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Standardization and Optimization of Computed Tomography Protocols to Achieve Low-Dose

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Abstract

The increase in radiation exposure due to CT scans has been of growing concern in recent years. CT scanners differ in their capabilities and various indications require unique protocols, but there remains room for standardization and optimization. In this paper we summarize approaches to reduce dose, as discussed in lectures comprising the first session of the 2013 UCSF Virtual Symposium on Radiation Safety in Computed Tomography. The experience of scanning at low dose in different body regions, for both diagnostic and interventional CT procedures, is addressed. An essential primary step is justifying the medical need for each scan. General guiding principles for reducing dose include tailoring a scan to a patient, minimizing scan length, use of tube current modulation and minimizing tube current, minimizing-tube potential, iterative reconstruction, and periodic review of CT studies. Organized efforts for standardization have been spearheaded by professional societies such as the American Association of Physicists in Medicine. Finally, all team members should demonstrate an awareness of the importance of minimizing dose.

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Radiation Exposure from Medical Imaging: Evidence for Harmful Effects

Tissue reactions (formerly referred to as deterministic effects) such as skin erythema and hair loss, which are due to radiation-induced cell death or damage satnd in contrast to stochastic effects such as cancer which are due to mutations. The former is a probability of a deleterious event occurring, whereas the latter a measure of energy deposition in matter. A variety of types of dosequantities are used, including organ doses, modality-specific measures such as the dose-length product in CT, and effective dose. Typical radiation doses from radiologic procedures have been described (Table 1), however there is tremendous variability in the range of radiation dose indices for a given procedure[2].

Several studies address the cumulative radiation burden from medical imaging [3–5]; together these demonstrate that the high burden from medical radiation to the US population is growing and not evenly distributed. Rather, dosedistributions are skewed and a small subset of the population receives a much higher dose of radiation, with gender, racial, and regional differences.

The evidence base relating low-dose (<100mSv) radiation exposure to cancer risk is limited due to the large sample size required for a study to have adequate power to detect an increased risk, given that radiation is a weak carcinogen. No study published contains all the elements of the ideal epidemiological study for drawing conclusions about radiation risk. The best low-dose evidence we have derives from atomic bomb survivors, nuclear industry workers, children exposed *in utero* to x-rays [6], and now from two large epidemiologic studies of children undergoing CT[7, 8]. Notwithstanding the limitations of current evidence[9], it all points towards a slightly increased cancer risk at the levels that many patients receive when undergoing medical imaging. This underscores the importance of tailoring the study to limit exposure to only what is needed for diagnosis and of practicing patient-centeredimaging.

Professionals' Roles in CT Protocol Review

The Physician

Physicians influence patient radiation dosethrough monitoring protocols and targeting body-part- and disease-specific protocols that can minimize dose. The goal in selecting protocols is not necessary to create the highest technical quality image but to generate a diagnostic image using the lowest dose possible.Strategies to reduce medical radiation exposure have in large part revolved around two aims; first, to achieve higherawareness regarding the significance of medical radiation exposure, and second, to leverage new technology to obtain high quality images from inherently noisier data. These two objectives are exemplified by widely publicized efforts on the part of professional medical imaging organizations such as ImageWisely (http://www.imagewisely.org) in the first case, and by the development of new iterative reconstruction algorithms for low-dose CT in the second. The thrust of efforts like these is to reduce overall medical radiation exposure to the public.By reviewing and designing CT protocols, the imaging physician stands in a unique position to further reduce exposure to patients within the scope of their own practice.

