index quantities displayed on the fluoroscope used to quantify radiation production during an examination.
2) Discuss fundamental steps required to estimate patient doses from displayed radiation dose indices.
3) Identify institutional team efforts that properly manage appropriate follow-up for patients who have received large radiation doses.
Are tissue effects common after pediatric interventional fluoroscopic procedures?

- Tissue effects are uncommon after pediatric interventional procedures even though total procedure time for infants and toddlers can be much longer than for adults.
- Exposure rates for infants and toddlers are significantly lower than those for adults.

Tissue effects are uncommon after pediatric interventional procedures even though total procedure time for infants and toddlers can be much longer than for adults. Longer pediatric examinations are a result of the increased difficulty in performing these procedures on small patients with small organs. However, the radiation dose rate on a properly configured fluoroscope for children can be up to 10 to 20 times less for an infant compared to the radiation dose rate for an average adult-sized patient. This means that 10 to 20 times more fluoroscopic and radiographic images must be created of the infant to generate the radiation dose typically received by an adult-sized patient. This scenario is unlikely in pediatrics unless the interventional fluoroscopy case is extremely difficult and complex.
Why do we need an estimate of the peak skin dose for complex interventional procedures?

- Peak skin dose is the best predictor of tissue effects.
- The approximate threshold for skin erythema is 2,000 mGy.

A careful estimate of peak skin dose is important because it is the best predictor of tissue effects. If the estimated peak skin dose exceeds the threshold for skin erythema, the pediatric patient may exhibit this effect. The threshold for a given patient varies due to individual physiology, but it is approximately 2,000 mGy. If this level is reached, the patient and parents should be notified, as tissue effects may be painful or require treatment. Additional actions the medical imaging team can take will be discussed later in this section.
Since tissue effects are less likely in small children, why do their radiation doses need to be carefully managed?

- Some organs in children are more radiosensitive than those of adults.
- Leukemia, thyroid, skin and brain cancer are more likely in children due to their increased sensitivity than adults.

Radiation doses typically received by children should be carefully monitored because data suggest that stochastic injuries (i.e., cancer induction) can result from ionizing radiation. Leukemia, thyroid, skin, and brain cancer are more likely in children due to their increased sensitivity than adults.

More recent data from the Japanese atomic bomb survivors indicate that adults are also radiosensitive and that for lung cancer, for example, adults may be more sensitive than children to the stochastic effects of radiation.
What is the displayed air kerma?

- Displayed air kerma values on fluoroscopic equipment are for a specific location from the focal spot.
- This location is typically at the patient entrance reference point.
- A QMP can assist with determining the location.

The value of air kerma displayed by the fluoroscope at the end of the procedure is sometimes called the cumulative air kerma. Recall that air kerma quantifies the amount of radiation that reaches the entrance plane of the patient. One manufacturer labels its display of cumulative air kerma as "K" as shown in this figure. Air kerma is not the dose to the patient despite the fact that it uses the same unit of measure (mGy). Air kerma obeys the inverse-square law as discussed in Module 1. Displayed air kerma values on fluoroscopic equipment are for a specific location from the focal spot, typically at the patient entrance reference point. Your QMP can assist with determining this location.
What is the displayed kerma area product (KAP)?

KAP:

- Is equal to the total air kerma multiplied by the area of the x-ray beam at the entrance plane of the patient.
- Tracks changes in radiation output of the fluoroscope and area of the x-ray field.
- Is correct regardless of SSD, or distance from the focal spot.

The KAP displayed by the fluoroscope is the total air kerma multiplied by the area of the x-ray beam at the entrance plane of the patient. KAP tracks changes in both the radiation output of the fluoroscope and the area of the x-ray field. Unlike air kerma, KAP is correct regardless of the SSD, or distance from the focal spot. Older fluoroscopes may label the displayed KAP as dose area product or DAP as shown in the figure, but KAP is the current preferred term.
KAP may be expressed in μGy m². Unfortunately, all manufacturers do not use the same units for KAP. One manufacturer may use cGy cm², which has the same numerical value as KAP expressed in units of μGy m². Another manufacturer may use units of mGy cm², which results in a numerical value that is 10 times larger. The radiologic technologist must be aware of the units used to display KAP, especially if multiple vendors have supplied the fluoroscopes in a given department.
What types of information are displayed on state-of-the-art fluoroscopes to assist with the estimation of patient dose?

