

ACR Appropriateness Criteria® Radiation Dose Assessment Introduction

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Many of the diagnostic imaging examinations described in the ACR Appropriateness Criteria® (AC) guidelines involve exposure of patients to ionizing radiation from radioactive materials or x-rays. Potential adverse health effects associated with radiation exposure are an important factor to consider when selecting the appropriate imaging procedure. Because there is a wide range of radiation exposures associated with different diagnostic procedures, relative radiation levels (RRLs) have been included for most imaging examinations (see Table 1) [1,2]. The RRLs are based on effective dose, which is a radiation dose quantity used to estimate population total radiation risk associated with an imaging procedure. This quantity takes into account the sensitivity to radiation of different body organs and tissues [3]. It is expressed in units of millisievert (mSv). It is important to note that, because effective dose does not delineate differences in risk based on age and sex, it cannot accurately specify risk for an individual patient. However, effective dose does provide a way to approximately compare relative risk among different imaging examinations. All RRL assignments are based on reviews of current literature and the experience of medical physicists and radiologists. A partial list of literature consulted is provided [4-13]. In some examinations, dose estimates from published studies and/or practice experience vary significantly; in these cases, the reviewing committee conservatively assigned the RRL for the examination to the higher level. These assignments will be periodically reviewed and updated, as practice evolves and further information becomes available.

The primary risk associated with exposure to ionizing radiation is potential induction of cancer. The National Academies Health Risks from Exposure to Low Levels of Ionizing Radiation report, BEIR VII [14], states:

On average, assuming a sex and age distribution similar to that of the entire U.S. population, the BEIR VII lifetime risk model predicts that approximately one individual in 100 persons would be expected to develop cancer (solid cancer or leukemia) from a dose of 100 mSv while approximately 42 of the 100 individuals would be expected to develop solid cancer or leukemia from other causes. Lower doses would produce proportionally lower risks. For example, it is predicted that approximately one individual in 1000 would develop cancer from an exposure to 10 mSv.

However, BEIR VII also emphasizes that:

At doses of 100 mSv or less, statistical limitations make it difficult to evaluate cancer risk in humans.

The vast majority of diagnostic imaging examinations are performed at doses far less than 100 mSv. Consequently, Hendee and O'Connor [15] further caution that:

Estimates of cancers and cancer deaths resulting from medical imaging procedures that use ionizing radiation are computed by multiplying very small hypothetical risks by large patient populations to yield thousands of "cancer victims."

Keep in mind that cancer, regardless of the etiologic process, has a latent period of 10-20 years or more. Further, it is important to remember that in addition to radiation exposure from imaging procedures, individuals are exposed to ubiquitous radiation from natural sources, including radon, cosmic rays, soil, building materials, and food. The average annual amount of natural background radiation for someone living in the United States is approximately 3 mSv [7].

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The RRL designations specified in these guidelines assume an average adult patient size (or applicable pediatric size) and that typical imaging equipment, radiographic techniques, and radiopharmaceutical dosage levels are used. Radiation levels vary substantially as a function of differences in local imaging practices and patient size [16]. When radiopharmaceutical agents are used, radiation levels also vary with the patient's physiology. For procedures where a more general description is provided (eg, CT appendicular skeleton), dose will vary depending on the area being imaged. A qualified medical physicist must be consulted for more accurate dose estimates in specific clinical situations.

In the current version of the AC, RRLs are designated as “varies” for most image-guided interventional procedures, because the actual patient doses in these procedures vary as a function of a number of factors. These include patient factors, such as body habitus and age, and technical factors, such as type of imaging modality used for guidance, specific nature of the intervention, treatment modality used, and skill and experience of the operator. For example, biopsy of a lung nodule may be done with fluoroscopic or CT guidance. The CT may involve static imaging or CT fluoroscopy. The lesion may be peripheral, large, and readily accessible, or central, small and technically very challenging to reach. Similarly, if a patient is undergoing visceral angiography for the treatment of a gastrointestinal bleed, the procedure may be very brief if a precise bleeding site is readily identified and treated with embolization, or it may require a long period of fluoroscopy and many recorded angiographic runs due to unclear or confusing findings, or inability to easily cannulate a small suspect artery. For these reasons, the actual dose to a given patient for a given intervention may vary from none too high.