According to many practice models, the primary role of the physician in these efforts is that of a gatekeeper to imaging. Most radiologists are comfortable answering questions about when CT is indicated, or whether other imaging modalities may be more appropriate. Imaging physicians are also now increasingly familiar with the concept of tailoring scan parameters to better match patient size in an effort to reduce dose. However, there has been relatively little focus on how examinations like CT can be more deliberately adjusted to match clinical indication. In neuroradiology, for example, most practices still adopt a “one size fits all” approach to CT protocols. A head CT is a head CT, and the selection of parameters such as reconstruction algorithm, tube current and tube voltage is based upon a consideration of what results in the highest technical quality of the final image. Often, significant dose reductions can be achieved in the individual patient by adopting a different mentality, one not based on the absolute quality of the image but rather on the diagnostic quality of the image for a specific clinical indication, and on a consideration of how the ability to detect certain abnormalities ultimately impacts clinical management.

A number of CT protocols lend themselves easily to dose reduction when clinical indication and diagnostic impact are considered together. For example, children with suspected craniosynostosis are frequently referred for evaluation by CT, as it is the best modality to verify the patency of the bony sutures of the calvarium. This diagnostic goal can be achieved with a fraction of the dose of conventional head CT by adjusting CT acquisition parameters to match the diagnostic goal of visualizing the bones of the skull at the expense of the brain parenchyma. There are many examples in virtually every other regionof the body, such aslow-dose screening CT in the lungs of smokers, visualization of stones of clinically significant size in patients with renal colic, and screening the orbits for metallic foreign bodies.

Through a process of continuous quality improvement it is possible to develop a useful monitor of how well CT protocols are matched to indication and ultimately to diagnostic impact. Periodic review of CT studies by clinical indication provides those physicians responsible for CT protocols a powerful tool with which to iteratively adapt examinations to achieve lower patient doses. Additional information is also obtained by input from specialty physicians who make management decisions on the basis of the CT examinations, such as the otologist in the case of temporal bone CT. Taking small steps like these to design, implement, and monitor CT protocols as an imaging physician will set your practice apart from other groups by achieving the lowest possible *diagnostic dose* for ourpatients.

The Technologist

Complementing the physician's role is that of the technologist.The technologist's role in CT protocol review and management is often perceived as being minimal. Technologists are given the scan protocols, usually from the manufacturer and perhaps with some input from a physicist who visits once a year,and they perform the scans as prescribed. However, technologists are not only responsible for performing the scan correctly; they are also at the center of the entire patient experience in the CT suite. They are the individuals who escort the patient into the room, position them on the table, and provide instructions and reassurance over the course of the scan. They must accommodate a wide range of patient medical conditions, patient apprehension, atypical scan situations, and, in many cases, contrast administration. They perform the needed reconstructions, sometimes on separate workstations, network the images appropriately, and provide billing information for the scan. Consequently, the technologist has a very unique insight into the entire scanning session—beginning to end—and the associated workflow. It is this perspective, which is different but complimentary to that of the radiologist and physicist, which makes the technologist an essential member of the protocol review core team. The role of technologist member of the core team, or “protocol technologist”, should be assigned to a single individual who will retain the position long-term.

During the protocol review session the protocol technologist is expected to present his or her perspective on any proposed protocol changes, particularly on how the implementation will affect workflow and patient care. The radiologist defines the imaging task and the physicist determines the technical parameters to achieve the task, but the protocol technologist has the experience and insight to note any practical implementation limitations and to suggest how the workflow and patient experience, including but extending beyond the acquisition of image data, could be improved.The protocol technologist also assumes the role of maintaining and managing the protocol collection. He or she must assure that the protocols are securely kept so they are not altered or removed by other individuals and that they are available in some form to the technologists at the scanner. Maintaining a protocol change history, which lists the major changes, when they were implemented, and who they were approved by, is also very useful. Any outdated protocols should be archived. This provides a documented history of each protocol, which is invaluable if any questions arise regarding the justification for changes, and provides a means to verify that any proposed changes were not previously implemented and then abandoned in the past. Finally, the protocol technologist is responsible for making sure that the correct and up-to-date protocols are programmed in the scanner. The assumption can never be made that updated printed or electronic protocols will be followed if they differ from those in the scanner. However, all technologists at a facility should always cross-reference the electronic (or printed) versions of the protocol to those in the scanner, and to alert the protocol technologist of any discrepancies.