Three numbers are typically displayed:

- Cumulative air kerma.
- Kerma area product.
- Fluoroscopy time of the procedure.

Three numbers are typically displayed on the fluoroscopic tower as shown in this figure. They indicate the radiation administered during the procedure up to that point. In this example, 7.12 mGy, is the estimated cumulative air kerma. Note that the display incorrectly labels this quantity as accumulated skin dose. The second number, 101.50 μGy\text{m}^2, is the kerma-area product, labeled here as DAP, or dose area product. The final number, 2.27 min, is the fluoroscopy time of the procedure.
How should this information be transferred to the patient’s medical record?

Displayed values are estimates and should be recorded as follows:

- Air kerma = 7.1 mGy (1 decimal place).
- KAP = 102 μGy·m² (rounded whole number).
- Fluoroscopy time = 2.2 min. (1 decimal place).

All of these values, air kerma, KAP and fluoroscopy time, are estimates. The values displayed on the fluoroscope suggest that the values are accurate up to two decimal places, but this is incorrect. The recorded dose estimates in this image should be recorded as follows:

Air kerma = 7.1 mGy (1 decimal place)

KAP = 102 μGy·m² (rounded whole number)

Fluoroscopy time = 2.2 min (1 decimal place)
How accurate are displayed KAP and air kerma values?

- Displayed air kerma or KAP may contain errors as great as ± 35%.
- Displayed values should be calibrated by a qualified medical physicist (QMP).
- With a QMP-provided correction factor, display reading accuracy can increase to ± 10%.

The displayed air kerma or KAP values may contain accuracy errors as great as plus or minus 35% by current standards. Prior to using these displayed values for estimating patient doses, the displayed values should be calibrated by a qualified medical physicist (QMP) using a calibrated dosimeter. Some manufacturers allow the calibration of their displayed values to be corrected in the field by service representatives, while other manufacturers do not. In either case, the QMP should provide a correction factor that can be applied to the displayed value to obtain a reading accurate to plus or minus 10%. The error bars in the figure for a value of air kerma of 1,000 mGy are shown for plus or minus 35% and plus or minus 10%. Clearly, the displayed value should be calibrated by a QMP to reduce the uncertainty in the displayed indices used to estimate patient dose.
Does the displayed KAP need correction as a function of pediatric patient size in addition to the calibration previously described?

- KAP does not need an additional correction as a function of patient size.
- The displayed KAP value is independent of the SSD, which is affected by patient size.

Other than the calibration factor provided by the QMP, the displayed KAP does not need additional correction as a function of pediatric patient size, which affects the source-to-skin distance (SSD). The displayed KAP value is independent of the SSD during the examination.
The displayed air kerma value does not need correction as a function of pediatric patient size if one is using a general (GI) fluoroscopic table. However, if the fluoroscope is a C-arm unit, the displayed air kerma value does need this type of correction. Radiologic technologists should discuss the appropriate corrections for their fluoroscopes with the QMP. While the displayed air kerma calibrated to within plus or minus 10% by a QMP reasonably approximates the entrance skin dose for the adult abdomen, the calibrated, displayed air kerma for a properly positioned newborn abdomen can exceed the actual entrance plane air kerma by as much as 30% for either an interventional fluoroscope or a mobile C-arm unit. The differences are due to the location of the air kerma measurement point in space (the patient entrance reference point) on different kinds of fluoroscopes.
How does one estimate the peak skin dose from the calibrated air kerma?

- Air kerma calibrated by QMP is affected by:
  - Patient position relative to the patient entrance reference point.
  - The number of skin ports used.
  - How the ports are distributed over the patient’s skin.
  - How much the ports overlap.
- QMP analysis of exposed Gafchromic film allows estimation of peak skin dose.