Certain patient groups require special attention with regard to radiation exposure. Radiation-induced cancer mortality risk in children is 3 to 5 times higher than for adults [3], both because of increased organ sensitivity and longer life expectancy (relevant to the long latency that appears to accompany radiation exposure). For these reasons, the RRL dose estimate ranges for pediatric examinations are lower as compared to those specified for adults. Even though radiation levels required for imaging examinations of children are generally lower than those for adults due to their smaller size, it is particularly important to consider radiation exposure levels when selecting appropriate imaging examinations for children due to their significantly greater sensitivity to radiation exposure [17,18]. However, in practice, radiation doses may not be lower for small patients and children. If the radiation exposure from a protocol designed for an adult is used for smaller body sizes, the dose is larger. Unless specific pediatric-reduced techniques have been implemented by the facility, the radiation levels for small patients and children may exceed typical adult radiation levels. It is also important to note that, as people age, their risk of radiation-induced cancer decreases. As a result, when compared to a 40-year-old, an 80-year-old is 3 to 4 times less likely to develop cancer from radiation exposure [14].

The developing conceptus is also particularly sensitive to radiation exposure, which may result in various adverse effects the fetus. Depending on the magnitude of the radiation dose and the gestational age of the fetus, these effects may include cognitive impairment, organ malformations, and childhood cancer [19]. Though the fetal dose from diagnostic x-ray procedures is generally below the threshold for increased risk of developmental damage, unintended fetal exposure should be avoided by establishing the pregnancy status of female patients of reproductive age prior to conducting any imaging procedure which involves direct exposure of the abdomen [20]. Radiological examinations outside the abdominal region in general result in only minimal fetal exposure and can be done safely. Before any imaging procedures involving ionizing radiation are performed on pregnant patients, however, the clinical necessity, possible alternatives that do not involve ionizing radiation, and all other risk factors should be carefully evaluated, and if the examination is undertaken, it should potentially be modified to reduce radiation dose.

Although the overall risk of cancer induction from a diagnostic imaging procedure involving ionizing radiation is small, it has not been proven to be zero. Therefore, it is important to ensure that a patient's radiation exposure is only that necessary to accomplish the diagnostic task. There are several ways to help accomplish the goal of limiting exposure to ionizing radiation so as to maximize the benefit-risk ratio of imaging procedures. First, use the appropriateness criteria recommendations to select the most suitable procedure for the patient's condition; avoid ordering procedures that are not likely to provide useful information. Second, prior to ordering an imaging procedure, review the patient's history, results, and clinical indications to determine whether the procedure can provide additional information to assist in patient management. This should be balanced with any potential risks associated with the imaging procedure. Consider using imaging procedures that do not use ionizing radiation but only when they have similar test accuracy to procedures that use ionizing radiation [21].

Frequently patients will ask physician's questions about the radiation exposure associated with imaging examinations and the risk of ionizing radiation in general. An easily-accessible resource that can be used for these discussions is the RadiologyInfo website (www.radiologyinfo.org). This website provides information to the public on radiologic procedures, including specific content on radiation exposure and safety. The material is provided by experts in the field of radiology from the ACR and the Radiological Society of North America. Additional information on radiation in imaging is available for imaging professionals, referring practitioners and patients and their families at the Image Wisely (www.imagewisely.org) and the Image Gently (www.imagegently.org) websites.

Table 1. Relative radiation level designations along with common example examinations for each classification

Relative Radiation Level*	Adult Effective Dose Estimate Range	Pediatric Effective Dose Estimate Range	Example Examinations
○	0 mSv	0 mSv	Ultrasound; MRI
⊕	<0.1 mSv	<0.03 mSv	Chest radiographs; Hand radiographs
⊕⊕	0.1-1 mSv	0.03-0.3 mSv	Pelvis radiographs; Mammography
⊕⊕⊕	1-10 mSv	0.3-3 mSv	Abdomen CT, Nuclear medicine bone scan
⊕⊕⊕⊕	10-30 mSv	3-10 mSv	Abdomen CT without and with contrast; Whole body PET
⊕⊕⊕⊕⊕	30-100 mSv	10-30 mSv	CTA chest abdomen and pelvis with contrast; Transjugular intrahepatic portosystemic shunt placement

*The RRL assignments for some of the examinations cannot be made, because the actual patient doses in these procedures vary as a function of a number of factors (eg, the region of the body exposed to ionizing radiation, the imaging guidance that is used, etc.). The RRLs for these examinations are designated as "Varies."

