

UCSF

UC San Francisco Previously Published Works

Title

Practical CT Dose Monitoring: Current Tools and the Clinical Relevance

Permalink

<https://escholarship.org/uc/item/7d37h1gg>

Journal

Seminars in Roentgenology, 53(2)

ISSN

0037-198X

Authors

Cross, Nathan M

Zamora, David A

Moirano, Jeff M

et al.

Publication Date

2018-04-01

DOI

10.1053/j.ro.2018.02.002

Copyright Information

This work is made available under the terms of a Creative Commons Attribution-NoDerivatives License, available at <https://creativecommons.org/licenses/by-nd/4.0/>

Peer reviewed



Practical CT Dose Monitoring: Current Tools and the Clinical Relevance

Nathan M. Cross, MD, MS,^{*} David A. Zamora, MS,[†] Jeff M. Moirano, MS,[†]
Michael N. Hoff, PhD,[†] and Kalpana M. Kanal, PhD[†]

Introduction to Dose Monitoring

Radiation dose stewardship and safety is critical to the mission of every radiology department. Unfortunately, active management of radiation dose has been driven by occasional mishaps that have drawn the focus of both the public and the industry professionals. An effective dose monitoring program ensures patient safety without sacrificing clinical image quality, and facilitates protocol optimization, operation, and dissemination. The diagnostic task should be the foundation of every imaging protocol and the key to determining the appropriate technique parameters—and thus radiation dose—for an examination. The methods by which dose can be manipulated through CT scan parameters have been discussed elsewhere. This article will review the clinical need to scrutinize and optimize protocols, and present tools for oversight by offering one institution's approach to monitoring and improving examinations over a multisite academic enterprise.

Tools for Radiation Dose Monitoring

Multiple methods of radiation dose management in CT have become available over recent years, some in response to requirements set by regulatory/oversight/accreditation bodies. These different approaches establish recipes for radiation dose monitoring through comparison to peers, leveraging internal metrics of performance, or by putting systems in place to decrease the risk of overexposure. The following subsections detail some different common methods of dose management.

American College of Radiology Dose Index Registry

The American College of Radiology (ACR) Dose Index Registry (DIR) is a component of the National Radiology Data Registry that collects and analyzes data pertaining to CT radiation dose from an extensive network of facilities throughout the country.¹ These comparisons provide a method for a site to assess their scan protocols against a robust set of benchmark data and make informed decisions for CT dose optimization.¹

Participating sites provide anonymous scan and dose data from all CT radiation events to the DIR through a dedicated server pathway either direct from the modality itself or via an intermediate software package. Each site must map each of its individual scan protocols to a standardized RadLex Playbook identifier² in order to allow a direct comparison with similar protocols at other institutions. (Fig. 1) After the initial server configuration and mapping steps are complete, dose data will automatically and continuously be sent to the DIR with minimal maintenance from the site.

The DIR distributes a summary report of the data collected from all institutions on a regular basis. Sites are categorized based on geographical and clinical demographics such as location, size, and type of institution. The aggregate data for each particular RadLex Playbook identifier is compiled for all examinations that reach a sufficient number of scan instances nationwide. Reports include dose metrics such as volume CT dose index (CTDI_{vol}), dose-length product (DLP), and size-specific dose estimate (SSDE). Historic data for each site is also presented to allow for trend analysis. Statistical measures such as median and various percentiles are generated for each identified scan type of the combined data, individual sites, and demographic categories. Site protocols that are outside of the combined interquartile range are highlighted for easy identification. Data for patients aged 18 or older are compiled as a singular adult group, while several age ranges are described for patients under the age of 18.

Data submitted by each site is also accessible via the DIR website where various methods of database access are available. This allows a site to assess its own data by scanner, date range,

^{*}Department of Radiology, University of Washington, 1959 NE Pacific Street, Box 357115, Seattle, WA.

[†]Department of Radiology, University of Washington, 1959 NE Pacific Street, Box 357987, Seattle, WA.

Address reprint requests to Nathan M. Cross, MD, MS, Department of Radiology, University of Washington, 1959 NE Pacific Street, Box 357115, Seattle, WA 98195–7987. E-mail: nmcross@uw.edu