Peak skin dose relative to the air kerma calibrated by the QMP is affected by the position of the patient relative to the patient entrance reference point, the number of skin ports used, how they are distributed over the patient’s skin, and how much they overlap. Well-collimated individual skin ports can minimize the overlap. Gafchromic film is placed on the table top under the patient’s back in this figure prior to positioning the patient during representative clinical procedures to evaluate the overlap of the skin ports. The resultant film, shown in the insert at the upper right, demonstrates the distribution of skin ports and the overlap illustrated in the insert; color changes in the film provide an estimate of skin dose. These can be viewed at the end of the examination. The QMP can estimate peak skin dose with careful analysis of the film. This estimate can then be compared to the displayed, calibrated cumulative air kerma to determine a conversion factor for typical cases of the procedure.
Is there a more direct way to estimate peak skin dose from cumulative dose metrics?

- The film method is an approximation providing information after the procedure.
- Fluoroscope manufacturers are working to develop real-time peak skin dose mapping.

While the film method approximates the skin dose, it is not a practical solution for individual patients because it is labor intensive and only provides information after the termination of the procedure. However, this type of analysis on a few representative patients allows the QMP to make more accurate estimates of peak dose from the cumulative dose for all patients. Fluoroscope manufacturers are developing the real-time ability to map peak skin dose during a procedure to assist with the management of skin dose while the examination is in progress.
Is fluoroscopy time a reasonable parameter from which to estimate patient dose during pediatric fluoroscopic procedures?

- Fluoroscopy time is **not** a reasonable parameter to estimate patient dose during pediatric fluoroscopic procedures.
- The QMP can estimate patient dose with more information from fluoroscopy time if the technologist can provide additional information about the examination.

Recall that fluoroscopy time is not a reasonable parameter from which to estimate patient dose during pediatric fluoroscopic procedures. However, older fluoroscopes may not display KAP or air kerma at the end of an examination. In this instance, your QMP should be able to make a rough estimate of patient dose from fluoroscopy time provided the QMP knows the patient thickness, measured radiation output rates of the fluoroscope as a function of patient size and the number of radiographic images obtained during the procedure.
How is an estimate of KAP at the end of a case helpful?

- The calibrated KAP is an indicator of the risk of stochastic effects.
- KAP measurements incorporate the effects of both radiation dose and the area of the x-ray beam.

While the peak skin dose is a better indicator of the probability of tissue effects, the corrected KAP is a better indicator of the risk of stochastic effects. If the entire x-ray beam enters the patient (which will occur if the beam is collimated appropriately), then KAP is a reasonable measure of the x-ray energy delivered to the patient. The radiation dose and the area of irradiated patient tissues affect the probability of a stochastic effect. KAP measurements incorporate the effects of both radiation dose and the area of the x-ray beam.
Why do some states require an estimate of patient dose at the completion of every interventional fluoroscopic procedure?

States require an estimate of patient dose:

- To ensure the qualified medical physicist and staff assisting in the procedure are aware when the potential for a tissue reaction exists.
- To ensure that patients or their parents are notified of the possibility of tissue injury.

Some states require an estimate of patient dose at the completion of every interventional fluoroscopic procedure to ensure that the QMP and staff assisting in the procedure are aware of the potential for a tissue reaction. If a tissue reaction is possible, the patient must be informed of this possibility and given instructions on what to do if an injury occurs. While it is not common, the peak skin dose during difficult, complex adult procedures can exceed the 2,000 mGy threshold value for skin erythema.
If the estimated peak skin dose suggests that a tissue effect could be expressed, what information should be given to patients or their parents?

- A discussion with the parent and patient should occur immediately after the procedure.
- Written instructions should include:
  - When to look for a tissue effect.
  - What to look for.
  - Where to look.
  - What number to call and actions to take if a tissue effect occurs.

A discussion with the parent, and possibly the pediatric patient, should occur immediately after the procedure if the estimated peak skin dose suggests that a tissue effect could be expressed. Written instructions should also be provided. Topics to discuss include:

1. When to look for a tissue effect. Tissue effects are not expressed immediately. An estimate of the time period, or latent period that must pass before skin reactions will become noticeable must be provided. This is typically 2 to 4 weeks depending on the estimated peak skin dose.

2. Patients should be told what to look for. Transient skin erythema (reddening) or alopecia (hair loss) are two types of tissue effects.

3. Tell patients where to look. The peak skin dose area should be predictable after the procedure is complete, and it should be shown to the parent and possibly the pediatric patient. This area is
based on the most frequently used projection(s) of x-rays through the patient's body and is usually on the patient's back.