Strategies to achieve Low-Dose in Diagnostic CT

Head CT

In head CT, it is essential that proper attention be paid to the mechanics of scanning. For example, proper gantry angulation can reduce eye lens dose by as much as 87%. Proper patient centering leads to optimal automatic exposure control and image quality[10], with off-center positioning increasing radiation dose and image noise. Each scout should be tailored to the clinical question and should be acquired at a very low dose (e.g., 80kVp and 20–40mAs are sufficient). Good scanning protocols require that the scan series be at a minimum required for the clinical question at hand, and the scan length be targeted and focused. A lower beam collimation is preferred over a larger one as it reduces the contribution by scatter. Similarly, a faster gantry rotation is preferred to minimize motion artifacts.

Optimization of tube current and use of tube current modulation are commonly used for dose minimization. Lowest possible mAs (tube current times the rotation time) is proportional to the degree of intrinsic tissue contrast and acceptable level of image noise. In general, the image noise is proportional to the reciprocal of the square root of mAs. So for tissues with high intrinsic contrast, the scan protocol can be adjusted to have very lowmAs and still answer the clinical question. For example, 30 mAs is sufficient for sinus CT used for planning a functional endoscopic sinus surgery or for pituitary/sellar imaging prior to transphenoidal surgery[11, 12], and a pediatric CT scan for craniosynostosis can be performed at 80kVp, 60 mA and pitch of 1.4 resulting in extremely low dose to the patient (e.g.$CTDI_{vol}$ 1.8mGy, DLP 28 mGy·cm, effective dose <0.1 mSv).

The square root in the relationship between noise and dose implies that doubling the dose only increases the image quality by about 40%. Conversely, a 50% reduction in dose leads to only slightly noisier images that may be adequate for follow-up. Mullins et al [13]showed that reducing the mA by 50% resulted in no change in the HU or the gray-white conspicuity but decreased the contrast to noise ratio by 22%.

Adaptive tube current modulation varies mA both in radial and craniocaudal direction. Substantial dose reductions have been reported by the use of this technique where the amount of reduction depends on the baseline protocol[14].We have found this technique to be more useful for neck CT than in head CT because of the abrupt change in the lateral dimension at the cervicothoracic junction. Adaptive tube current modulation requires selection of a noise index value or another image quality parameter. It has been reported that noise index values of 11.4 and 20.2 result in 20% and 34% dose reduction, respectively [15].

Cardiac CT

Doses from cardiac CT vary markedly between scan modes, for example the dose from axial imaging is typically a fifth of that from a tradition helical protocol. Here too, dose indices vary tremendously between and even within laboratories[16]. The primary tools to enhance justification of cardiac imaging procedures are the appropriate use criteria developed by the American College of Cardiology and American College of Radiology, in partnership with numerous other professional societies[17]. New, multi-modality criteria are being developed focusing on diagnostic tasks rather than particular tests. Unfortunately, several valiant efforts to improve appropriate usehave proven unsuccessful[18]. Some more recent efforts at the point-of-ordering[19] and employing a multi-pronged intervention including letters to referring physicians threatening loss of payer coverage in the absence of a measurable change in appropriateness rate[20]have succeeded, suggesting that perhaps “sticks” are more effective than “carrots” in changing physician behavior.

In cardiac CT, a variety of optimization strategies can be used (Table 2). These include using prospectively-triggered scan modes, such as axial step-and-shoot, volume, and high-pitch helical imaging, as well as tailoring the selection of the x-ray tube potential and current to the patient's anatomy.

As in other CT applications, use of an iterative reconstruction algorithm generally enables comparable image quality at a lower tube current. In nuclear cardiology, dose optimization efforts should focus on tailoring the choice of protocol to the patient [21], generally aiming at using the lowest-dose protocol appropriate for a particular clinical scenario, and on minimizing the administered activity (mCi) to that needed to obtain good image quality with a high degree of confidence.

