CT Imaging: Radiation Risk Reduction—Real-Life Experience in a Metropolitan Outpatient Imaging Network

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The exponential growth of CT imaging has been fueled by recent technical advances, improved diagnostic accuracy, and medicolegal pressures. CT imaging has replaced many more invasive and expensive tests and has proven itself an indispensable part of diagnostic medicine. This growth in CT imaging, however, has also been accompanied by an unavoidable increased cumulative radiation exposure to the general public. It is important to fully understand the risks and benefits of and alternatives to CT imaging so that an informed decision can be made. A number of simple strategies may be used to minimize radiation exposure during CT imaging. These include protocol redesign and CT dose adjustments on the basis of each patient's body mass index, limiting length of coverage and multiphase examinations, and iterative reconstruction. At Imaging Healthcare Specialists, a highly successful program of radiation dose reduction was created, and dose savings of up to 90% have been achieved in select patients while maintaining diagnostic image quality. The approach is simple, reproducible, and inexpensive.

Key Words: CT, imaging, radiation, risk, reduction

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INTRODUCTION

In the past decade, there have been unparalleled technological advances and growth in CT imaging, with many lives saved and more costly and invasive procedures avoided. Experts estimate that >62 million CT scans are performed each year in the United States, compared with 3 million in 1980; approximately 4 million scans per year are performed in children [1]. An unavoidable consequence of this growth in CT imaging is an increased cumulative radiation exposure to the general public, with a theoretical increased cancer risk. Recent scientific literature suggests that approximately 0.7% to 2% of future cancers may be directly attributable to CT scanning [2,3]. Health care providers therefore have a responsibility to understand these risks and to take steps to mitigate them. To do so, it is necessary to review the biologic effects of ionizing radiation and define the physical properties that determine radiation dose in CT imaging. This knowledge and heightened awareness form the cornerstones of effective radiation dose reduction strategies as detailed below.

Most experts agree on a linear no-threshold model that predicts that any amount of radiation has the potential to cause biologic damage, and the risk is directly proportional to the dose [4]. Importantly, young patients are at higher risk because they are more radiosensitive and have a longer postradiation life span [5].

According to the "Biological Effects of Ionizing Radiation VII report" [6], for every 1,000 patients who receive a 10-mSv exposure, 1 excess cancer is predicted. Considering that the lifetime natural risk for developing cancer is 40%, this is a small incremental risk that should not discourage the use of CT for appropriate indications. The annual unavoidable background radiation is 3 mSv/y.

CT RADIATION DOSE REDUCTION STRATEGIES

Imaging Healthcare Specialists is a physician-owned and physician-operated outpatient imaging network located throughout San Diego County, California. Patients and referring physicians are served by 10 freestanding outpatient imaging centers operating 9 multidetector CT scanners (GE Healthcare, Milwaukee, Wisconsin; and Toshiba Corporation, Tokyo, Japan). In early 2010, Imaging Healthcare Specialists took the Image Gently® pledge, and the executive committee approved a proposal to revise CT protocols focusing on reducing CT radiation dose while maintaining diagnostic image quality for our referring physicians and patients. The goal was to develop smart CT protocols customized for each patient and clinical diagnosis. Key ingredients for success were leadership, commitment, a lead radiologist, a lead technologist, and CT applications special-

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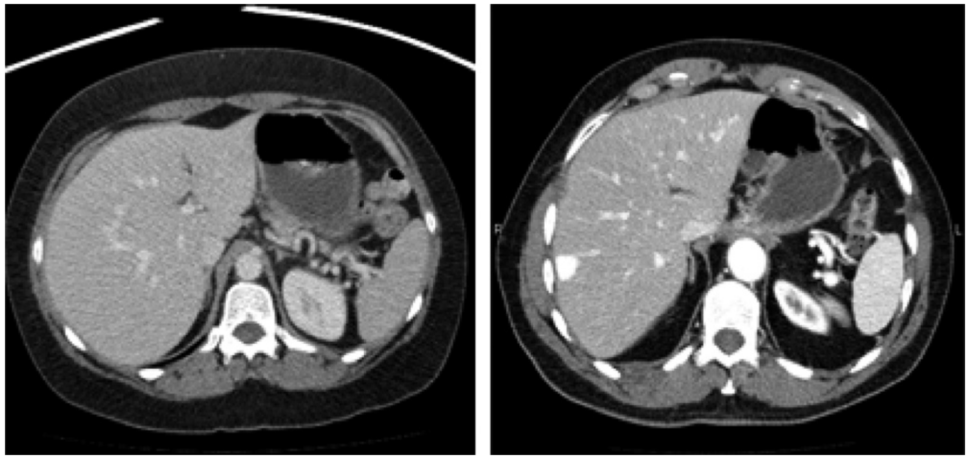