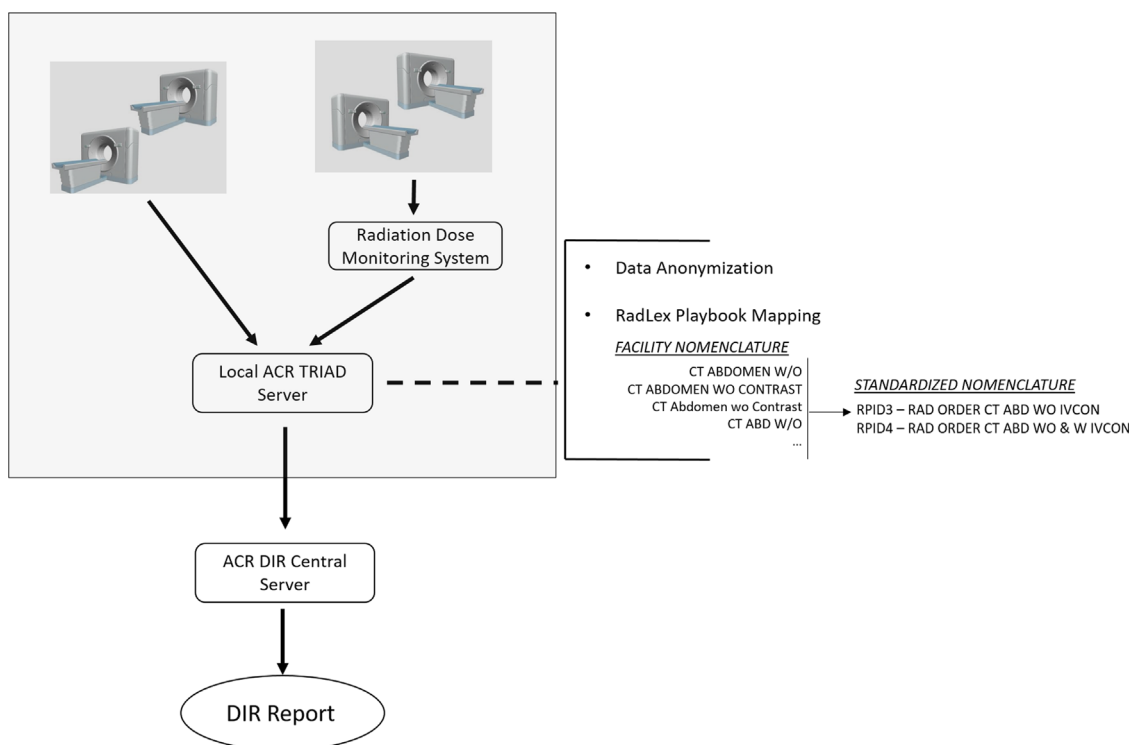


Figure 1 Data flow from site to Dose Index Registry. Individual sites push data (eg, image data, radiation dose structured reports, etc.) directly to a local ACR Triad server directly (Left) or via a radiation dose monitoring system (Right). Data are associated with a RadLex Playbook ID (RPID) as defined by each facility. The Local TRIAD server de-identifies the information to assure anonymity and then forwards it to the ACR DIR Central Server. Aggregate results are summarized in the DIR Facility Report, which is shared with all participating sites.

or exam types. Data can be presented in several formats, including figures, tables, or raw data downloads.

The DIR is one of the most extensive sources of data available for CT dose comparisons, both currently and historically. It facilitates robust and up-to-date comparisons from an individual site to that of its peers. Using data collected in these efforts, diagnostic reference levels have been suggested for common examinations.³ An important distinction between the DIR and previous attempts to aggregate dose data is that the dose metric data are continuously updated to remain current and reflect advances in technologies and techniques as they are deployed in the clinic.

Owing to the extensive volume of information available through the DIR, it is important to have a clear understanding of how the data are collected and presented. Radiology practice varies throughout the country, and thus some compromises must be made in data standardization to permit direct comparisons. The complex nature of the data leads to challenging decisions on how to best categorize and define the output dose measures. Careful consideration should be made to ensure that there is no confusion about the data handling and analysis process.

One of the biggest challenges in establishing a national registry is achieving consistency across the many individual sites. Mapping individual CT exam protocols to the RadLex playbook is a crucial task for each site and is a challenging and time-consuming process. At large institutions, thousands of protocol names may need to be accurately classified. Uncertain

or unreliable mapping may compromise the integrity of the data and confound its analysis. Care should be taken to succinctly describe each examination type so that they may be accurately mapped to the playbook such that a functional comparison may be made.

A limitation in the use of the RadLex Playbook is that certain examinations may appear to fit into more than one category. Making very granular and specific RadLex playbook designations may allow for more precise comparisons, but the drawback is limiting the number of examinations and statistical power available in each specific classification. Furthermore, multipart examinations are difficult to describe under one identifier by their nature.

At our institution, we review the DIR aggregate reports and make note of any exam group's dose data that are outside of the national interquartile range. The individual examinations that comprise these groups are collected and sorted based on attributes such as scanner unit or protocol names in order to determine the source of deviations from the national data. After a review of the scan parameters, various colleagues are consulted to discuss anomalies. This could include a lead technologist who assures that the examination is properly classified, or a radiologist who provides expertise on anatomy and image quality attributes. The team attempts to identify any areas that can be optimized with regard to patient dose, without compromising diagnostic quality or adversely impacting workflow. The implementation strategies for any proposed changes are discussed at a meeting of stakeholders

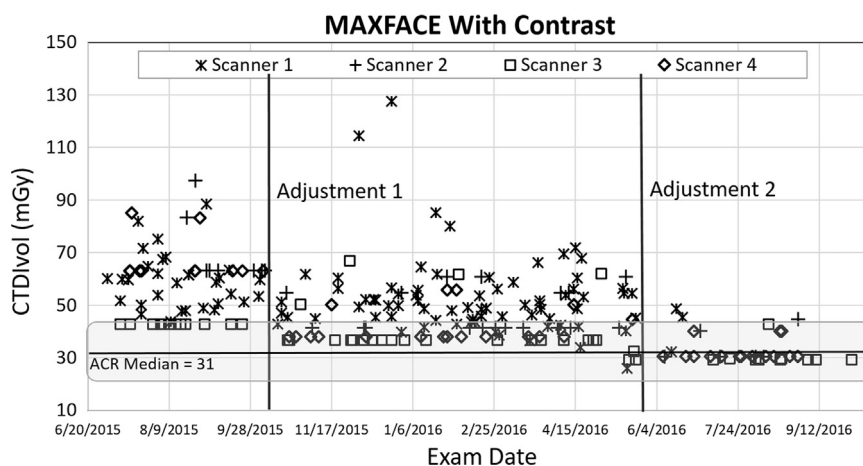


Figure 2 Protocol adjustment following data analysis. The Maxface with contrast examination was identified as having a dose much higher than the national median. After consulting with stakeholders, 2 separate protocol adjustments were made incrementally to bring the typical CTDIvol for this exam type closer to the national median.