ChestCT

Radiation dose is directly proportional to scan length, which should be kept as shortas possible for the specific indication. For example, coverage in pulmonary embolism studies in some centers is limited from the top of the aortic arch to 2 cm below the dome of the diaphragm, covering the vessels in which virtually all clinically significant pulmonary emboli can be identified. Coronary studies should be limited to the heart except in patients with bypass grafts. Helical scan mode is routinely performed but results in higher dose compared to axial or sequential scanning, which is commonly used to scan patients with interstitial lung disease where volumetric data is not required. When appropriate, 100kVptube voltage should be used for CTA chest to save dose to patients and improve image contrast. Tube current modulation must be switched on and radiologists and technologists should be trained in recognizing its presence. Iterative reconstruction algorithmscan reduce image noise and thus produce images of diagnostic quality at a lower radiation dose than those produced with filtered back projection.

Protocol optimization that is tailored to clinical indications reduces dosein chest CT. Dual phase (with and without contrast) scans should be avoided in most instances and should not be performed without radiologist approval and a specific clinical need, such as determining the degree of contrast enhancement of a mass, the presence of high-density material such as calcification, or the presence of intramural hematoma in suspected aortic dissection. Volumetric supine contrast CT chest is preferred for assessment of intrathoracic tumors, pulmonary consolidation, to differentiate atelectasis from tumor/infection, pleural or pulmonary abscess and mediastinal disease. For interstitial lung disease, volumetric supine inspiratory scan and axial expiratory and limited axial prone images are performed at the time of initial evaluation but prone images can be avoided on subsequent follow up studies in patients with established ILD. Volumetric inspiratory and expiratory scans are needed to diagnose tracheomalacia and volumetric inspiratory and axial expiratory scans may be sufficient to image patients with fixed tracheobronchial stenosis. Incidental pulmonary nodules including nodules ≤4 mm in a non-smoker, perifissural triangular opacities, pleural tethering, and calcified, fatty and high density nodules do not need to be followed.

For CTA for evaluation ofpulmonary embolism, only an arterial phase scan is required. Electrocardiographicgating of chest CTA will reduce motion artifact in the aortic root but may increase motion artifact elsewhere and will increase radiation dose; it should only be performedif there is a question about root dissection. In patients who are statuspost-surgical repair of the aorta or endovascular stent grafting, non-contrast CT helps differentiate high density material such as calcification or surgical material from active contrast extravasation. However, non-contrast CT can be avoided on follow up CTA studies if there has beenno interval surgical intervention. Use of 100kVptube voltage, tube current modulation and iterative reconstruction significantly reduces dose to patients undergoing CT angiography of the chest. For CT venography of the chest to evaluate central thoracic veins and upper extremityveins, a single volumetric scan acquired at a fixed delay of 120 seconds following 120–140ml of intravenous contrast given at 2ml/sec, with a scan length from mid neck to the bottom of the heart results in adequate visualization in most patients.

Abdominal CT

Compared to the chest where the intrinsic high contrast between aerated lung and soft tissue allows for lower radiation dose, the abdomen generally has overall higher attenuation and lower intrinsic contrast and may require higher radiation dose to obtain diagnostically adequate images. However, there are clinical indications for which scans can be performed at lower radiation dose.

Use of optimal scan parameters and technologies can help in optimizing radiation dose for abdominal CT examinations [22].Most patients with exception of the very large or morbidly obese patients can be scanned at 120kVp or lower. Increasing kVpincreases radiation dose and decreases image contrast on both contrast-enhanced and non-contrast CT examinations.Routine use of 140kVp should thus be avoided for abdominal CT except in morbidly obese patients. Most abdominal CT should be performed with use of automatic tube current modulation techniques to adapt radiation dose according to patient size and geometry. It is important to ensure appropriate centering of the patients when using automatic tube current modulation techniques [23]. Most CT protocols for abdomen must be performed with wider detector configuration and non-overlapping pitch to maximize scanner dose efficiency. Routine acquisition of multiphase abdominal CT (pre- and post-contrast images or pre/post/delayed images) should be discouraged. Iterative reconstruction processing algorithmshave been shown to reduce image noise compared to standard filtered back-projection reconstruction techniques, thus allowing scans to be performed at lower dose[24, 25].