Fig 1. Peak kilovoltage, 120 kVp vs 100 kVp. The axial image on the left was obtained at standard 120 kVp. The axial image on the right was obtained at 100 kVp. Note comparable image quality with expected increased image contrast at reduced peak kilovoltage.

ists. The primary focus was to reduce radiation dose for CT examinations of the chest, abdomen, and pelvis because these constitute the most frequent studies in our practice and those with the highest radiation dose. Ultimately, all imaging protocols were revised.

Our philosophy of CT dose reduction emerged from the Image Gently campaign, which emphasizes the idea that "one size does not fit all." A well-known strategy for reducing radiation exposure for children is to decrease CT dose on the basis of the patient's weight [7,8]. A natural extension was to incorporate this practice to our adult patients. We therefore set out to apply this concept methodically, one patient and one CT protocol at a time, until we arrived at an optimal balance between low dose and image quality. The following dose reduction strategies were developed over months of careful CT dose adjustment and image analysis. Other than the additional time commitment of involved individuals, the financial impact was minimal.

Decreased Peak Kilovoltage

Peak kilovoltage (kVp) is the single most powerful tool for radiation dose reduction because it is related to the dose in a nonlinear fashion. The standard kVp setting for adults is 120. Not all adults, however, are the same size or shape. We elected to use body mass index (BMI) to estimate patient size and adjust CT dose parameters accordingly. Much of our initial motivation to lower dose developed over concerns of unusually high radiation doses delivered during retrospectively gated coronary CT angiography. Previous publications have shown the benefit of reducing kVp from 120 to 100 in nonobese patients during CT angiography [9-11]. In early 2010, we began implementing such a protocol at our Heart Imaging Center. In keeping with published observations, subjective image quality was excellent. It was also readily apparent that the image quality of extracardiac anatomy was preserved. As such, we began using 100 kVp for all patients undergoing diagnostic chest CT and CT angiography with BMIs < 30 kg/m^2. Image quality as judged by 30 board-certified radiologists remained diagnostic, and radiation dose was reduced by 30-40%. It was a natural progression to apply this knowledge and experience to imaging of the abdomen and pelvis. Methodically, we began reducing the kVp from 120 to 100 for abdominal and pelvic CT. We initially decreased the kVp to 100 for patients with BMIs $<$18 kg/m^2. Slowly, we increased the BMI cutoff, until image quality began to erode, establishing a new cutoff of 25 kg/m^2 (Fig. 1). Since that time, we have performed hundreds of body imaging CT examinations. Image quality remains diagnostic, with the benefit of significant radiation dose reduction.

There is also a 140-kVp setting, which may be used for large patients, but we rarely use this option for body imaging because subjective improved image quality is not worth the additional radiation dose. In morbidly obese patients, after consulting a radiologist, the technologist may use this higher kVp, but routine or autonomous application of this kVp setting by the technologist is not permitted. We do routinely use 140 kVp for metal suppression in the spine and extremities.

Finally, for certain CT examinations, low-dose techniques may not be optimal. For example, we use 120 kVp for dedicated liver, renal, and pancreatic protocols in all adult patients regardless of BMI.

Low-Dose Automatic Dose Modulation

All modern CT devices have the ability to automatically adjust the tube current (mA) on the basis of each individual patient's size and shape. This is generically referred to as auto mA. Typically, at the time of installation, each scanner is set by default to standard auto mA. For Toshiba scanners, the amount of noise for auto mA is defined by the standard deviation (SD). For GE scanners, auto mA may be adjusted using a noise index (NI). As the SD or NI is increased, the mA and dose are decreased. For example, the default standard Toshiba setting is an SD of 12.5. Under direct radiologist and CT applications specialist supervision, we began increasing the SD on our Toshiba 64-slice scanner until image quality began to erode, arriving at an SD of 15. Dose was significantly reduced, and image quality remained diagnostic even at 100 kVp. In a similar fashion, we dialed in the optimal SD and NI for the remainder of our Toshiba and GE scanners and in this way established a new low-dose auto mA default.