[radiologists, technologists, physicists...], or addressed at a CT protocol review committee. We have been successful in reducing patient doses without affecting the diagnostic quality of the examinations by employing this method. Notably, we have realized that it is efficacious to make incremental changes in technique to limit any unintended image quality consequences (Fig. 2).

Radiation Dose Monitoring Systems

The Radiation Dose Monitoring (RDM) systems are now widely available dose monitoring systems.⁴⁻⁶ These software-based systems collect dose information through the Picture Archiving and Communications System (PACS) or individual imaging systems.⁷ RDM systems actively collect data and generate e-mail alerts when an examination exceeds a predefined dose threshold (Fig. 3).

At our institution, we use DoseWatch (version 2.2, trademark of General Electric Company), an enterprise-wide dose management system which automatically collects and analyzes patient radiation dose metrics across multiple facilities, imaging modalities, and vendor imaging environments.⁴

Prior to installation of this RDM at our institution, dose information could not easily be collected for analysis from the CT scanner. Further, limited monitoring was performed retrospectively and periodically, and was therefore, not real-time. One benefit of using RDM systems is active and rapid collection of data and alerting. When the dose for a CT examination exceeds a predefined threshold, the RDM system automatically notifies users via e-mail (Fig. 3).

Specific advantages of using RDM in CT include the acquisition and storage of data including patient-specific historical dose (cumulative and exam-specific), size-specific dose estimates, exam-specific patient-centering information, site-specific and exam-specific dose comparison analyses, and comparison to national benchmarks and diagnostic reference levels.

The predominant disadvantage of the RDM is the cost. Beyond the initial software costs, timely IT support is essential for installation and successful connection of multivendor systems. Further, there are ongoing maintenance tasks and upgrades that occur with some regularity. This may be a concern for hospitals where dedicated IT support and sufficient funding is not available.

Overall, each institution should assess the costs and benefits of characterizing the current CT practice. The benefits of monitoring CT performance are numerous, but they should be weighed against cost expectations of system management.

The XR-25 Standard: CT Dose Check

Dose Check is a software solution that is incorporated into the individual CT scanner system that displays a message if a currently prescribed CTDI_{vol} or DLP value surpasses predefined values. In practice, alerts are generated based on one of two underlying predefined technique parameters: the user is informed if the dose exceeds a predefined value computed from those parameters prior to patient irradiation. Therefore, it offers some practical advantage over other approaches in that it allows for a verification that the prescribed technique parameters lie within a user-defined “normal dose” before the patient is irradiated.⁸

In an effort to improve the safety record of CT service providers, multiple regulatory and advisory bodies implemented requirements aimed at improving the availability dose management tools. Most notably, the Centers for Medicare and Medicaid Services (CMS), under the authority of the Protecting Access to Medicare Act (H.R. 4302; P.L. 113–93, enacted 2014)⁹ now requires that CT scanners meet the standards set forth in the National Electrical Manufacturer’s Association (NEMA) XR-29 SmartDose publication.^{10,11} One component of the SmartDose requirement is the availability of CT system’s dose check functionality described in NEMA XR-25.⁸

Patient Series Radiation Dose Notification						
Patient Information						
Patient internal key: [REDACTED]						
Patient ID: [REDACTED]						
Domain: UW Medicine						
Reason for Notification						
This alert is triggered by the following event(s):						
Examination CTDI_{vol} is over CTDI_{vol} threshold						
Alert Type	Series	Target region	Measure	Value	Warning	Alert
Protocol	4	Abdomen	CTDI _{vol} (mGy)	21.89	13.11	16.42
Study Information						
Date / Time:			2017-09-14 [REDACTED]			
Device:			UMCT3			
Model:			Discovery CT750 HD			
Modality:			CT			
Site:			University of Washington			
Accession number:			[REDACTED]			
Study Description:			A/P W			
Protocol:			6.5 A2 ABD/PELVIS W/CONTRAST, DMPPR**small**			
Standard Study Description:			RPID145 : RAD ORDER CT ABD PELVIS W IVCON			
BMI:						
Weight (Kg):			94.0			
Height (cm):			0.0			

Figure 3 DoseWatch dose alert. A snapshot of an alert generated by the dose management system DoseWatch (version 2.2, trademark of General Electric Company) indicates that the examination CTDI_{vol} is greater than the CTDI_{vol} threshold. The CT abdomen exam has a CTDI_{vol} value of 21.89 mGy, which is higher than both the warning level of 13.11 mGy and the maximum CTDI_{vol} of 16.42 mGy for this type of examination. This value (16.42 mGy) is generated from a moving average over the past 6 months. (Color version of figure is available online.)