Certain abdominal CT protocols, such as for suspected kidney stone and CT colonography,shouldbe performed at lower radiation dose. Since kidney stones generally have substantially higher CT numbers than surrounding soft tissues, CT for kidney stones should be performed at lower radiation dose compared to the routine abdominal CT and be performed at lower fixed tube current or optimally with use of automatic tube current modulation. A non-overlapping pitch and kVp of 100–120 should be used for imaging urinary tract calculi. Likewise,presence of high contrast between colonic polyps and intraluminal air allowsthe use of even lower dose for CT colonographythanfor kidney stones. CT enterography or CT for evaluation of inflammatory bowel disease can also be performed at lower dose with use of automatic tube current modulation.

CT angiography and the arterial phase of dual-phase liver CT examinations can be performed at 80–100kVp in most small to average size patients to reduce radiation dose while enhancing image contrast. Iterative reconstruction techniques can help reduce image noise in such images and improve acceptability of lower kVp images.

On the other hand, higher radiation doses, with increases in mA or kVp or both, may be required for patients being evaluated for small or low contrast lesions (such as in liver or pancreas) since increased image noise will affect the conspicuity of such lesions.

Pregnancy and Diagnostic CT

CT scanning in pregnancy should be avoided if possible.Radiologists must take into account the benefits of CT versus potential harmful effects to the pregnant patient and the fetus. Maternal health has profound effect on fetalhealth and therefore, CT personnel and referring physicians must balance the potential effects of CT on the fetus versus the requirement for diagnostic information in the mother.

Effects of ionizing radiation on the fetus include both stochastic effects and tissue reactions. Tissue reactions occur when exposure is greater than a threshold level andtheir severity dependson the organ irradiated and the delivered dose. For example, severe mental retardation has a threshold of about 300mGy[26]. Stochastic effects are less predictable, have linear relationship with radiation dose and can theoretically occur at any non-zero exposure.These risks include mutagenesis and carcinogenesis. International Commission on Radiological Protection guidelines state that fetalradiation doses less than 100mGy should not be a reason for terminating the pregnancy[27]. A recent publication estimated fetal radiation doses from abdominal-pelvic CT between 8.6 and 23.4mGy/100mAs, depending on scanner, kVp, and beam collimation[28]. This is a range in which there is real concern for effects on the fetus.

Because of the risksrelated to CT, all women of child-bearing age scheduled for CT should be asked if there is a possibility they might be pregnant. A rapid pregnancy test should be done if there is any uncertainty. If pregnancy is confirmed, then an evaluation should be made as to whether imaging can be delayed until after delivery or at least until after the first trimester, during which the fetus may be most radiation sensitive[26]. As with non-pregnant patients, it is important ensure that there is an appropriate clinical indication for CT and that similar or better information cannot be obtained with imaging tests that do not expose the patient to ionizing radiation, such as ultrasonography and MR imaging. Once CT is deemed appropriate, CT radiation dose should be kept as low as reasonably achievable (ALARA). Written consent should be obtained from all pregnant patients prior to CT scanning after discussing the risks and benefits, including the risks of missed or delayed diagnosis if CT imaging is deferred.