Decreased Length of Coverage

The length of a scan is directly proportional to the radiation dose. Every centimeter of additional coverage delivers extra radiation. Consequently, it is important to limit the length of coverage (z axis) and the number of phases (arterial, venous, delayed) to include only the clinical region of interest. For each CT protocol, we carefully defined the start and stop points and educated our technologists. For example, each CT scan of the abdomen and pelvis starts at the top of the diaphragm and stops at the inferior symphysis pubis. It is not necessary or desirable to include more lung (or the testicles in male patients) unless clinically indicated. Our renal stone protocol starts at the top of the kidneys and stops at the symphysis rather than including the entire liver. During CT pulmonary angiography, we scan from the lung apex to the costophrenic angle rather than through the adrenal glands, as is customary with standard chest CT.

Pitch

The faster the pitch, the lower the dose. In conjunction with our CT application specialists, we have adjusted the pitch to provide the lowest dose possible while maintaining diagnostic image quality. Ideally, the pitch should be >1.

Limit Double Scans and Multiphase Examinations

Physicians often order CT scans without and with intravenous contrast. With the exception of head CT, CT urography, and dedicated renal mass, pancreatic, or aortic stent graft protocols, the without-contrast phase adds little additional diagnostic information but significantly increases radiation dose and cost. This practice, commonly referred to as double scans, has been discouraged. In addition, when performing multiphase examinations of the liver, we either eliminate the without-contrast phase or lower the dose and use 100 kVp regardless of BMI. The arterial and venous phases are routinely performed with an optional limited delayed phase to include only the lesion of interest rather than the entire liver.

Low-Dose Follow-up CT Examinations

Several types of follow-up CT examinations lend themselves to manual low-dose techniques with reduced mA and kVp. Examples include CT colonography, CT abdominal and pelvic stone protocols, and abdominal or pelvic CT for abscesses after percutaneous drainage. These examinations may be performed with low fixed mA (50-75 mAs) and 100 kVp for all patients, regardless of BMI. This strategy may reduce dose up to 90% in select patients.

Iterative Reconstruction and Noise Reduction Software

The standard type of image reconstruction in CT is filtered back projection. Iterative reconstruction is the newest method of image reconstruction and is available as an option on most new scanners. It is also available on some older scanners as a retrofit option. Although expensive, it is a highly effective method of reducing image noise and can reduce patient dose by 40% to 50%. There are also third-party vendors with noise reduction software options that are less costly and potentially just as effective at reducing dose. One such product, SafeCT® (Medic Vision Imaging Solutions, Tirat Carmel, Israel), has been successfully deployed at Imaging Healthcare Specialists, with a dramatic reduction in radiation dose while maintaining diagnostic image quality (Fig. 2). We used SafeCT in conjunction with our existing low-dose smart CT protocols. SafeCT recommended further lowering the mA by increasing the SD or NI by a factor of 1.4. For example, we increased the SD from 15 to 19 on our Toshiba scanners and the NI to 35 on our GE devices. This resulted in a further decrease in mA by approximately 50%. The only exception was morbidly obese patients with BMIs > 40 kg/m^2. In this patient population, we use 120 kVp, low-dose auto mA, and SafeCT without further increasing the SD or NI. We have found this combination to produce diagnostic quality and a reasonable radiation dose exposure.

The benefits of SafeCT extend beyond body imaging, and this technology is used routinely for all CT examinations. Sinus CT examinations, for example, are now routinely performed with dose estimates similar to a routine chest x-ray, or approximately 0.1 mSv.

It is important to emphasize that the greatest dose savings can be achieved only by implementing smart CT protocols first and then applying iterative reconstruction. The smart CT protocol is as follows:

- For chest CT, use 100 kVp for patients with BMIs < 30 kg/m^2.
- For abdominal or pelvic CT, use 100 kVp for patients with BMIs < 25 kg/m^2.
- Use low-dose auto mA.
- Limit the length of coverage and the use of multiphase examinations.
- Add iterative reconstruction.

CT-guided Biopsies

CT-guided biopsies and percutaneous interventions should routinely be performed with low kVp of 80 to 100 and reduced fixed mAs of 50 to 75. The length of the scan should also be shortened to include only the region of interest.

