Imaging Wisely and Gently:
The Use of Diagnostic Radiation in 2012 and Beyond
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Internal Medicine Grand Rounds
University of Texas Southwestern Medical Center
May 18, 2012

This is to acknowledge that Ronald M. Peshock, M.D. has no financial interests or other relationships with commercial concerns related directly or indirectly to this program. Dr. Peshock will not be discussing off-label uses in his presentation.

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Interests: Since training in Internal Medicine and Cardiology my research has focused on the use of imaging in the management of patients with cardiovascular disease. My clinical focus has been in the application of magnetic resonance imaging and computed tomography in these patients. As the Assistant Dean for Informatics, I have been able to work with clinicians and information technology professionals at UT Southwestern and Parkland Health and Hospital System to help implement the electronic medical record, picture archiving and communications systems and other components of the information systems infrastructure on campus.

Purpose and Overview: The purpose of this Grand Rounds is to provide an introduction to the issues in the use of diagnostic radiation, insight into developments which will allow us to use radiation more effectively to address our important clinical questions, and to review the major initiatives now underway both locally and at a national level to insure that we use diagnostic radiation to image both wisely and gently.

Objectives:

1. To understand the growth of total radiation exposure due to diagnostic imaging.
2. To gain a basic understanding of x-ray creation and measurement
3. To appreciate our present understanding of the risk of diagnostic radiation.
4. To understand evolving technical and other approaches to radiation reduction.
5. To become aware of the local and national efforts underway to improve patient and physician understanding of the wise use of diagnostic radiation.

Case presentation

Introduction

The use of diagnostic radiation is essential to medical care in the 21st century. However, on the basis of my interactions with physicians, technologists and patients, it is clear that there is a wide range of understanding of the benefits and risk of diagnostic radiation. The purpose of this Grand Rounds is to provide an introduction to the issues in the use of diagnostic radiation, insight into developments which will allow us to use radiation more effectively to address our important clinical questions, and to review the major initiatives now underway both locally and at a national level to insure that we use diagnostic radiation to image both wisely and gently.

Is there a problem?

Is it possible to imagine practicing medicine today without using imaging? We are all familiar with the Case Records of the Massachusetts General Hospital in the New England Journal of Medicine: of the 484 cases over the last 10 years, 298 (62%) mention a CT scan, 212 (44%) mention Ultrasound, and 204 (42%) mention an MRI. Clearly, imaging is viewed as an essential component of medical practice in Boston. With the continued growth of the practice at UT Southwestern we have seen a comparable growth in the use of imaging.

Given that we are all astute clinicians and do the best for our patients, is there a problem? The short answer is yes. First, recently there have a number of events involving the administration of inappropriately high radiation doses to patients. One of the most high profile of these events occurred at Cedars-Sinai Medical Center in Los Angeles where in 2009 it was determined that 206 patients had received inappropriate doses of radiation in the setting of CT brain perfusion studies.[1] This procedure involves repeated CT scanning of the brain during injection of a bolus of contrast agent and is used to assess regional perfusion in the brain. It has been performed safely in many hospitals, including Parkland. At Cedar-Sinai the overdoses went undetected for 18 months during which these patients received 8 times the dose normally used for the procedure. This occurred in spite of forty percent of the patients losing patches of hair following the procedure. This event led the FDA to issue an alert nationwide for hospitals to review their procedures for CT scans. In spite of this warning, a similar even was reported at another hospital in 2011.[2] Thus, it is clear that present imaging devices in the best of settings can be used in such a way that inappropriate levels of radiation are delivered to the patient.

Second, the growth of the use of imaging has led to a potential for a single patient to receive many imaging studies in the context of care provided by one or multiple physicians. The growth of diagnostic radiation since 1980 has been striking.[3] In the 25 years since 1980, medical radiation has increased by a factor of 6 while non-medical radiation is essentially unchanged. For example, since 1994 the use of myocardial perfusion scanning has increased by a factor of three.

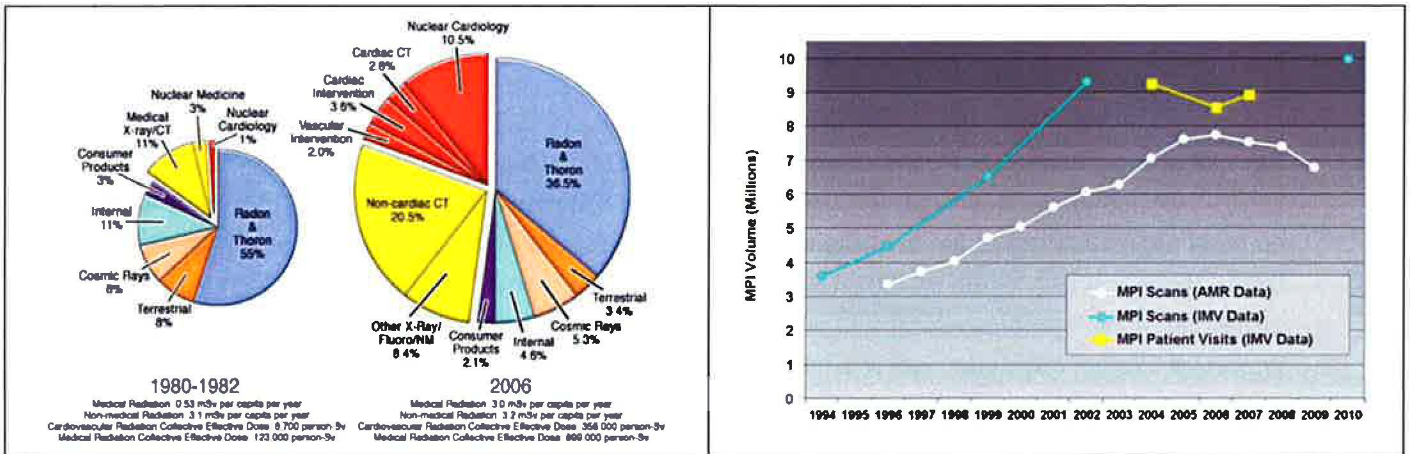
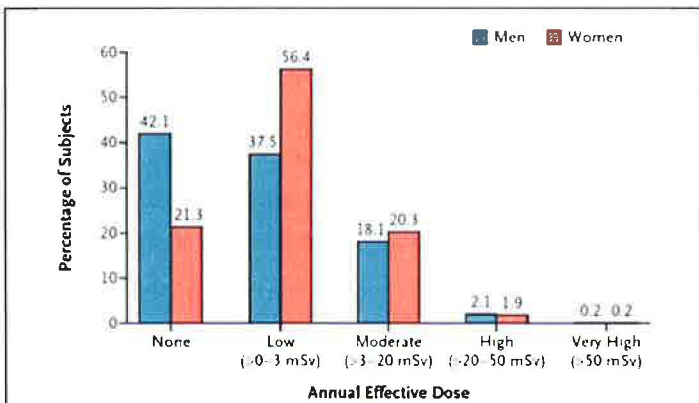