4. Tell patients what number to call and what actions to take if a tissue effect occurs. At some centers, routine follow-up after the latent period with a physical exam is part of routine postprocedure care. At other centers, follow-up may only occur if initiated by the patient or parent.
Where should the estimate of the pediatric patient’s peak skin dose and KAP be archived?

- Peak skin dose estimates should be stored in the patient’s medical record.
- Automated methods for recording these values are under development.

Estimates of peak skin dose to the patient from fluoroscopic examinations should be stored in the patient’s medical record. Automated methods that transfer displayed values of air kerma and/or KAP at the end of a procedure to the patient’s medical record are under development and may become a new standard of patient care in the near future.
What is a patient dose database and how is it helpful?

- A single master dose database helps identify:
  - Patients who undergo frequent examinations.
  - Operators who deliver higher doses than their colleagues.
  - X-ray units that deliver elevated radiation doses.
- Monitoring should be part of a larger quality assurance effort in pediatric fluoroscopy.

Estimates of patient dose should also be automatically transferred to a single master dose database within the institution. This collective database helps identify pediatric patients who undergo frequent examinations, operators who deliver higher doses than their colleagues, an individual x-ray unit that delivers elevated radiation doses or other studies of interest. This type of monitoring should be part of a larger quality assurance effort in pediatric fluoroscopy.
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This concludes Image Gently: Steps To Manage Radiation Dose and Possible Tissue Effects After a Fluoroscopic Procedure. You should now be able to:

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Conclusion

This concludes our review of the care of the pediatric patient before, during and after a diagnostic or interventional fluoroscopic procedure.

Thank you for participating!

This concludes our review of the care of the pediatric patient before, during and after a diagnostic or interventional fluoroscopic procedure. Through this study of the more important technical aspects of ionizing radiation and its use in pediatric patients for diagnosis and treatment of disease, it is our hope that the best and safest care of children is realized. Thank you for participating!
Acknowledgements

Subject Matter Experts

Keith Strauss, MSc, FRAPM, FACR
Medical Physicist
Assistant Professor of Radiology
Cincinnati Children’s Hospital Medical Center

Marilyn Goike, MD, FAAP, FACR
Chair, Alliance for Radiation Safety in Pediatric Imaging
Professor of Radiology and Pediatrics
Cincinnati Children’s Hospital Medical Center

Acknowledgements

Module Review Team

Carrie Ruiz-Shipman, MD
Morgan Stanley Children's Hospital of New York Presbyterian

Marcia Early, MSN, RN
Cincinnati Children’s Hospital Medical Center

Marta Herszyn-Schulman, MD, FAAP, FACR
Vanderbilt Children’s Hospital, Tennessee

Acknowledgements

Photography

Keith Strauss, MSc, FRAPM, FACR
Cincinnati Children’s Hospital Medical Center

Marilyn Goike, MD, FAAP, FACR
Cincinnati Children’s Hospital Medical Center
Acknowledgements
Administrative Support
Greg Morrison, MA, R.T.(R), CMRT, CAE
Chief Operating Officer
American Society of Radiologic Technologists

Corey Bell
Administrative Director for the Alliance for Radiation Safety in Pediatric Imaging
Cincinnati Children’s Hospital Medical Center

Development Team
Narration
Sharon Faesser

Editor
Kathyrn Olt, MD, FLS
Lisa Ragusdale, MA

Module Production
Kevin J. Powers, EDO, R.T.(R)(M)

Development Team
Project Management and Instructional Design
Marilyn Gokker, MD, AAPM FAPM
Tracy Herrmann, MS.Ed., R.T.(R)
Kevin J. Powers, EDO, R.T.(R)(M)
Keith Groauce, MSc, R(R)PM, ECR

Illustrations
Laura Reed, MA, ICC-SLP/A

Lead Designer
Kevin J. Powers, EDO, R.T.(R)(M)
This module is now complete.

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Suggested Additional Reading


16. Imaging Pediatric Patients [https://www.theonlinelearningcenter.com/course-catalog/Product/module/5055/103]
20. Paediatric Radiology [https://rpop.iaea.org/RPOP/RPoP/Content/AdditionalResources/Training/1_TrainingMaterial/Pae diatricRadiology.htm]
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