The Table summarizes the main attributes of the 2 primary terms introduced in the Dose Check standard: (1) Notification Value (NV) and (2) Alert Value (AV).⁸ The 2 terms serve different purposes, but share the goal of lowering the likelihood of radiation overexposure. The NV is a local or incremental threshold (CTDI_{vol} or DLP) that is compared to a value derived from currently prescribed scan parameters within an individual series. Because of the incremental nature, an appropriate NV should be assigned for every series on every scanner protocol. If a particular series is projected to surpass the NV, a notification message is displayed, and the technologist can either modify the scan parameters to lower the projected dose or provide a diagnostic reason for surpassing the NV.⁸

The AV is a global threshold (CTDI_{vol} or DLP) that is compared to the z-axis distributed cumulative dose over the

course of the entire examination. Only a single AV is prescribed that applies to all the CT scans performed on a given patient (with adult and pediatric options possible).⁸ Figure 4 offers 2 different scanning scenarios, where one can imagine that over the course of the examination, a histogram of cumulative CTDI_{vol} vss z-axis scan location is being generated. Only if the maximum z-location CTDI_{vol} is projected to exceed the AV will an alert message be displayed. The technologist has the option to modify the parameters or to provide a diagnostic reason for exceeding the AV while providing an AV Exceeder login. An AV alert message is meant to mitigate acute skin effects (eg, erythema and epilation) over the course of the whole exam, whereas the NV ensures that no single incremental dose exceeds what is determined to be “above normal.”

An important consideration in using Dose Check is where to set the NV and AV thresholds. Regarding NV, the AAPM has released general recommendations delineated by patient age, body region, or examination type.⁸ However, individual practices may also employ internal dose metrics, DIR data, or other dose-monitoring sources for guidance. For the AV threshold, the FDA has recommended a default CTDI_{vol} value of 1000 mGy, which corresponds to approximately one-half of the dose that would lead to skin injury.^{12,13}

Another important consideration when using Dose Check is the establishment of a technologist response tree to promptly address alerts. The technologist response may vary with institution, depending on the clinical setting. For example, a neighborhood clinic may require the technologist to attain radiologist’s approval to surpass a threshold, but a trauma center may give the technologist individual authority to bypass threshold alerts when time is critical. Ultimately, the responsibility lies with the individual practice to set appropriate thresholds and to establish a reasonable clinical response when a Dose Check alert occurs.

Protocol Review and Management

CT protocol reviews are receiving increased attention and are now required for ACR CT accreditation¹⁴ and by the Joint Commission.¹⁵ One of the responsibilities of the lead CT radiologist is to convene a team that includes the supervising radiologist, the medical physicist, and the lead CT technologist to design and review all new or modified CT protocol settings to ensure that both image quality and radiation dose are appropriate. The benefits of reviewing protocols on a regular basis are as follows: eliminating unused protocols, optimizing high-dose protocols, adding new protocols, modifying protocols, and standardizing protocols across sites.

At our institution, it is the practice for the section chief of each imaging section (eg, body, neuro, MSK etc.) to initiate, participate, and ensure participation from the CT technologist/s, medical physicist/s, and other radiologists in CT protocol meetings. The protocols are projected on a screen and the technical scan parameters, dose, injected contrast, and number of phases are reviewed. Subsequently, edits are documented, protocols are updated, and they are applied to all CT scanners (Fig. 5).

Table Summary of Attributes for Notification and Alert Values.

	Notification Value (NV)	Alert Value (AV)
Where it applies	At local level, per series (or group)	Z-axis distributed cumulative dose throughout the examination
What is compared	Estimated CTDI _{vol} (or DLP) vs assigned NV	Max cumulative CTDI _{vol} (or DLP) vs assigned AV
User notice	Warning message, user provides name and diagnostic reason for exceeding NV	Warning message, "AV Exceeder" credentials entered along with diagnostic reason for exceeding AV

All CT protocols at our institution are reviewed annually and published internally online. After formal review, any protocol changes require that a CT change control form are submitted, reviewed, and discussed prior to implementation (Fig. 6).

This process is time intensive for institutions with many CT protocols. The strategy can be modified to first review frequently used and high-dose protocols before others. Another option is to consider vendor-specific protocol management systems. These systems can manage protocols online, compare protocols from different scanners and institutions, make edits, and automatically send changes to CT scanners for implementation.¹⁶ These systems are currently being actively developed.

Other scenarios that may initiate protocol review include a dose alert from a dose management system discussed above (Fig. 3). If alerts consistently show high doses, the protocol will be assessed for review and any adjustments needed. We also participate in the ACR DIR, and the reports from the registry show how our data compares to other hospitals in the United States. This information can also trigger a protocol review if our doses are high compared to others (Fig. 7).

Overall, though the process of protocol review is beneficial, the associated details and logistics are not well codified. An approach driven by quality improvement, consensus among the various team members of the CT protocol review

committee, and robust communication (both for proposed and implemented changes) are exceedingly important.