Figure 1: The left panel shows the growth in total radiation exposure between 1980-82 and 2006 due to the increase in the use of diagnostic radiation. The right panel shows the growth in myocardial perfusion imaging since 1994.[3]

A study published in the New England Journal of Medicine in 2009 looked at claims data from UnitedHealthcare on the exposure to low-dose ionizing radiation from medical imaging procedures.4 Claims data were available from multiple healthcare markets (including Dallas, which actually contributed the largest number of subjects to the cohort). They identified almost a million enrollees and found that 68.8% of those patients had had at least one radiation exposure during a two year period. The mean effective dose in the population was 2.4 mSievert (mSv) per enrollee per year which is considered low. However, there was wide variation in the dose on an individual basis. Moderate doses (<2 to 20 mSv) were seen in almost 20%, high (>20 to 50 mSv) in almost 2% and very high doses (>50 mSv) in 0.2%. In general the cumulative effective dose increased with age and was higher in women than men (Figure 2).



Source	Typical Dose (mSv)	Chest X-Rays (Posteroanterior)
Chest x-ray (posteroanterior)	0.02	1
Chest x-ray (posteroanterior and lateral)	0.10	5
Round trip flight, New York to New Orleans	0.02	1
Backscatter scanner for airport screening	0.001	1/20
Mammogram	0.7	35
Head CT	2	100
Background radiation to public (annual)	3	150
Abdominal CT	10	500
Average annual occupational dose limit* (ICRP) (6)	20	1,000
Dual isotope MPI or helical coronary CTA	25	1,250
Highest doses received by Fukushima workers	250	12,500

*Average over 5-year period. Allows for up to 50 mSv in any single year.
CT = computed tomography; CTA = computed tomography angiogram; ICRP = International Commission on Radiological Protection; MPI = myocardial perfusion imaging.

Figure 2: Left panel: Overall Distribution of Annual Effective dose of radiation in the 655,613 patients in the UnitedHealthcare cohort.[4] Right panel: Typical doses for different sources.[3]

The authors concluded that the pattern of use of medical imaging in the United States was exposing many nonelderly patients to substantial doses of ionizing radiation and that strategies of optimizing and ensuring appropriate use of these procedures should be developed.

Third, physicians across a wide range of specialties including radiology, cardiology, gastroenterology, rheumatology, urology and others have responded to these concerns. In cardiology, there are now new guidelines and appropriateness criteria for the use of cardiac catheterization which include recommendations on the use of radiation.[5,6] The Food and Drug Administration and Center for Devices and Radiological Health also have an initiative to reduce unnecessary radiation exposure from medical imaging.[7]

Finally, it is clear that patients are increasingly concerned about their radiation exposure. The events at Three Mile Island, Chernobyl and Fukushima Dai-ichi have raised the public consciousness about radiation as has the use x-rays in airport screening. There are now multiple iPhone applications for estimating radiation exposure and even Geiger counter add-on devices (Figure 3).

Figure 3: Screen shots of iPhone applications: The panel on the left shows a free app which allows a patient to estimate their cumulative radiation exposure based on typical effective doses. The panel on the right shows an additional code sensor that could be used to estimate local radiation levels.

Thus, it is clear that regulators, physicians and patients feel that radiation exposure is an important concern. To understand how we can address these concerns we need to know a little more about diagnostic radiation and it properties.

What are X-rays and how are they created?

X-rays were discovered by Wilhelm Conrad Roentgen (Figure 4) in 1895.[8,9] Although Roentgen had his lab notes burned after his death, the details of his experiments beginning November 8, 1895, and continuing over the subsequent weeks have been extensively investigated.[10] Interestingly, we know some of the details because his wife. She became very angry one evening in November because he did not comment on the excellent dinner she had made. Even worse, he did not even notice that she was angry. When she asked him why he so distracted, he took her to his laboratory in the same building to show her the wonders of the x-ray. On December 22, 1895, he asked his wife to allow him to take a picture of hand using the new rays (Figure 4). After a 15 minute exposure, the first radiograph showed the bones in her hand with two rings. This was all reportedly documented in a letter she sent to Professor Roentgen's cousin in Indianapolis!

After several weeks of experimentation he sent his preliminary communication to the president of the Würzburg Physical Medical Society on December 28, 1895, and presented his first public talk on his discovery January 23, 1896. Even without Twitter or the Internet (although there was the trans-Atlantic telegraph cable) news of the discovery raced around the world over the next month. Physicians and patients were fascinated with the potential to look inside the body. Amazingly, the first clinical journal-- Archives of Clinical Skiagraphy ("the art, science, or act of depicting or projecting shadows")-- was launched in May 1896, less than a year after Roentgen's discovery. He was awarded the first Nobel Prize in Physics in 1901 "in recognition of the extraordinary services he has rendered by the discovery of the remarkable rays subsequently named after him".

Figure 4: The left panel is a photograph of Wilhelm Roentgen at the time of his Nobel Prize. The right panel is the first radiograph of Bertha Roentgen's hand obtained December 22, 1895.