Head CT in pregnant patients does not result in significant radiation exposure to the fetus, and there is thus no need to modify standard protocols. Chest CT does not result in exposure of the fetus to the primary CT beam, but it is exposed to scatter radiation. The most important strategy for reducing radiation dose to the fetus from chest CT is to restrict the scan length to the level of the diaphragm, thus limiting direct irradiation of the abdomen. This should be the standard for evaluation of suspected pulmonary embolism. If lungs are of primary clinical interest with CT, a low dose protocol similar to those used for lung cancer screening should be considered. For chest CT protocols, oral administration of 30% barium sulfate just prior to their CT can reduce radiation doses to the fetus. In many institutions it is standard to shield the abdomen and pelvis of pregnant patients with lead aprons when chest CT is performed. However, since most of the exposure to the fetus is internal scattered radiation, the benefit is largely psychological.

For abdominal CT in pregnant patients, the region scanned should be kept to a minimum, avoiding scanning through the fetus if possible and multiphase CT protocols should be avoided whenever possible. Suspected kidney stones are not uncommon in pregnancy. If ultrasound is not available or non-diagnostic, CT should be performed with lower dose compared to routine abdominal CT since reduced dose CT has been shown to have good sensitivity for kidney stones[29].

CT Guided Interventional Procedures

Spine

Common procedures to relieve spinal pain include epidural, facet joint, nerve root and medial branch blocks. CT guidance ensures accuracy and may improve precision for diagnostic and therapeutic spine injections and may be essential for some procedures such as biopsies. Without affecting outcome, three simple steps can result in significant reduction in radiation to patients undergoing CT guided spine-related pain intervention: reducing tube current; using axial acquisitions for short scan lengths; and eliminating nonessential imaging guidance. This dose-reduction strategy is also effective for significantly reducing radiologist-dependent variability and can be valid for CT guided procedures in all specialties.

CT guided spine procedures may be divided into three phases: “survey” phase consisting of the initial CT acquisition for procedure planning utilizing a grid or marker; “guide” phase where multiple series are acquired during needle advancement to specific target(s); and “contrast” phase during which iodinated contrast may be injected for verification of needle placement. This last “contrast” phase may not be necessary for many CT procedures in different specialties and may therefore be eliminated, further reducing patient dose.

Between 2009 and 2010, 100 consecutive outpatients undergoing spine-related pain injections before (2009) and after (2010) CT protocol modification for radiation dose reduction were retrospectively analyzed. The tube current was decreased for each phase of the procedure. Short image lengths, generally less than 10 mm, were used during guide and contrast phases and therefore switching from helical acquisitions to axial acquisitions significantly reduced radiation dose from over-ranging. The mean total DLP for all procedures decreased 86% from 1458±1022 to 199±101mGy·cm ($p<0.001$). More than 70% of the total DLP reduction was attributable to lower mean DLP during the guide phase (decreased by 926mGy·cm in 2010). Per image series, the DLP during the guide phase decreased by more than 95% from 86±51 to 3±3mGy·cm ($p<0.001$). In 2010, the survey phase of the procedure became the largest component to the total patient effective dose (75%) for the procedure. Dose reduction persisted even when total procedure DLP was normalized to the number of sites and spinal levels injected. All procedures were technically successful and without complications. There were no differences between preand post-procedure pain scores between 2009 and 2010. In 2010, CT guided spinal injections were successful with estimated effective doses as low as 0.17mSv, a dose that is equivalent or lower than has been reported for fluoroscopy guided procedures. Variability between the supervising neuroradiologists was reduced by 95% after the dose-reduction strategy was implemented [30].

Organized efforts in protocol standardization

TheAmerican Association of Physicists in Medicineworking group has identified goals for reducing CT dose: protocol parameters, dose check, and nomenclature standardization. A working group on standardization of CT nomenclature and protocols was formed in 2010 with two distinct goals:

1. Develop consensus protocols for frequently performed CT examinations, summarizing the basic requirements of the exam and giving several model-specific examples of scan and reconstruction parameters.
2. Develop a set of standardized terms for use on CT scanners.

Membership includes medical physicists from academic and consulting perspectives, manufacturer representatives (including the Medical Imaging and Technology Alliance), and representatives from the Food and Drug Administration, American College of Radiology, Digital Imaging and Communications in Medicine (DICOM), and the American Registry of Radiologic Technologists. Recently two pediatric radiologists were invited to help address CT issues faced when scanning children.