References

- Royal College of Radiologists. Making the best use of a department of clinical radiology: guidelines for doctors. 5th ed. London: The Royal College of Radiologists; 2003.
- Martin CJ. Effective dose: how should it be applied to medical exposures? *Br J Radiol.* 2007;80(956):639-647.
- 1990 Recommendations of the International Commission on Radiological Protection. *Ann ICRP.* 1991;21(1-3):1-201.
- American College of Radiology. Dose Index Registry. Available at: <http://www.acr.org/Quality-Safety/National-Radiology-Data-Registry/Dose-Index-Registry>. Accessed March 10, 2017.
- Radiation dose to patients from radiopharmaceuticals (addendum 2 to ICRP publication 53). *Ann ICRP.* 1998;28(3):1-126.
- United States Pharmacopeia Drug Information: Drug Information for the Health Care Professional.* Vol 1. 27th ed. Greenwood Village, CO: Thomson Micromedex; 2007.
- Ionizing Radiation Exposure of the Population of the United States.* Bethesda, MD: National Council on Radiation Protection and Measurement. NCRP report 160; 2009.
- Conference of Radiation Control Program Directors, Inc. Nationwide Evaluation of X-Ray Trends (NEXT) - Tabulation and Graphical Summary of 2005-2006 Survey of Computed Tomography. 2015; Available at: http://c.ymcdn.com/sites/www.crcpd.org/resource/collection/81C6DB13-25B1-4118-8600-9615624818AA/NEXT_CT2005-2006Tabulations&GraphicalSummary.pdf. Accessed March 10, 2017.
- Bor D, Sancak T, Olgar T, et al. Comparison of effective doses obtained from dose-area product and air kerma measurements in interventional radiology. *Br J Radiol.* 2004;77(916):315-322.
- Lassmann M, Treves ST. Paediatric radiopharmaceutical administration: harmonization of the 2007 EANM paediatric dosage card (version 1.5.2008) and the 2010 North American consensus guidelines. *Eur J Nucl Med Mol Imaging.* 2014;41(5):1036-1041.

11. Mettler FA, Jr., Bhargavan M, Faulkner K, et al. Radiologic and nuclear medicine studies in the United States and worldwide: frequency, radiation dose, and comparison with other radiation sources--1950-2007. *Radiology*. 2009;253(2):520-531.
12. Mettler FA, Jr., Huda W, Yoshizumi TT, Mahesh M. Effective doses in radiology and diagnostic nuclear medicine: a catalog. *Radiology*. 2008;248(1):254-263.
13. Wall BF, Hart D. Revised radiation doses for typical X-ray examinations. Report on a recent review of doses to patients from medical X-ray examinations in the UK by NRPB. National Radiological Protection Board. *Br J Radiol*. 1997;70(833):437-439.
14. National Research Council (U.S.). Committee to Assess Health Risks from Exposure to Low Level of Ionizing Radiation. *Health risks from exposure to low levels of ionizing radiation : BEIR VII Phase 2*. Washington, D.C.: National Academies Press; 2006.
15. Hendee WR, O'Connor MK. Radiation risks of medical imaging: separating fact from fantasy. *Radiology*. 2012;264(2):312-321.
16. Amis ES, Jr., Butler PF, Applegate KE, et al. American College of Radiology white paper on radiation dose in medicine. *J Am Coll Radiol*. 2007;4(5):272-284.
17. National Cancer Institute. *Radiation Risks and Pediatric Computed Tomography (CT): A Guide for Health Care Providers*. Available at: <http://www.cancer.gov/cancertopics/causes/radiation-risks-pediatric-CT>. Accessed March 10, 2017.
18. Image Gently. The Alliance for Radiation Safety in Pediatric Imaging. Available at: <http://www.imagegently.org/>. Accessed March 10, 2017.
19. McCollough CH, Schueler BA, Atwell TD, et al. Radiation exposure and pregnancy: when should we be concerned? *Radiographics*. 2007;27(4):909-917; discussion 917-908.
20. American College of Radiology. ACR-SPR Practice Parameter for Imaging Pregnant or Potentially Pregnant Adolescents and Women with Ionizing Radiation. Available at: http://www.acr.org/~media/ACR/Documents/PGTS/guidelines/Pregnant_Patients.pdf. Accessed March 10, 2017.
21. Image Wisely. Radiation Safety in Adult Medical Imaging. Available at: <http://www.imagewisely.org/>. Accessed March 10, 2017.