So what exactly did he discover? Basically be began with a glass tube containing electrodes and from which the air had been removed (termed a Crooke's tube). By placing a voltage across the electrodes he was able to move electrons from one electrode to the other. Crookes had demonstrated that the stream of electrons (essentially, a plasma) caused fluorescence of the wall of the tube, was blocked by metal and elicited beautiful colors from certain minerals.[11,12] Roentgen was working with a similar device and found that paper covered with barium platino-cyanide lit up with brilliant fluorescence up to two meters from the tube! The invisible radiation penetrated paper and other materials but was blocked by aluminum and lead glass. As was stated in his original paper "a piece of aluminum, 15 mm thick, still allowed the X-rays (as I will call the rays, for the sake of brevity) to pass, but greatly reduced the fluorescence."

But where were the X-rays coming from? Roentgen was using an induction coil which allowed him to generate a voltage difference between the electrodes on the order of 70,000 or 70 kilovolts or kV. The electrons were liberated from on electrode, accelerated towards the other target electrode where they interacted with the metal atoms in the target.

Several different types of interactions are known to occur. The first and most important is termed "braking radiation" (Bremsstrahlung in German, from bremsen "to brake" and Strahlung "radiation") which occurs as the electron is decelerated by the nucleus of the tungsten atom. The energy of the x-ray produced depends upon the original energy of the electron and the amount of braking that occurs. Thus, the energy is spread over a broad spectrum with the highest energy equal to that of the original incident electron. You will note as shown in Figure 5, that the majority of the energy is at a lower energy with a maximum at about one-third of the kV used. The fall off at lower energies is related to absorption by the wall of the x-ray tube. In addition, incident electrons can move the electrons in the tungsten atom from one electron shell to another which adds specific lines (termed "characteristic interactions") to the spectrum. In the case of tungsten this occurs at 69.5 kV which reflects the k-shell binding energy of tungsten.

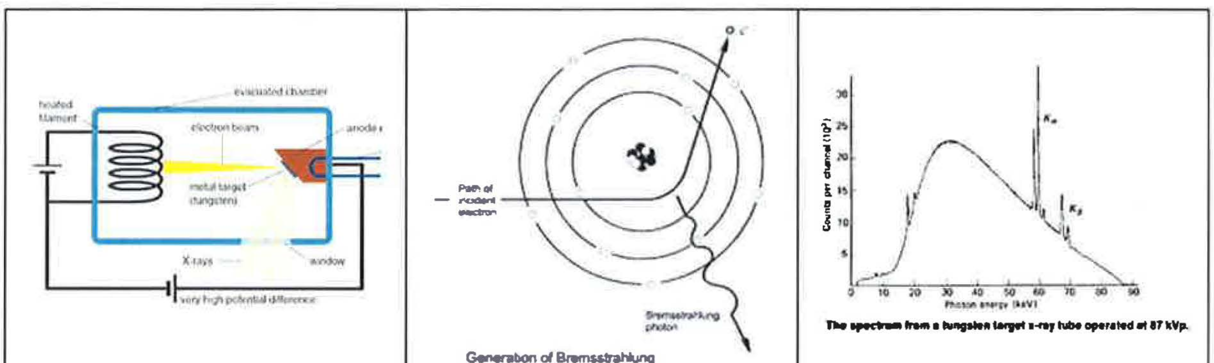


Figure 5: The left panel shows the basic components of an x-ray tube. The middle panel shows the interaction between the incident electron and the target atom. The right panel is a schematic diagram of a typical x-ray spectrum showing the broad range of energies from the braking interaction, and the lines from the characteristic interaction.

By increasing the voltage or kV, we can increase the peak energy of the individual x-ray photons and shift the spectrum to the right. (Note that the peak due to the characteristic interaction remains at the same point). The choice of kV is driven by the need to penetrate the tissue but not lose contrast between the tissues of interest. Too low a kV and the different tissues are not penetrated. Too high a kV and all tissues are penetrated and there is no contrast. In addition, the radiation dose increases as the square of the kV which means that there is usually an optimal range of kV for a particular imaging study.

If we need more photons in the same energy range we can increase the current or mA. Importantly, the radiation dose increases linearly with the mA so that in general, increasing mA will potentially penetrate a large patient with less of an increase in x-ray exposure than increasing the kV.

So what determines contrast between tissues in the body? Although the details are more complex, at low energies the attenuation of the x-rays depends upon the thickness of the material and its physical density, electron density and effective atomic number. For example, fat has a lower physical density than bone or soft tissue and contains predominately low atomic number elements so that the x-rays are attenuated less. In the case of bone the physical density is high and its effective atomic number is much higher than soft tissue or fat. The iodine in contrast agents has a much higher atomic number and therefore can be used to selectively attenuate x-rays in vascular and other studies.

A discussion of the radiation used in nuclear scanning is beyond the scope of this discussion and the reader is referred to excellent discussions available in the literature.[13]

How do we measure ionizing radiation?

Reading and understanding the literature dealing with the risk of radiation is made more difficult by the multiple measures used to describe radiation (Figure 6). There is good rationale for all of these measures but the list can appear daunting. However, there are two core ideas: exposure and effective dose. Exposure is easier to calculate is some sense. It depends on the voltage potential (kV), the current (mA), the exposure time (sec) and distance. Exposure is reported using a variety of units. The effective dose is a weighted calculation which reflects the type of energy and the radio sensitivity of each organ summed over all organs.[14] The effective dose is then expressed in milliSievert (mSv). It is important to remember that the mSv is based on a "reference" standard person and is not a measure of the actual radiation exposure to an individual person from and individual imaging exam.

