Current Methods of Monitoring Radiation Exposure From CT

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Increased public and regulatory scrutiny of imaging-related radiation exposure requires familiarity with current dose-monitoring techniques and best practices. CT-related ionizing radiation exposure has been cited as the largest and fastest growing source of population-wide iatrogenic ionizing radiation exposure. Upcoming federal regulations require imaging centers to familiarize themselves with available dose-monitoring techniques and implement comprehensive strategies to track patient dose, with particular emphasis on CT. Because of institution-specific and vendor-specific technologies, there are significant barriers to adoption and implementation. In this article, the authors outline the core components of a universal dose-monitoring strategy and detail a few of the many available commercial platforms. In addition, the authors introduce a cloud-based hybrid model dose-tracking system with the goal of rapid implementation, multicenter scalability, real-time dose feedback for technologists, cumulative dose monitoring, and optional dose communication to patients and into the record; doing so results in improved patient loyalty, referring physician satisfaction, and opportunity for repeat business.

Key Words: Radiation dose, patient dose, monitoring, CT, angiographic dose monitoring, DICOM-SR, PACS

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SIGNIFICANCE AND CANCER RISK

Exposure from CT constitutes the bulk of imaging-related radiation. Patients with recurrent conditions such as hydrocephalus, pulmonary thromboembolism, and renal colic undergo the greatest number of total examinations and receive the highest aggregate dose. This trend has been shown to be increasing in recent years, with many of these patients receiving cumulative effective doses of >50 mSV [1]. Pediatric and bariatric patients are especially at increased risk, as pediatric patients are most susceptible to the long-term harmful effects of radiation exposure [2], and bariatric patients are subject to logarithmic increases in individual scan dose per cross-sectional area to maintain image quality [3].

Cancer prevalence attributable to CT use has been shown to be a nontrivial percentage in the general population [4]. Individual cancer risk, however, is multifactorial and difficult to estimate. Important contributing factors include patient age, scan type, and delivered examination dose. The use of shielding and other protective measures has been shown to significantly decrease delivered dose, and appropriate breast and gonadal shielding is considered best practice. In particular, younger female patients (aged <30 years) who undergo multiphase abdominopelvic CT are at the highest risk [5].

The most accurate method of determining organ-specific dose requires mathematical Monte Carlo simulation and phantom anatomic modeling [6,7]. Although this method may underestimate actual organ-specific dose [8], it is the currently accepted model of estimating true organ dose. The alternative method of dose calculation is the effective estimate, which does not involve phantom modeling or Monte Carlo simulation and possesses a significant advantage from a computational standpoint.

A newly discussed alternative to adjusting for patient body habitus is the size specific dose estimate (SSDE) calculation. Doing so requires the ability to estimate phantom size from patient body habitus as established by scout images in one or two dimensions. The SSDE calculation allows for more accurate dose estimation but cannot be converted to an effective dose or sequentially added to obtain a cumulative dose. Currently we are considering providing the estimate as an alternative measure alongside effective dose (mSV). Since the goal is to estimate patient dose and adjust protocols to optimize delivered dose, effective dose (mSV) offers the most practical approach.

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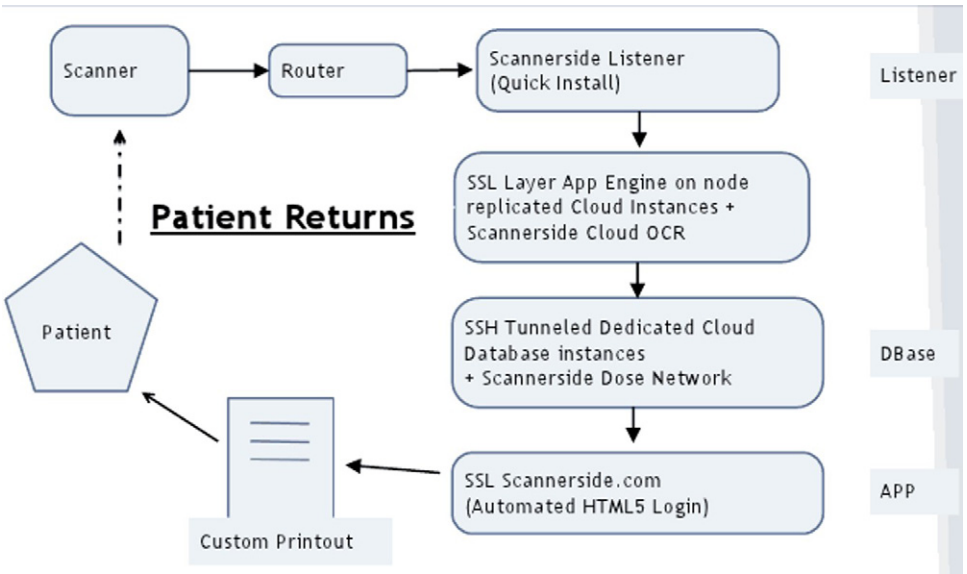