Clinical Relevance of Dose Monitoring

Ionizing radiation's risks have been discussed and debated in the clinical and popular press extensively. Radiation's effects are usually divided into stochastic and deterministic categories. Deterministic effects include skin changes, cataracts, sterility, radiation sickness, and teratogenesis. Presentation is usually only slightly delayed from exposure (hours/days/weeks), with the exception of cataracts. Accidents with CT perfusion imaging have highlighted some of the deterministic effects including skin erythema, burns, and epilation. In contrast, stochastic effects are much more difficult to study because of the random chance associated with their incidence and the significant delay before they present clinically, usually greater than 10 years. The main function of dose monitoring is to ensure diagnostic imaging doses optimized to avoid tissue reaction and to minimize stochastic risk. It is also prudent to follow the ICRP system of radiation protection which is based on 3 fundamental principles: justification, optimization, and dose limitation.¹⁷ Justification implies that radiology

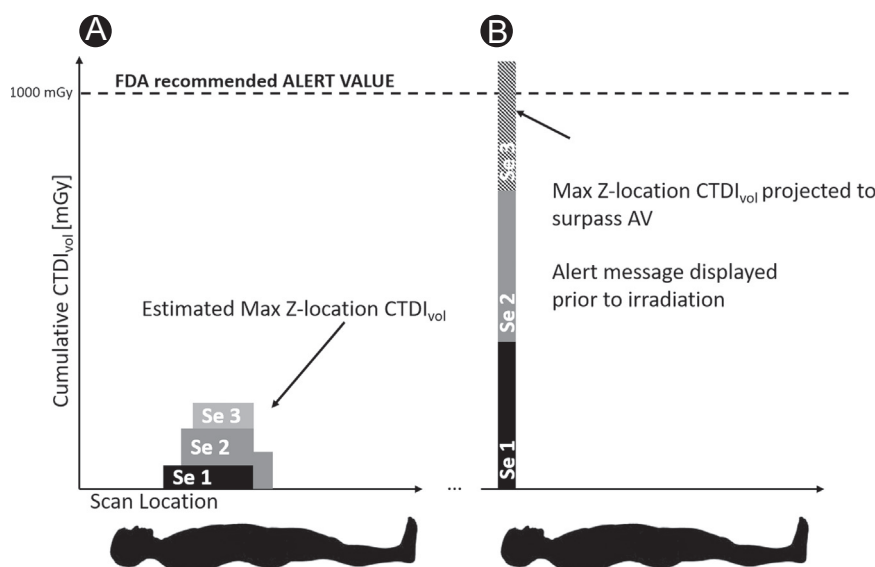


Figure 4 Dose Check alert value. Sample application of Alert Value being compared to the estimated max z-location for (A) multiple series (Se) performed that does not lead to an alert message, and (B) multiple scans over the same region of the brain that would lead to an alert message.

Revolution Abdomen Protocols

last edited 12/13/16

Protocol # A2

Abdomen/Pelvis survey Scan

Anatomy Selection
Diaphragm to Ischial Tuberosities
SFOV Large Body
DFOV to cover anatomy
kV and mA Control
Manual 80 to 120 kV
Smart/ Auto mA 80-740/NI(see chart)
Contrast
Optional If w/iv, Use P3T
Timing
Smart Prep @ upper ¼ liver, SOHu threshold
Scan Type Axial
Coverage Speed One or More/SC 0.28-1.0sec
Primary Recon 0.625mm/Std/ASIR V 70/400@40
Gating And Trace Off



Scout

0.625mm std

0.625mm STD ASIRV 70 Recon mode +

Cor Body

Sag Body

Abd/Pel 2.5mm STD ASIRV 70 Recon mode +

Coach for breathing instructions **Breath hold for the duration of the scan**

IV CONTRAST: Optional, If w/ IV use P3T program

Oral Contrast Omnipaque solution for positive,

Breeza for Negative Icup @ 1hr prior to study, Icup @ 30min before study, 2cups on the table

Small(<= 34 FOV)	17NI	80- 100 kVp
Med(35-41 FOV)	18 NI	100-120 kVp
LG(>= 42 FOV)	20 NI	120 kVp

Bill as:

CABDPELWC, CABDPELW0/06360095+volume given, as directed by P3T program

Figure 5 Example of CT protocol data sheet. Abdominal scan technical parameters, reconstruction settings, and contrast prescription are listed. Technique variations related to patient size (delineated by Field of View—FOV) are provided, in addition to the date of last edit.

examinations ordered on a patient should do more good than harm, optimization depends on As Low As Reasonably Achievable (ALARA) principles, and dose limitations implies that dose to individuals from planned exposure situations (ie, to personnel) should not exceed appropriate limits.

The clinical impact of a dose-monitoring program is in optimizing clinical image quality while using the minimum amount of radiation to answer the clinical question. Before any assessment of image quality is made, the clinical question must be clearly defined. In a modern radiology setting, this can often be a technical challenge in itself owing to a lack of readily available clinical information, and a poor or misleading clinical indication provided. The goal is not to produce elegant images but clinically adequate images; thus, imaging protocols should be considered individually and subdivided by purpose if the same clinical question may be answered with a lower dose scan.

Central to the concept of dose monitoring is the adequacy of a given scan technique to answer the clinical question. If the images are of insufficient quality, technique parameters should be changed and the dose may be increased as a result. More difficult to determine is the possibility that the image

quality—and thus radiation dose—exceeds the clinical need. This is complicated by the desire to consistently obtain a diagnostic quality exam for every patient without needing to repeat an exam. This challenging balance between clinical needs and adhering to ALARA is the principal goal of a dose monitoring program and requires input from multiple stakeholders to ensure diagnostic yet safe clinical care.