- Projection radiography (X-ray, computed/digital/dental radiography)
  - Entrance surface dose/entrance surface air kerma
  - Dose-area product (DAP)/Kerma-area product (KAP)
  - Exposure index
- Fluoroscopy
  - Fluoroscopy time
  - Fluoroscopy runs
  - Cine time
  - Cine runs
  - DAP/KAP
  - Cumulative dose/air kerma at the interventional reference point ($K_{a,r}$)
  - Peak skin dose
- Computed tomography
  - CT dose index, weighted ($CTDI_w$)
  - CT dose index, volume ($CTDI_{vol}$)
  - Dose-length product (DLP)
- Mammography
  - Incident entrance air kerma
  - Average glandular dose
- Nuclear medicine
  - Administered activity (MBq)

Quantity	Unit	Determination
Exposure	Coulomb per kilogram (C/kg), roentgen (R)	Measurement
Dose	Gray (Gy), rad	Multiply exposure by f-factor or a conversion factor
Equivalent dose	Sievert (Sv), rem	Multiply dose by a quality factor
Effective dose	Sv, rem	Multiply equivalent dose by a tissue weighting factor

Dose Estimate = Radiation Measurement X Factors

Figure 6: The left panel left panel is a table of common modality specific dosimetry terminology.[24] The right panel upper panel shows the basic relationship between measures of exposure and effective dose.[30] The right lower panel shows the relationship between radiation measurement and dose estimate.

What is the risk?

Two fundamental terms are used to describe radiation effects: deterministic and stochastic. The term deterministic (or tissue reaction) is used to describe effects that occur above a specific threshold, such as skin or hair changes or cataracts where cells are damaged or killed. Stochastic effects are those for which the probability of the effect is dependent on the dose of the radiation received. Stochastic effects are felt to be due to mutations related to the radiation and not cell death. These mutations are manifest as inherited disease in the offspring of the affected individual or as malignancies. Interestingly, although there is extensive experiment on the heritable effects of radiation, there is no direct evidence of this in humans.[15]

Studying the impact of diagnostic radiation on the rate of malignancy in population-based studies is difficult. The background rate of cancer in the population is a lifetime risk of approximately 42%.[16] It has been estimated that a cohort study to investigate the impact of typical diagnostic radiation doses on the background risk of cancer would involve 100,000 to 10 million participants. [17,18] Thus, it is unlikely that such a study will ever be done. However, there are three studies that have examined relatively large cohorts. The first is the Life Span Study performed in the survivors of the atomic bomb in Japan. With a sample size of over 120,000 a mean effective dose of 29 mSv and 40 year follow-up there was an excess of common cancers varying from 2 to 4.3 % with 81 excess cancers (2%) attributed to radiation.[19] A second major study examined the cancer risk of radiation workers in 15 countries with a sample size of 407,391 workers with a typical dose of 19.4 mSv also showed an excess relative risk of cancer of approximately 2%.[20] The third study examined the effects of radiation exposure in utero on children by examining all children under the age of 16 who died of cancer and radiation exposure based on maternal recollection and prenatal records.[21] The observed excess relative risk of cancer was 39% for a typical dose of approximately 10 mGy. Thus, these relatively large studies indicate an increased risk for cancer.

It has been argued that these studies do not address the specific use of ionizing radiation in standard clinical practice in adults. However, there multiple studies which show excess relative risk for thyroid cancer based on childhood radiotherapy at doses as low as 100 mGy and studies in multiple cohorts demonstrating increased risk for breast cancer in women receiving radiation for other reasons.[22]

The only study that directly addresses the issue of radiation used in contemporary cardiology was published in 2011.[23] In this study they reviewed administrative records in 82,861 patients in Canada who had a myocardial infarction between April 1996 and March 2006. Of these patients 77% had at least one cardiac imaging or therapeutic procedure involving low-dose ionizing radiation in the first year after acute myocardial infarction. The radiation exposure was 5.3 mSv per patient-year and 84% occurred in the first year following infarction. For every 10 mSv of low-dose radiation they observed a 3% increase in the risk of age and sex-adjusted cancer over a mean follow-up period of 5 years (Figure 7). Needless to say, this article has provoked considerable comment and controversy.[24]

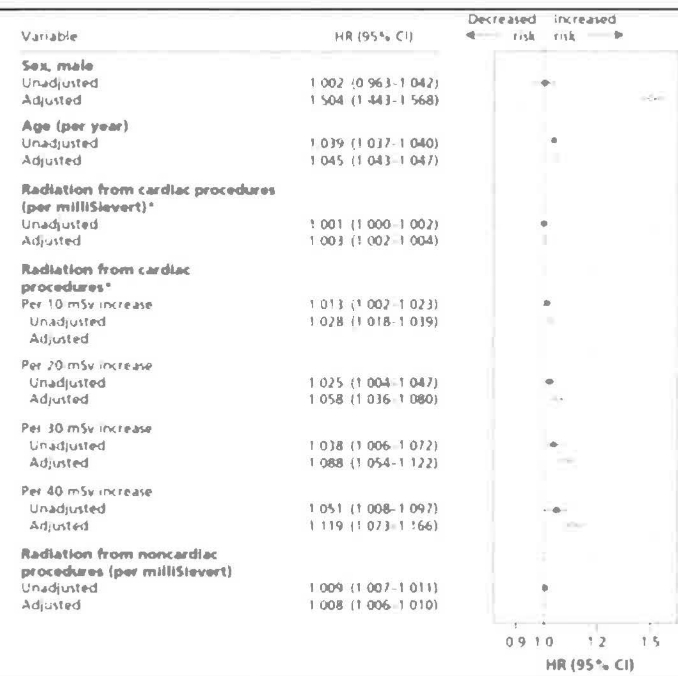


Figure 7: Risk of cancer during a mean follow-up of 5 year following low-dose ionizing radiation exposure in the setting of an acute myocardial infarction.[23]

Considerable review of the available data led the Board on Radiation Effects Research to state that at dose estimates less than 100 mSv statistical limitations made it difficult to evaluate cancer risks in humans. Their review of the biology data led them to conclude that the risk would continue in a linear fashion without a threshold and that the smallest dose has the potential to cause a small risk in humans. This assumption was termed the Linear No-Threshold (LNT) model (Figure 8). The BEIR (Biological Effects of Ionizing Radiation) VII committee also developed their best risk estimates for low-dose radiation in humans. The risk depends on the gender and age at the time of exposure. These best risk estimates have been used estimating the cancer risk from abdominal CT scanning (Figure 8) and myocardial perfusion scanning.[25,26]