Fig 1. Sample workflow illustrating Scannerside dose-processing system with patient communication. OCR = optical character recognition.

The ACR continues to encourage monitoring and tracking of imaging-related patient exposure [9]. The implementation of an institutional policy presents significant technical and institutional challenges. In this article, we highlight the primary challenge of capturing dose information from existing CT scanners. We also discuss other considerations for implementation, such as patient and referring physician communication, dose analytics, and cumulative patient dose reporting.

Our cloud-based solution (http://www.scannerside.com), developed at our institution, has a modular architecture that allows efficient load balancing and processing of dose sheets for optical character recognition (OCR). To do this, we use server-side worker thread pools. A cloud-based service removes the need for onsite hardware and the associated costs, resulting in a cost-effective, simple, automated CT dose–tracking platform.

Our technologist-driven workflow model (Fig. 1) allows technologists to generate a customized branded card or printout for a patient after an examination, eliminating the need for verbal feedback regarding dose. This may or may not include the current and cumulative dose values for the examination. Delivering this printout or card is entirely optional, but doing so improves patient relations, satisfaction, referrer appreciation, and patient return rates.

OVERVIEW: COMPONENTS OF A COMPREHENSIVE DOSE-MONITORING STRATEGY

A robust platform that allows dose monitoring includes 6 major components: dose capture, effective dose conversion, patient-specific storage, dose analytics, dose communication, and data export. We discuss each of these in more detail. We characterize the currently available tools for dose capture below.

Dose Capture

Before DICOM structured reporting (DICOM-SR), delivered dose information arising from CT and other examinations is by default not available in a computer-readable format as a standard component in the DICOM header set. Instead, most scanners provide these data in image format, which is then stored in the PACS as a separate series. The critical dose data, including volume CT dose index (CTDIvol) and dose-length product (DLP), is effectively "burned" into a PACS image (Fig. 2) without a textual or numeric correlate. Conversion into a value that can be parsed thus requires "image reading" using custom-trained OCR [10] algorithms. Developing such algorithms with sufficient accuracy is a significant challenge.

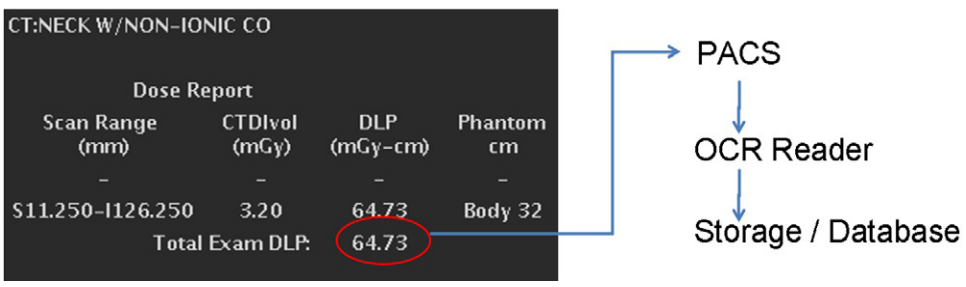

Fig 2. Example dose sheet (GE specific). CO = contrast; CTDIvol = volume CT dose index; DLP = dose-length product; OCR = optical character recognition; SR = structured report.

To allow universal implementation, it is necessary to implement a dose platform that supports extracting dose data from prior dose sheets.

The solution developed at our institution involves a cloud-based multinode architecture for providing OCR from the dose information sheet from a CT examination. Our custom-developed in-house OCR algorithm can be optimized from a central location allowing us to fine-tune the ability to accurately capture dose data across multiple vendors.