Diagnostic imaging protocols contain a variety of parameters that affect the administered radiation dose. The most direct are the tube voltage (measured as kV) and tube current-time (measured as mAs). These settings affect the energy and number of photons in the beam, respectively. Filtering of the beam also affects its average energy and can optimize the energy profile in the beam. Restricting the scan extent is another way to minimize dose while imaging only areas of clinical interest. Contrast timing is a complex task with multiple approaches, but the number of phases in an exam can quickly increase an exam's dose. General dose reduction in CT has been discussed elsewhere.

CT image reconstruction uses raw projection data from the scanner to create clinical two-dimensional images. In addition to conventional Filtered Back-Projection (FBP), alternative

CT CHANGE CONTROL

Submission Date: 10/1/2015

Proposal: Decrease "Max Face with contrast" CT Protocol Dose

Proposal: Decrease the max face with contrast CT protocol dose by reducing kV and mAs**Reason for Change:** Our doses are higher than the national level according to the ACR DIR median CTDI_{vol}. We want to decrease dose so we are more in agreement with national datao **Requested By:** Physicists**Who does this potential change impact:** Patients, Radiologists**Need discussion at CT meeting?** ☒ Yes ☐ No

When finished with the proposed form, place the document in the "Awaiting Approval" folder on server A, and distribute via xxx@xxx.edu

Approval:

This proposal was: ☒ Approved ☐ Not Approvedo **Approved by:** Members of CT committeeo **Date:** 10/14/2015o **Reason for Denial:****Who will implement this proposal:** Lead CT Technologist**Target Date for Implementation:** ☒ ASAP ☐ Routine

Implementation:

Who is responsible for this: CT Lead Tech**IMPLEMENTATION STEPS:** (An empty box assumes "N/A")

	Date	Completed by:	How was this done?
Communication to Leads	10/20/2015	CT lead Tech	Email
Communication to Techs	10/20/2015	CT lead Tech	Email
Communication to Radiologists	10/20/2015	CT lead Tech	Email
Comm. to Residents / Fellows	10/20/2015	CT lead Tech	Email
Comm. to Clinicians	10/20/2015	CT lead Tech	Email
Communication to Physicists	10/20/2015	CT lead Tech	Email
Change on Scanner(s)	10/20/2015	CT lead Tech	On scanner
Discussion with Coding /Billing	10/20/2015	CT lead Tech	Email
Protocols Updated	10/20/2015	CT lead Tech	On protocol page
Other			

o **Comments:**

Completion:

o **Completed by:** CT Lead Techo **Completion Date:** 10/20/2015o **Reported to CSIC:** Yes

When completed, convert this Word document to a .pdf document, and attach it to an email addressed to xxx@xxx.edu for circulation. Then move the document to the "Implementation Complete" folder, and update the Excel spreadsheet.

Figure 6 Example of CT change control form. This form documents the process used to propose CT protocol changes. It includes 4 sections: proposal for change, approval, implementation, and completion. This change control form requests reducing the dose for the maxface protocol discussed above (Fig. 2).

reconstruction techniques have been developed over the past decade. Many of these newer methods use iterative reconstruction (IR) techniques and incorporate a priori knowledge about the scanner, scan parameters, and patient. The challenge with some more recent reconstruction tools is the variable appearance of anatomy and pathology and increased computation time. If a reconstruction technique alters the appearance of the noise or produces new artifact, the radiologist must

develop experience with the technique to judge whether an individual case is adequate for the clinical question.

The challenge for the radiologist with changes in reconstruction method is that the final images may have new artifacts and portray clinical findings differently. One of the hardest tasks for a radiologist, encountered with every case, is expressing the degree of confidence in each finding and diagnosis. A radiologist's judgment is developed over a large

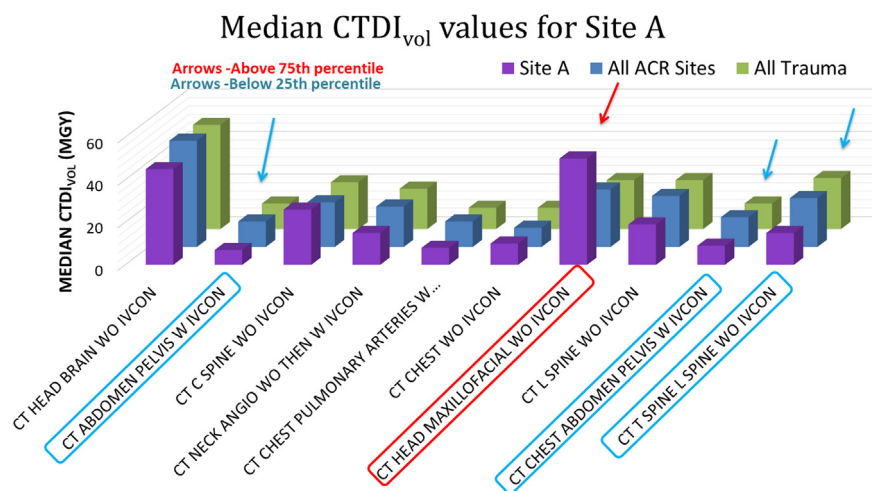


Figure 7 Example of data analysis figure. CT dose data from one of our sites are compared to ACR DIR and designated trauma sites for the 10 most frequent examinations. Red boxes indicate examinations where our dose is greater than the 75th percentile, and blue boxes indicate that our dose is lower than the 25th percentile. (Color version of figure is available online.)

collection of cases and from seeing variations of the same pathology.