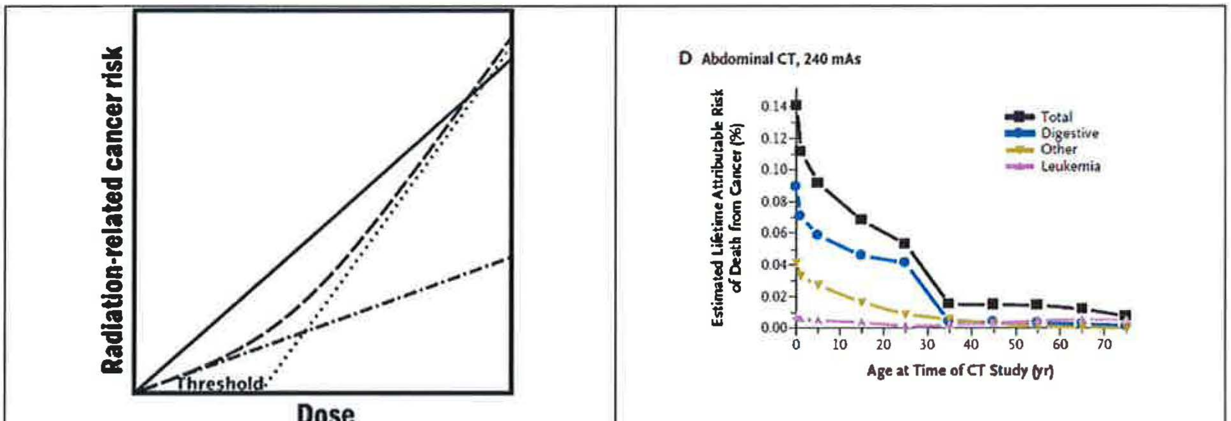


Figure 8: The left panel illustrates the Linear No-Threshold (LNT) model.[16] The right panel shows a typical estimate of lifetime attributable risk of death from cancer following a single abdominal CT.

Approaches to reducing the exposure and risk

Although considerable controversy remains and the ideal study has not been performed, there appears to be a growing body of evidence that cannot be ignored and that imaging approaches that reduce exposure and risk are appropriate. In fact it has been suggested that the informed consent explaining medical radiation risk might be appropriate for each imaging procedure.[27 28]

One can argue that the best approach to reducing radiation exposure is not to not expose the patient at all. This can be encouraged through the use of appropriateness criteria and guidelines for use of alternative imaging approaches. The American College of Radiology has, in collaboration with other professional societies, developed appropriateness criteria.[29,30] However, the routine use of these criteria at the time of ordering has been difficult. This is really a form of clinical decision support and for it to be effective the data to guide the clinical decision needs to available in the EMR at the time of ordering.

Effective clinical decision support would seem to require several components: (1) integration of the appropriateness criteria and other guidance into the ordering process, (2) a reasonable estimate of the expected exposure for the proposed imaging study and (3) some kind of record of the prior exposure of an individual patient. All of these are achievable.

The effect of clinical decision support integrated into the computerized order entry process has been investigated extensively at the Massachusetts General Hospital.[31 32] They implemented a clinical decision support system based on the American College of Radiology Appropriateness Criteria. During the ordering process the clinician is asked several questions regarding the clinical indications and is provided a 1-9 appropriateness score. The clinician can then an alternative or proceed with the original order. As shown in Figure 9, this resulted in a significant decrease in the number of outpatient examinations:

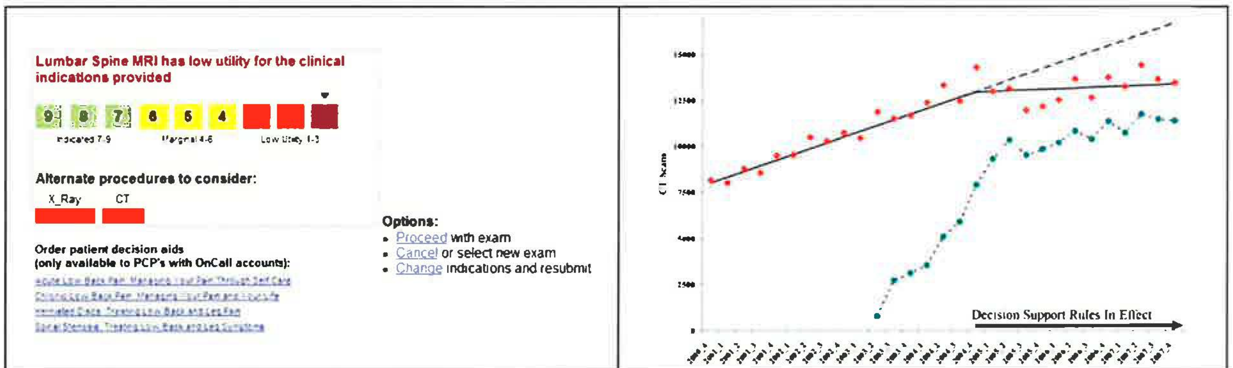


Figure 9: The left panel shows typical feedback to the ordering clinician. The right panel shows the reduction in CT examinations (dashed line is the extrapolated number of CT scans on the basis of the historical growth rate while the solid line indicated the actual number of CT scans after the introduction of the decision support rules.

The use of clinical decision support has recently been evaluated by the MGH in regards to the use and yield of CT pulmonary angiography in the emergency department.[33] Interestingly, they used natural language processing to capture if the radiology report contained positive or negative findings for pulmonary emboli (this approach has been used by Dr. Toomay and Browning at UTSW to capture content in radiology reports regarding the diagnosis of appendicitis). They found that evidence-based clinical decision support was associated with a significant 20.1% decrease in the use of CT angiography as well as a 69% increase in the yield of positive studies. These kinds of successes encouraged the state of Minnesota to implement a commercialized version of the MGH system across the state[34] and a similar system has been considered for implementation at Parkland Health and Hospital System. However, all such projects have not been successful.[35] Interestingly, it has been shown that CT ordering practices do not change if we simply educate residents about the effects of radiation exposure.[36]

Another important approach is to reduce the inappropriate duplication of imaging procedures. Recently, the group at the Brigham and Women's Hospital has reported that the simple ability to import images from external CDs reduces subsequent imaging utilization in emergency department transfer patients.[37] Going beyond what we can presently do with CareEverywhere the Radiological Society of North America and the NIH have funded image exchange projects at several institutions around the country. In addition, there are now a number of companies which offer cloud based image exchange so that patients can make their images available at all their points of care across the community.[38]

The second important component is the accurate tracking of radiation exposure. Both UT Southwestern and Parkland Health and Hospital System have implemented dose tracking, particularly for high radiation dose procedures such as fluoroscopy and CT. However, these both involve manual entry of information from the devices and which is suboptimal. Both intend to move as rapidly as possible to automated capture of this information as the imaging devices and electronic medical record support it. In the meantime patients can chose to track their procedures on paper or using smartphone applications as described earlier.