Bismuth Breast and Thyroid Shields

Breast and thyroid shields have routinely been placed on patients to reduce anterior dose. Breast and thyroid

Fig 2. Renal stone protocol in a patient with previous gastric bypass and a body mass index of 39 kg/m^2. The left image, at 120 kVp with low-dose automatic dose modulation, with a dose-length product (DLP) of 1,060 mGy · cm and a dose of 15.9 mSv, shows the left lower pole renal calculus and left-sided hydronephrosis. The center image (follow-up CT examination), at 100 kVp and 50 mAs, with a DLP of 160 mGy · cm and a dose of 2.4 mSv, shows the left lower pole calculus with increased image noise. The right image, using SafeCT postprocessing, shows a substantial reduction in image noise.

shields may reduce dose to these sensitive organs by up to 30% to 40% [12]. Step-off pads placed under the shields minimize beam hardening artifacts. On the basis of recent recommendations from the American Association of Physicists in Medicine, however, we have discontinued the routine use of such shields. According to this document, shields may cause unpredictable changes in automatic dose modulation (auto mA) with certain scanners and degrade image quality [13]. Furthermore, we have concluded that the combination of smart CT protocols and SafeCT iterative reconstruction is a superior method of dose reduction, and we do not wish to introduce variables with uncertain effects on image quality.

Implementation of a Comprehensive CT Radiation Dose Reduction Program

At Imaging Healthcare Specialists, we have successfully implemented the above-outlined strategies, with a marked reduction in radiation dose while maintaining diagnostic image quality for our patients and referring physicians. To implement such a program requires dedication, leadership, and commitment. Key components include a lead CT physician, a lead CT technologist, a CT applications specialist, a continuous feedback loop, and systems in place to educate staff members and audit compliance.

An important part of success is having robust IT and PACS in place. For example, using DR Systems' PACS (DR Systems, Inc, San Diego, California), our technologists enter key patient history information in the "Tech Notes" field, which is included in the demographics screen. We require technologists to enter a BMI for each patient. This allows the radiologist to review each CT examination and assess image quality and CT parameters in relationship to patient size and shape. If the protocols are not followed, the radiologist can send the technologist a "QA Tech" note with constructive feedback. The lead CT technologist also monitors these notes and provides further education as needed. We have all CT protocols, policies, and procedures posted on our intranet for rapid access. In addition, random audits are performed and reviewed for protocol compliance. This is an important step, because protocol "drift" invariably occurs. Feedback to technologists is never punitive.

Finally, data should be sent to the ACR's Dose Index Registry so that results can be analyzed against national benchmarks. The registration process and data entry are straightforward but do require a nominal time commitment by the lead CT technologist. On the basis of initial Dose Index Registry results, Imaging Healthcare Specialists has emerged as a low-dose leader compared with similar sites throughout the country (Fig. 3). For example, our median size specific dose estimate for a CT abdomen and pelvis with intravenous contrast (10 mGy) is less than half the national average (23 mGy). These data further validate our approach and should encourage others to institute similar protocols in their practices.

CONCLUSIONS

It is possible to perform high-quality CT at a fraction of the radiation dose previously thought possible. Using a combination of dose reduction strategies with or without iterative reconstruction, risks can be minimized, thereby