In theory, it may be possible to avoid the use of OCR by calculating DLP from DICOM header information sent with each image. Recent work [11] has suggested that CTDIvol and DLP calculation may be possible by collecting headers per slice (tube voltage and tube current–time product) and accounting for pitch. The challenge of this approach is that dose calculation would require series identification (reconstructed or reformatted images vs new passes), which has yet to become fully automated. Ongoing work in this area may provide a method of accurately calculating DLP from an examination without the need for OCR.

Another method for calculating the DLP value may be possible by using tube voltage and tube current data and a lookup table for CTDIvol data, as is available for manual use via the imPACT project. The challenge of identifying reconstructed versus new-pass series still exists. Separating these series from true new passes requires custom development and machine-specific or vendor-specific code. Incorrectly doing so would mean doubling or tripling the dose for a given examination, depending on the number of reconstructed series.

Certain types of legacy scanners use a message identifier known as modality-performed procedure step as part of the DICOM field structure that stores dose data as key-value pairs in the DICOM header. Capturing this information would allow automated dose capture much like DICOM-SR. However, these DICOM fields are often private, so they are variable and poorly adopted. This would also require custom development and could become cost prohibitive.

When fully supported, DICOM header messages under the DICOM-SR protocol provide an ideal method for dose capture from CT because DLP and CTDIvol values will be in numeric format in public DICOM header fields. However, because a majority of CT scanners do not send DICOM-SR messages, doing so would require either new equipment or a costly infrastructure upgrade.

Manual dose entry by CT technologists may be an acceptable alternative in certain situations. Although there is potential for error, prior work in semiautomated dose entry has found approximately 94% accurate dose capture from technologists [12]. The majority of errors from dose entry were due to identifiable and correctable causes, such as incorrect decimal placement [12]. Of these errors, 90% were easily correctable in retrospect. Given the ease of setup and use, we include this option of dose monitoring, which avoids vendor-specific and technical issues. Because dose is entered at the time of the examination, it promotes CT technologist awareness and direct patient communication (Fig. 1). Our cloud-based model also offers this entry process as a web-based service (http://www.scannerside.com).

Our automated dose-entry workflow allows the performing technologist to access a secure portal with the ability to generate a patient printout (or dose card) for communication (Fig. 1). This portal remains open throughout the day and is capable of handling multiple examinations.

The dose-capture methods discussed above apply only to CT scanner–specific dose. Capturing non-CT and procedural dose requires tools using DICOM-SR or dose-entry tools (Fig. 3). For example, OCR or modality-performed procedure step dose monitoring does not allow for fluoroscopic or angiographic dose tracking. Our currently available platform (http://www.scannerside.com) allows angiographic dose tracking.

Effective Dose Conversion

Delivered dose from a CT examination is presented initially as CTDIvol, which represents the estimated dose of a single weighted CT slice accounting for CT pitch [13]. DLP is CTDIvol multiplied by scan length (cm). To estimate the effective dose, DLP may be multiplied by a conversion factor to obtain millisievert values [14], as follows:

$$\text{effective dose}\,(\text{mSv}) = \text{DLP} \times k\ (\text{conversion factor in mSv}).$$

As previously mentioned, organ-specific values may be calculated [6,7] using more advanced Monte Carlo techniques, which do vary from the above millisievert values. However, the above method of calculating effective dose provides a sufficient estimate of patient risk for most purposes, without the extensive calculation and modeling necessary to calculate organ-specific dose in a practical setting. Calculated millisievert values may be serially added to estimate cumulative patient risk.

An accurate *k* factor requires patient age and habitus and examination type, which may be either stored for later calculation or used after dose capture to calculate the effective dose.

Although OCR and DICOM-SR tools allow potentially automated dose capture and communication, these tools do not, by default, handle effective dose conversion (Fig. 3) or patient-specific storage or aggregation.

We incorporate effective dose conversion at the time of the scan, before generating patient printouts for communication. We use validated *k*-factor tables to convert to effective dose, which varies for pediatric and bariatric patients [14].