Reduce the dose per exam: There have been extraordinary efforts over the past 3 years at UT Southwestern and its affiliates to review the radiation protocols for clinical examinations. This project termed CAARE (Clinically Appropriate and Accurate Radiation Exposure) was initiated by Dr. Neil Rofsky, Chair of the Department of Radiology, in collaboration with other department chairs and the hospitals. These efforts have been led by Drs. Orhan Oz (Nuclear Medicine) and include many individuals including Drs. Jose Joglar (Internal Medicine, Cardiology), Jon Anderson (Medical Physics), Jeff Guild (Medical Physics), Ceclia Brewington (UTSW Hospitals and Clinics), Julie Champaine (Parkland Health and Hospital System), Nancy Rollins (Children's Medical Center) and many others. They have worked with imaging and referring physicians and medical physicists to minimize radiation dose using ALARA (As Low As Reasonably Achievable) principles on present imaging devices.

For example, in cardiac CT angiography one can achieve significant reduction in radiation exposure by changing settings on our present imaging devices. As you would expect reducing the kV[39], reducing the time the x-ray beam is turned on (prospective triggering)[40] and moving the patient through the beam more quickly (high pitch)[41] can reduce the overall dose. An example of the dose reduction possible for chest CT is shown in Figure 10. Similar efforts are underway in cardiac nuclear imaging and in the cardiac catheterization and electrophysiology laboratories.[42]

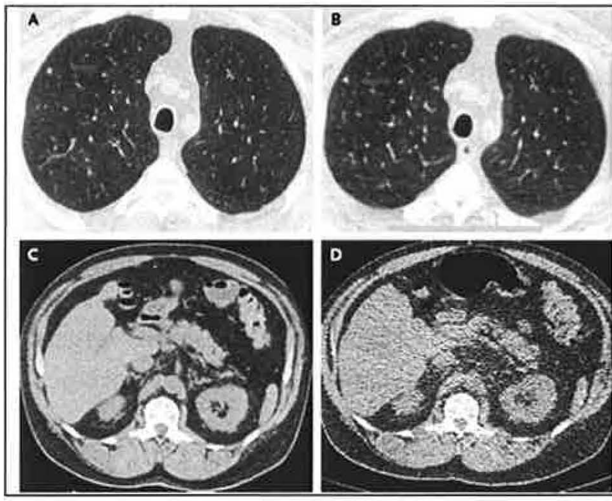


Figure 10: CT images of the chest and upper abdomen: The left panels were obtained with a "routine" protocol (dose length product of 938 mGy per centimeter, effective dose of 15.9 mSv). The panels on the right were obtained with a low dose protocol (88 mGy per centimeter, effective dose 1.5 mSv). There is clearly more noise in the low dose images, but the pulmonary nodule is well demonstrated on both scans.[43]

From this example, however, it is apparent that we can only reduce the dose so much before the image would become non-diagnostic. Thus, one of the fundamental factors limiting our ability to reduce the dose has been the decrease in signal to noise in the images which occurs. Recently there have important advances in a technique known of as iterative reconstruction which allows one to improve the image quality at very low radiation exposures.[44] This approach has been applied successfully in body CT[45], chest CT[46] and coronary CT angiography[47,48,49,50] (Figure 11). New CT scanners have raised the potential for CT examinations to be feasible with effective doses below 1 mSv.

Figure 11: Coronary CT angiogram obtained in a normal weight patient (BMI 22) with an effective radiation dose of 0.56 mSv. Scanning parameters 100 kV, 325 mA with iterative reconstruction.

The 320 slice CT scanner at UT Southwestern and the new 256 slice scanner at Parkland support this reconstruction method.

Patient education: It is quite clear that patients have dramatic varying levels of understanding of the radiation dose associated with imaging studies, both overestimating and underestimating. In a recent study in Italy, 79% patients underestimated their radiation dose for cardiac stress scintigraphy by a factor of 500.[51] Some institutions have developed smart cards for patients which give the estimated dose for patients and even the estimated cancer risk (Figure 12).[52]

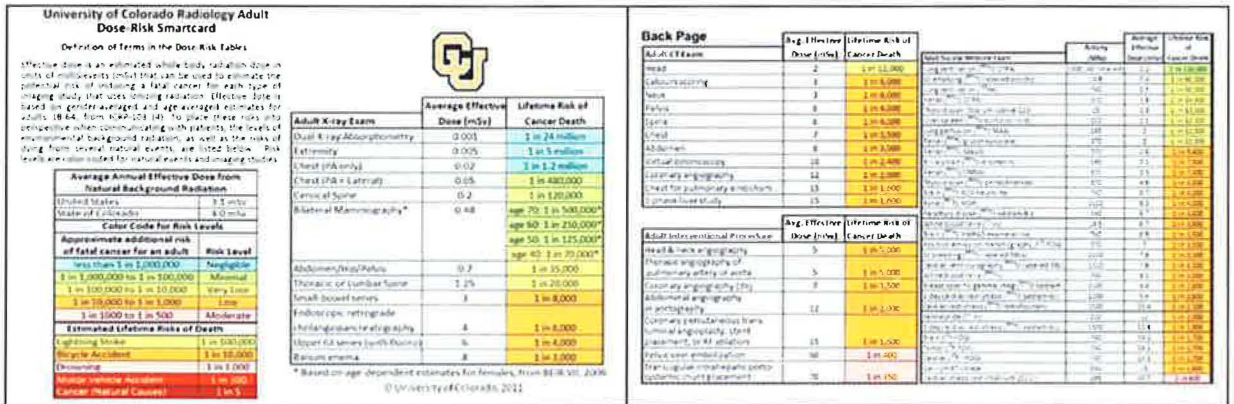


Figure 12: The University of Colorado Adult Dose-Risk Scorecard which shows average effective dose for imaging procedures and estimated lifetime risk of cancer.