Adequacy of imaging can be assessed quantitatively and qualitatively. Quantitative image quality metrics which relate to radiation dose include the contrast-to-noise ratio or noise texture, but these fall short of assessing the true clinical utility for a variety of reasons.¹⁸ For instance, a lower dose is favored in smaller patients due to the relatively smaller anatomy and paucity of fat planes compared to larger patients. Qualitative image assessment is based on the radiologist’s past experience and the ability to estimate whether the degree of noise, contrast, and artifact may mask findings.

Growing clinical qualitative evidence documents the efficacy of these techniques in the assessment of multiple anatomical regions. Machida et al¹⁹ demonstrates improved visualization of the anterior spinal artery. Nishida et al²⁰ use model-based iterative reconstruction to improve visualization of the artery of Adamkiewicz, and Schulz et al²¹ show comparable visualization of the mastoid air cells and sinuses with substantially decreased doses. A body of phantom and clinical evidence increasingly supports either improved visualization of structures or comparable visualization despite reduced doses with iterative and model-based techniques.²²

To implement CT technique changes, there must be engagement between radiologists, physicists, and technologists

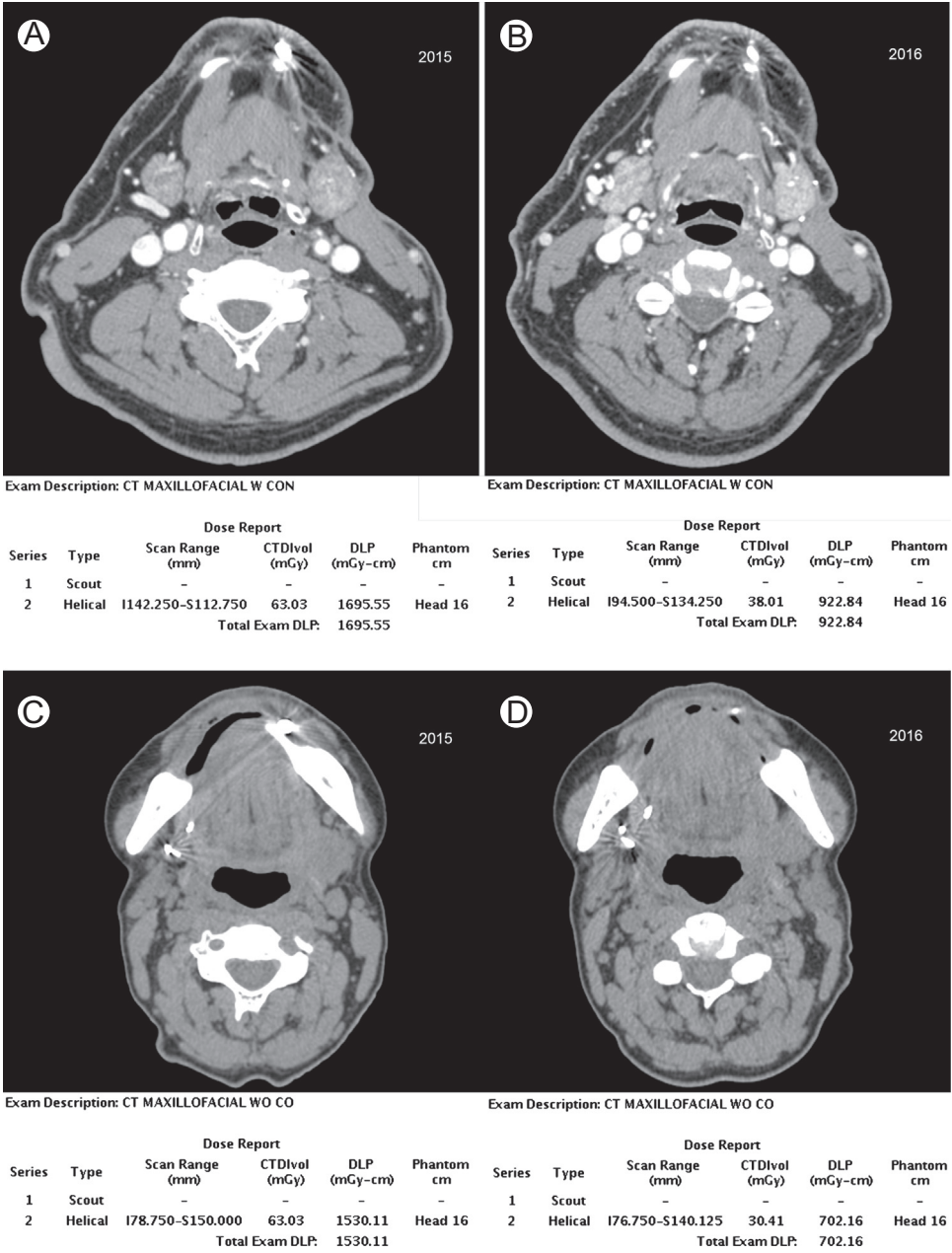


Figure 8 Clinical image comparison. Two examples of an intervention from an active dose monitoring program are depicted. Concern over the dose in the initial images (A and C) was brought to the attention of the CT protocol review committee. Dose was subsequently lowered via a reduction in tube current (B and D) while maintaining diagnostic image quality.