Fig 3. Comparison of selected tools to track radiation dose. DIR = Dose Index Registry; OCR = optical character recognition,

	Scannerside (Stony Brook)	Radiance (UPENN)	eXposure (Radimetrics)	ACR DIR
Data Source	DICOM	DICOM	DICOM / Chamber	DICOM
OCR	Yes	Yes	Yes (?)	Yes
Compatibility	All	All	All	All
Cost	$	Free	$$$$	$
Reporting	Comprehensive	None	Comprehensive	None
Installation	Software	Software	Hardware / Software	Software
Patient Communication	Yes (Optional)	No	No	No
Protocol Feedback	Yes (real-time)	No	Yes	Yes
Setup Difficulty	Easy	Very Difficult	Moderate	Difficult
Analytics	Comprehensive	None	Comprehensive	Basic
Dose Network	Yes	No	No	Yes

Patient-Specific Storage

Storing examination information is best managed through a distributed relational database with a schema that allows query-based reporting. Structured query language (eg, MySQL; Oracle Corporation, Redwood Shores, California) or "not only structured query language" databases suffice. Dose information should have internal references to identifying patient information such as medical record number or identifier, in a HIPAA-compliant manner.

There is a need for integration with internal hospital-based electronic medical record (EMR) systems to facilitate clinical decision making; this may be done via Health Level 7 protocol information transfer from an external storage source. Once the data are transferred, EMR-specific components to process dose information could then incorporate cumulative patient dose into clinical decision making or ordering systems. Given the complexity of implementation, we do not further discuss this option.

Our cloud stores encrypted dose information using an elastic, scalable, and relational database adhering to the necessary HIPAA requirements. Data can be transferred securely to a remote location via the Health Level 7 protocol, which can be integrated with internal EMR systems or decision systems in a customized institution-specific fashion. Potential advantages of cloud architecture are significantly reduced costs and improved scalability.

Institutional Dose Reporting

A real-time graphical display of dose data allows the optimization of doses and protocols. In a data-driven department, this is highly valuable in day-to-day operations. Flagging scans with certain millisievert values, for example, allows the identification of problem areas and the potential for protocol improvement. Reporting packages should provide sufficient information to monitor the effects of altering protocols.

Comprehensive dose reporting requires scanner-specific and patient-specific reports for a given time frame. Scanner-specific reports should illustrate the maximum effective dose (mSv) per examination in a given time frame, trends in dose, and comparison information. Patient-specific reports should provide a summary of patient cumulative dose and examination details for a given medical record number or patient identifier.

These analytics are provided in a graphical display in our cloud-based online tool (http://www.scannerside.com), which displays scanner-specific and patient-specific data (Fig. 4) for a given time frame. It is possible to use these reports to track protocol changes over time and reduce delivered patient dose. Refer to Figure 3 for a comparison of specifics for other dose-monitoring platforms. Our solution has the advantage of providing real-time feedback from our multicenter dose-reporting database for technologists per examination relative to a real-time average in our cloud-based database.

Patient and Referring Physician Communication

Dose communication is an important component of a dose-monitoring platform. Options include patient health records, radiology reports, and direct referring physician communication. The choice of appropriate communication is dependent on the institution. We find that simple patient dose communication after a scan followed by cumulative communication that is easy to access in the health record improves both patient and referring physician satisfaction while safely not reducing overall scan volume. Reporting should be performed in a manner that reassures patients without causing undue concern.

We have found that other existing tools do not offer direct real-time patient or technologist communication. Technologist-driven verbal patient feedback regarding dose after each examination can become cumbersome and interruptive to workflow. As a result, we developed our service to allow for easy-to-print custom patient marketing materials after a scan. The goal of such a system is to reassure a patient that dose is being tracked without causing undue concern. Doing so begins to establish a relationship with the imaging center and a potential for repeat business.

Our cloud-based automated dose-tracking platform using HTML5 push notifications generates custom dose printouts or cards as soon as an examination is processed.