This lack of understanding has also led to several important national initiatives to inform patients and physicians on the value and risks of diagnostic radiation. In 2006 the Alliance for Radiation Safety in Pediatric Imaging developed the image gently®[53] campaign to facilitate the education of pediatric patients and their families and clinicians involved in their care regarding the optimal use of diagnostic radiation. Image wisely™[54] is a similar initiative for radiation safety in adult medical imaging which involves the American College of Radiology, the Radiological Society of North America, the American Society of Radiologic Technologist and the American Association of Physicists in Medicine. As you are all aware, Choosing wisely®[55] is an initiative of the American Board of Internal Medicine which was recently launched "…encouraging physicians, patients and other healthcare stakeholders to think and talk about medical tests and procedures that may be unnecessary…" This effort has broad representation across medical and surgical specialties and has generated lists of "Five things physicians and patients should question". In the case of the American College of Cardiology this includes the use of stress cardiac imaging annually and in the initial evaluation of patients without cardiac symptoms unless high risk markers are present.

We all have roles to play

Diagnostic radiation will continue to play an increasing role in the diagnosis and management of patients. However, with this comes the need for responsible use of these technologies. All of us have a role to play. Patients need to have a better understanding of the risks and more importantly the benefits of diagnostic radiation. With information technology we can facilitate the exchange of images to reduce duplicate studies and provide a measure of at least the exposure that patients have received. Clinical decision support at the point of care in the EMR can be used help guide clinicians through the thousands of potential imaging exams. However, no EMR system can replace the personal consultation between the clinician and their imaging physician colleague to develop the best approach in an individual patient. Finally, there are exciting developments in imaging physics and technology which allow us to obtain diagnostic studies with less radiation.

The ability to see inside the body seems so routine and trivial to us today. It is difficult to imagine what Roentgen and physicians at the turn of the century felt when they saw that first image of his wife's hand. A new world was opened and has changed medicine forever. I hope by imaging wisely and gently we can continue to build on that insight and enthusiasm and provide the best possible diagnosis and care for our patients.

References

1. Ceders-Sinai investigated for significant radiation overdoses in 206 patients. Los Angeles Times. October 10, 2009.
2. Radiation Overdoses Despite F.D.A. Warnings. New York Times March 5, 2011.
3. Einstein AJ. Effects of Radiation Exposure from cardiac imaging. How good are the data? J Am Coll Cardiol 2012;59:553–65)
4. Fazel R, et al. Exposure to Low-Dose Ionizing Radiation from Medical Imaging Procedures. N Engl J Med 2009;361:849-57.
5. Bashore TM, et al. 2012 American College of Cardiology Foundation/Society for Cardiovascular angiography and intervention expert consensus document on cardiac catheterization laboratoty standards update. J. Am. Coll. Cardiol. published online May 8, 2012.
6. Gerber TC, et al. Developing an action plan for patient radiation safety in adult cardiovascular medicine: Proceedings From the Duke University Clinical Research Institute/American College of Cardiology Foundation/American Cardiovascular Medicine Heart Association Think Tank Held on February 28, 2011 : J. Am. Coll. Cardiol. 2012;59;1833-1847.
7. Initiative to Reduce Unnecessary Radiation Exposure from Medical Imaging. FDA Whitepaper:February 2010.
8. Roentgen WC. Sitzungsberichte der Würsburger Physik-medic. Gesellschaft, 1895.
9. Roentgen WC. On a new kind of rays (Translated by Arthur Stanton) Nature 1896;53, 274-277.
10. Glasser O. W.C. Roentgen and the Discovery of the Roentgen Rays. AJR 1995;165:1033-1040.
11. The true cathode rays. Prof. Crooke's celebrated discover as related by himself. The New York Times. Published: February 23, 1896
12. http://www.crtsite.com/page7.html
13. Mettler, FA, et al. Effective doses in Radiology and Diagnostic Nuclear Medicine: A catalogue. Radiology, 2008;248:254-263
14. The 2007 recommendations of the International Commission on Radiological Protection. ICRP Publication 103. Ann ICRP 2007;37:1-332.
15. The 2007 recommendations of the International Commission on Radiological Protection. ICRP Publication 103. Ann ICRP 2007;37:1-332.
16. Committee to Assess Health Risks from Exposure to Low Levels of Ionizing Radiation, National Research Council. Health Risks From Exposure to Low Levels of Ionizing Radiation: BEIR VII Phase 2. Washington DC: The National Academies Press, 2006.
17. Committee on an Assessment of CDC Radiation Studies. National Research Council. Radiation Dose Reconstruction for Epidemiologic Uses. Washington DC: National Academy Press, 1995.
18. Brenner DJ, Doll R, Goodhead DT, et al. Cancer risks attributable to low doses of ionizing radiation: assessing what we really know. Proc Natl Acad Sci U S A 2003;100:13761-6.