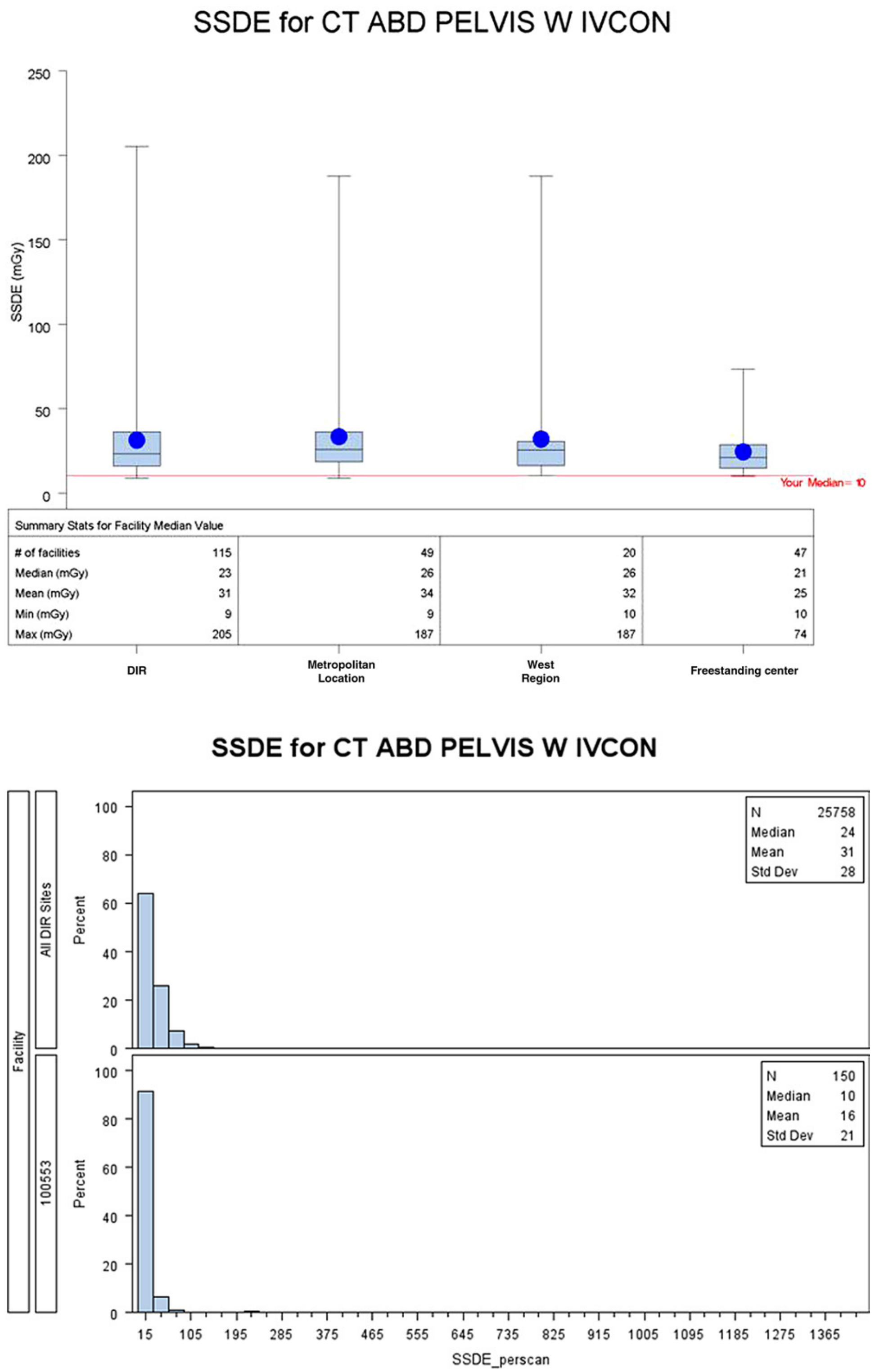

Fig 3. Screen capture from ACR Dose Index Registry reports size specific dose estimate (SSDE) for abdominal pelvic CT with IV Contrast. Imaging Healthcare Specialists' facility is compared using a box plot and histogram with other registrants. Note that the facility's box plot median dose of 10 mGy (red line online) is significantly below the median SSDE of 23 mGy. The histogram (below) also shows the facility's mean SSDE (bottom panel) is significantly lower than others. The facility's mean SSDE is 16 mGy, compared with a mean SSDE of 31 mGy for all other DIR sites.

ensuring the health and welfare of our patients. Please see appendix below for a list of useful low dose resources.

TAKE-HOME POINTS

- Peak kilovoltage is the single most powerful tool for radiation dose reduction because it is related to dose in a nonlinear fashion. Reducing the kVp from 120 to 100 will decrease the radiation dose by 30% to 40%.
- The automatic exposure control of each CT scanner may be set to a new "low-dose default."
- Peak kilovoltage may be reduced according to an individual's BMI. For chest CT examinations, 100 kVp may be used when the BMI is <30 kg/m^2. When scanning the abdomen and pelvis, 100 kVp may be used when the BMI is <25 kg/m^2.
- Smart CT protocols include (1) reduced kVp on the basis of BMI, (2) low-dose auto mA default, and (3) limited length of coverage and multiphase examinations.
- The greatest dose savings may be achieved by adding iterative reconstruction software to preexisting smart CT protocols. This may reduce the radiation dose by 90% in select patients.
- A successful comprehensive CT radiation dose reduction program requires leadership, commitment, a lead radiologist, a lead CT technologist, and CT applications specialists.

APPENDIX

Resources

ABIM Foundation Choosing Wisely™ campaign	http://www.abimfoundation.org/News/ABIM-Foundation-News/2011/ABIM-Foundation-Announces-the-Choosing-Wisely-Campaign.aspx
ACR Dose Index Registry	https://nrdr.acr.org/Portal/DIR/Main/page.aspx
FDA, "Radiation-Emitting Products"	http://www.fda.gov/Radiation-EmittingProducts/default.htm
Image Gently® campaign	http://www.pedrad.org/associations/5364/ig/
Imaging Healthcare Specialists	http://www.imaginghealthcare.com
Image Wisely® campaign	http://www.imagewisely.org
SafeCT (Medic Vision Imaging Solutions)	http://www.medicvision.com/usa/
RadiologyInfo.org	http://www.radiologyinfo.org
X-RayRisk.com	http://www.xrayrisk.com

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