to find the best compromise between technique and image quality that provides a clinical answer with the lowest dose possible. As discussed above, a committee should be established to regularly discuss existing protocols, their parameters, and the addition or subtraction of protocols. Clinical input from radiologists should include audits of existing protocols to assess dose adequacy/excess for given indications. An example of the result of such an audit and committee decision is provided in Figure 8. This figure demonstrates an existing CT protocol of the maxilla and face that employed a higher dose than similar studies. The protocol was reviewed and tube current was implemented that cut the dose in half while maintaining sufficient diagnostic image quality needed for assessing the facial soft tissues.

Summary

This article reviews the clinical reasons to review and monitor CT protocols, the tools for monitoring and evaluating CT exam dose, and one institution's approach to monitoring and improving exams over a multisite academic enterprise. Consistent and timely CT protocol reviews by a CT protocol review committee consisting of radiologists, physicists, and technologists are considered essential. Using tools such as Dose Check, Radiation Dose Monitoring Systems and comparing institutional doses with diagnostic reference levels proposed by the ACR DIR are all good practices for a robust dose reduction program. It is essential to justify dose-sparing protocol changes, as it is essential to maintain image quality. A balance between dose reduction and image quality is thus important for the benefit of the patient.

References

1. Robinson TJ, Robinson JD, Kanal KM: Implementation of the ACR dose index registry at a large academic institution: Early experience. *J Digit Imaging* 26(2):309-315, 2013
2. RadLex Playbook User Guide. RSNA Informatics, 2016.
3. Kanal KM, Butler PF, Sengupta D, et al: U.S. diagnostic reference levels and achievable doses for 10 adult CT examinations. *Radiology* 284(1): 120-133, 2017
4. Dose Management. 2017; (http://www3.gehealthcare.com/en/products/dose_management). Accessed 9/11/2017, 2017.
5. Radimetrics Enterprise Platform. 2017; (http://www3.gehealthcare.com/en/products/dose_management). Accessed 9/12/2017, 2017.
6. DoseMonitor. 2017; (http://www3.gehealthcare.com/en/products/dose_management). Accessed 9/13/2017, 2017.
7. Gress DA, Dickinson RL, Erwin WD, et al: AAPM medical physics practice guideline 6.a.: Performance characteristics of radiation dose index monitoring systems. *J Appl Clin Med Phys* 18(4):12-22, 2017
8. AAPM. AAPM Recommendations Regarding Notification and Alert Values for CT Scanners: Guidelines for Use of the NEMA XR 25 CT Dose-Check Standard. 2011.
9. Protecting Access to Medicare Act of 2014. Pitts RJR, trans. 113th Congress ed: United States Congress; 2014.
10. Association NEM. NEMA XR 29-2013: Standard Attributes on CT Equipment Related to Dose Optimization and Management. 2013.
11. Group DSaC. In: Directors SSA (ed): Computed Tomography (CT) Compliance Clarifications under Section 218(a)(1) of the Protecting Access to Medicare Act (PAMA)- Information Only. CMS Center for Clinical Standards and Quality/Survey & Certification Group,
12. Jeffrey Shuren MD, J.D. Letter to the Medical Imaging Technology Alliance Regarding CT Recommendations. 2010.
13. Balter S, Hopewell JW, Miller DL, et al: Fluoroscopically guided interventional procedures: a review of radiation effects on patients' skin and hair. *Radiology* 254(2):326-341, 2010
14. CT Accreditation Program Requirements. American College of Radiology,
15. Commission TJ: Diagnostic Imaging Requirements. The Joint Commission,
16. Healthcare GE. DoseWatch: Protocol Management in Computed Tomography.
17. ICRP Publication 103: The 2007 Recommendations of the International Commission on Radiological Protection. In: Valentin J, ed2007.
18. McCollough CH, Bruesewitz MR, Kofler Jr. JM: CT dose reduction and dose management tools: Overview of available options. *Radiographics* 26 (2):503-512, 2006
19. Machida H, Tanaka I, Fukui R, et al: Improved delineation of the anterior spinal artery with model-based iterative reconstruction in CT angiography: a clinical pilot study. *AJR Am J Roentgenol* 200(2):442-446, 2013
20. Nishida J, Kitagawa K, Nagata M, et al: Model-based iterative reconstruction for multi-detector row CT assessment of the Adamkiewicz artery. *Radiology* 270(1):282-291, 2014
21. Schulz B, Beeres M, Bodelle B, et al: Performance of iterative image reconstruction in CT of the paranasal sinuses: a phantom study. *AJNR Am J Neuroradiol* 34(5):1072-1076, 2013
22. Geyer LL, Schoepf UJ, Meinel FG, et al: State of the art: Iterative CT reconstruction techniques. *Radiology* 276(2):339-357, 2015