19. Preston DL, Ron E, Tokuoka S, et al. Solid cancer incidence in atomic bomb survivors: 1958–1998. Radiat Res 2007;168:1-64.
20. Cardis E, Vrijheid M, Blettner M, et al. The 15-Country Collaborative Study of Cancer Risk among Radiation Workers in the Nuclear Industry: estimates of radiation-related cancer risks. Radiat Res 2007;167:396-416.
21. Knox EG, Stewart AM, Kneale GW, Gilman EA. Prenatal irradiation and childhood cancer. J Soc Radiol Prot 1987;7:177-89.
22. Preston DL, Mattsson A, Holmberg E, Shore R, Hildreth NG, Boice JD Jr. Radiation effects on breast cancer risk: a pooled analysis of eight cohorts. Radiat Res 2002;158:220-35.
23. Eisenberg MJ, Afilalo J, Lawler PR, Abrahamowicz M, Richard H, Pilote L. Cancer risk related to low-dose ionizing radiation from cardiac imaging in patients after acute myocardial infarction. CMAJ 2011;183:430-6.
24. Einstein AJ and Knuuti J. Cardiac imaging: does radiation matter? European Heart Journal (2012) 33, 573–578.
25. Berrington de Gonzalez A, Kim KP, Smith-Bindman R, McAreavey D. Myocardial perfusion scans: projected population cancer risks from current levels of use in the United States. Circulation 2010;122: 2403–10.
26. Einstein AJ, Weiner SD, Bernheim A, et al. Multiple testing, cumulative radiation dose, and clinical indications in patients undergoing myocardial perfusion imaging. J Am Med Assn 2010;304:2137–44.
27. Semelka RC, Armao DM, Elias J and Picano E. The Information Imperative : Is It Time for an Informed Consent Process Explaining the Risks of Medical Radiation? Radiology 2012;262:15-18.
28. Brink JA. et al. Informed Decision Making Trumps Informed Consent for Medical Imaging with Ionizing Radiation. Radiology 2012; 262:11–14.
29. http://www.acr.org/ac
30. Amis, ES, et al. American College of Radiology White Paper on Radiation Dose in Medicine. J Am Coll Radiol 2007;4:272-284.
31. Sistrom CL, et al. Effect of Computerized Order Entry with Integrated Decision Support on the Growth of Outpatient Procedure Volumes: Seven-year Time Series Analysis. Radiology 2009;251,:147-155.
32. Rosenthal DI, et al. Radiology Order Entry With Decision Support: Initial Clinical Experience. J Am Coll Radiol 2006;3:799-806.
33. Raja AS, Prevedello LM, Zane RD, Khorasani R. Impact of computerized clinical decision support on the use and yield of CT pulmonary angiography in the emergency department. Radiology. 2012; 262(2):468-74.
34. www.icsi.org/health_care_redesign_/diagnostic_imaging_35952/ minnesota_htdi_usage_data/
35. Bowen A, et al. The Effect Of Incorporating Guidelines Into a Computerized Order Entry System for Diagnostic Imaging. J Am Coll Radiol 2011;8:251-258.
36. Horowitz JM, et al. Will CT Ordering Practices Change if We Educate Residents About the Potential Effects of Radiation Exposure? Experience at a Large Academic Medical Center. Acad Radiol 2011; 18:1447–1452

37. Sodickson A, Opraseuth J, Ledbetter S. Outside imaging in emergency department transfer patients: CD import reduces rates of subsequent imaging utilization. Radiology 2011;260(2):408-413.
38. http://www.lifeimage.com/
39. Leipsic J, LaBounty TM, Mancini GB, et al. A prospective randomized controlled trial to assess the diagnostic performance of reduced tube voltage for coronary CT angiography. Am J Roentgenol 2011;196:801– 6.
40. Buechel RR, Husmann L, Herzog BA, et al. Low-dose computed tomography coronary angiography with prospective electrocardiogram triggering: feasibility in a large population. J Am Coll Cardiol 2011;57:332– 6.
41. Achenbach S, Goroll T, Seltmann M, et al. Detection of coronary artery stenoses by low-dose, prospectively ECG-triggered, high-pitch spiral coronary CT angiography. J Am Coll Cardiol Img 2011;4:328–37.
42. Pamela S. Douglas, J. Jeffrey Carr, Manuel D. Cerqueira, Jennifer E. Cummings, Thomas C. Gerber, Debabrata Mukherjee, and Allen J. Taylor. Developing an Action Plan for Patient Radiation Safety in Adult Cardiovascular Medicine. Proceedings From the Duke University Clinical Research Institute/American College of Cardiology Foundation/American Heart Association Think Tank Held on February 28, 2011. J. Am. Coll. Cardiol. 2012;59;1833-1847.
43. Smith-Bindman R. Is computed tomography safe? N Engl J Med 2010;363;1.
44. Silva A.C., Lawder H.J., Hara A., et al., "Innovations in CT Dose Reduction Strategy: Application of the Adaptive Statistical Iterative Reconstruction Algorithm," American Journal of Roentgenology, January 2010:194.
45. Hara A.K., Paden R.G., Silva A.C., et al., "Iterative Reconstruction Technique for Reducing Body Radiation Dose at CT: Feasibility Study," American Journal of Roentgenology, September 2009:193.
46. Prakash P., Kalra M.K., Digumarthy S.R., et al., "Radiation Dose Reduction With Chest Computed Tomography Using Adaptive Statistical Iterative Reconstruction Technique: Initial Experience," Journal of Computer Assisted Tomography, January 2010:34.
47. Leipsic J, Labounty TM, Heilbron B, et al. Estimated radiation dose reduction using adaptive statistical iterative reconstruction in coronary CT angiography: the ERASIR study. AJR Am J Roentgenol 2010; 195:655– 60.
48. Halliburton SS, Abbara S, Chen MY, et al. SCCT guidelines on radiation dose and dose-optimization strategies in cardiovascular CT. J Cardiovasc Comput Tomogr 2011;5:198 – 224.
49. Jonathon Leipsic J, Heilbron BG, and Hague C. Iterative reconstruction for coronary CT angiography: finding its way. Int J Cardiovasc Img 2012;28:613-620.
50. Gibbons, et al. The year in cardiac imaging. J Am Coll Cardiol 2012;59:1849-1859.
51. Bidetti G, et al. Suboptimal Awareness of Radiologic Dose Among Patients Undergoing Cardiac Stress Scintigraphy. J Am Coll Radiol 2008;5:126-131.
52. Hendrick RW, et al. The University of Colorado Radiology Adult Dose-Risk Smartcard. Jour of the American College of Radiology 2012:290-292.
53. http://www.pedrad.org/associations/5364/ig/
54. http://www.imagewisely.org/
55. http://choosingwisely.org/