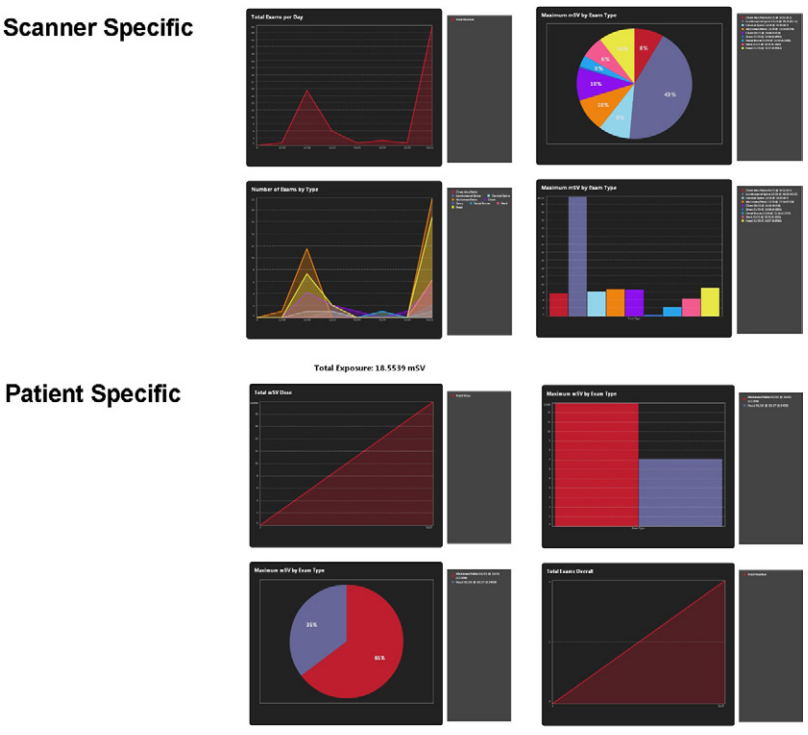

Fig 4. Sample dose report detailing examination and patient-specific dose data. When used in combination with time frame, this can reveal important information for adjusting protocol and lowering patient dose.

Several available tools offer radiology information system communication for automated entry to radiology reports. The ability to monitor radiation dose using an easy-to-use graphical system provides benefits at the point-of-care.

Importantly, dose monitoring empowers radiologists and imaging centers to serve as "dose consultants" by being able to query dose data for given patients. This is a value-added benefit to hospitals and referring physicians. In addition to automated dose reporting into the health record, a comprehensive dose-monitoring service would allow case-by-case patient consultation with referring physicians regarding overutilized examinations and decrease ordering anxiety by reassuring referring physicians that patient dose is being tracked internally. Using our provided system, the involvement of radiologists in dose monitoring is minimal, and technologists are at the point of care.

Data Export

The use of a dose registry would allow obtaining multicentric or geographic dose data and benchmarks for participating institutions, which are highly valuable. Initiatives by the ACR such as the Dose Index Registry aim to catalogue and monitor institution-specific doses. The ACR Dose Index Registry supports DICOM-SR for dose capture as well as OCR with many vendor partners. A list of compatible and supported ACR Dose Index Registry tools may be found at the ACR's website (http://www.acr.org/Quality-Safety/National-Radiology-Data-Registry/Dose-Index-Registry).

CONCLUSIONS

A meaningful dose-monitoring strategy includes dose capture, effective dose conversion, patient-specific storage, institutional dose reporting, dose communication, and data export. We discuss these in detail and present several currently available technologies and associated barriers to adoption. In this paper, we also detail a cloud-based hybrid dose-tracking platform (http://www.scannerside.com) developed at our institution that allows automated dose monitoring, flexible dose tracking dose entry, real-time radiation dose and protocol feedback, graphical web-based and direct patient communication in a cost-effective manner. We hope this will significantly decrease the barriers to institutional dose tracking. Given the continued growth of regulatory oversight and public concern regarding radiation dose, implementing a sound radiation dose–monitoring strategy will likely become an expected component of any imaging or procedural facility in the near future.

TAKE-HOME POINTS

- Increased public and regulatory scrutiny of imaging-related radiation exposure requires familiarity with current dose-monitoring techniques and best practices.
- A universal dose-tracking platform includes dose capture, effective dose conversion, patient-specific storage, dose analytics, dose communication, and data export.

- A cloud-based hybrid model of dose tracking (http://www.scannerside.com) developed at our institution allows rapid implementation, multicenter scalability, real-time dose feedback, cumulative dose monitoring, and optional dose communication into the patient health record.

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