The CT protocols are provided by each CT manufacturer and are examined during a peer review process to assure that the protocol is generally reasonable. These protocols are publicly available and to date include CT Perfusion, Adult Head, Chest and Abdomen/Pelvis exams. Exams currently in progress include the adult chest-abdomen-pelvis, and the pediatric head CT.

The process of developing a single set of CT terminology which is not manufacturer specific is very challenging. In the short term, the working group has posted a lexicon (or translator) for current CT terms. The lexicon currently includes manufacturer specific parameter names for 6 CT manufacturers and is publically available at http://www.aapm.org/pubs/CTProtocols/documents/CTTerminologyLexicon.pdf.

This working group has also established radiation dose levels that can be implemented as notification values in the CT Dose Check safety feature found on many newer scanner platforms. A set of education materials regarding radiation dose in CT has been developed in the form of power point files, and is also available on the working group website (http://www.aapm.org/pubs/CTProtocols/default.asp).

Conclusion

Achieving a low dose scan is a team effort requiring tailoring of the scan to the patient and medical question, continuous quality improvement to implement emerging strategies for dose optimization, and awareness of the scanning team to the risk and hence the need for keeping the dose as low as possible. Attaining this goal in practice requires a considerable knowledge base, encompassing radiation physics, biology, and epidemiology, and spanning different clinical applications, team members, and patient populations. The first session of the 2013 UCSF Virtual Symposium on Radiation Safety in Computed Tomography was an attempt to cover much of this information, with the ultimate goal of improving standardization and optimization of CTprotocols for our patients.

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Summary points

- Optimizing radiation dose from CT is a team effort, with responsibility for patient care shared between the referring healthcare provider, imaging physician, technologist, and physicist.
- Patient-centered imaging, which tailors the study to the patient and clinical question, is essential for dose optimization.
- Many best practices are shared among CT applications, including careful selection of tube current and potential, minimizing the range scanned, use of iterative reconstruction, and period review of CT scans.

Table 1

Effective Doses of Some Medical Sources of Radiation

Source	Typical Dose (mSv)	# Chest X-rays
X-ray		
Chest X-ray (PA)	0.02	1
Mammogram	0.7	35
Abdomen: Kidney, Ureter, and Bladder	0.7	35
Nuclear Medicine		
Thyroid (1–123)	2	100
Thyroid (Tc-99m pertechnetate)	5	250
Lung ventilation-perflision (V/Q)	2	100
GI bleeding	8	400
Bone scan	6	300
CT		
Head	2	100
Chest	10	500
Chest (PE)	15	750
Abdomen/Pelvis	10	500
Virtual Colonoscopy	10	500

* From various sources e.g. [1]

Table 2

Optimization Strategies in Cardiac Imaging

Cardiac CT	
Employ dose-reduction methods when possible	
Scan modes	
	Prospectively triggered modes
Optimal selection of tube potential and current	
	Depends on habitus and clinical scenario
	Consider 100 kVp for nonobese patients
	Automatic mA selection using scout film
	Use iterative reconstruction to enable decreased tube current and/or potential
Minimize scan length	
Use ß-blockers to lower heart rate	
Nuclear Cardiology	
Know dosimetry of competing protocols	
^{99m}Tc agents preferred to ^{201}T1 when possible in SPECT	
Consider necessity of each dose injected	
Stress-first/stress-only myocardial perfusion imaging protocol for patients with low	
pretest probability of stress defect	
For CT attenuation correction, minimize tube current	
Hydrate after imaging and encourage early micturition	
Minimize activity (mCi) to that needed to obtain good image quality with high degree of confidence	
Consider lower activity in smaller patients	
Use technological advances to reduce dose	
	Improved reconstruction algorithms
	High-efficiency cameras (e.g., solid-state)