Automated Extraction of Radiation Dose Information for CT Examinations

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Exposure to radiation as a result of medical imaging is currently in the spotlight, receiving attention from Congress as well as the lay press. Although scanner manufacturers are moving toward including effective dose information in the Digital Imaging and Communications in Medicine headers of imaging studies, there is a vast repository of retrospective CT data at every imaging center that stores dose information in an image-based dose sheet. As such, it is difficult for imaging centers to participate in the ACR's Dose Index Registry. The authors have designed an automated extraction system to query their PACS archive and parse CT examinations to extract the dose information stored in each dose sheet. First, an open-source optical character recognition program processes each dose sheet and converts the information to American Standard Code for Information Interchange (ASCII) text. Each text file is parsed, and radiation dose information is extracted and stored in a database which can be queried using an existing pathology and radiology enterprise search tool. Using this automated extraction pipeline, it is possible to perform dose analysis on the >800,000 CT examinations in the PACS archive and generate dose reports for all of these patients. It is also possible to more effectively educate technologists, radiologists, and referring physicians about exposure to radiation from CT by generating report cards for interpreted and performed studies. The automated extraction pipeline enables compliance with the ACR's reporting guidelines and greater awareness of radiation dose to patients, thus resulting in improved patient care and management.

Key Words: Radiation dose reporting, quality assurance, patient safety, CT

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INTRODUCTION

Computed tomographic utilization has increased significantly in the past decade [1,2]. In the past two decades, the proportion of background radiation in the United States attributed to medical imaging has increased from approximately 15% in 1987 to nearly 50% today [3,4]. Furthermore, exposure to radiation as a result of medical imaging is currently in the spotlight, receiving attention from professional organizations such as the ACR and the American Association of Physicists in Medicine and, more notably, from the US House of Representatives Subcommittee on Health [5], as well as the lay press [6,7].

Although a number of scientific articles have debated the potential for deleterious effects as a result of this imaging boom [8-11], the answers to these questions are not easily obtained. What is clear, though, is that increasing awareness of health care professionals regarding imaging-related radiation dose is integral to improving patient care. The ACR's white paper on radiation dose [12] states that:

> there should be special attention paid to . . . education for all stakeholders in the principles of radiation safety, the appropriate utilization of imaging . . . the standardization of radiation dose data to be archived during imaging for its ultimate use in benchmarking, good practice, and finally, the identification and perhaps alternative imaging of patients who may have already reached threshold levels of estimated exposure.

Recent studies have demonstrated that there is wide variability in estimated effective radiation dose among CT scans, even when performed at the same institution using the same protocols [13,14]. Reported doses were also considerably higher than those previously quoted in the

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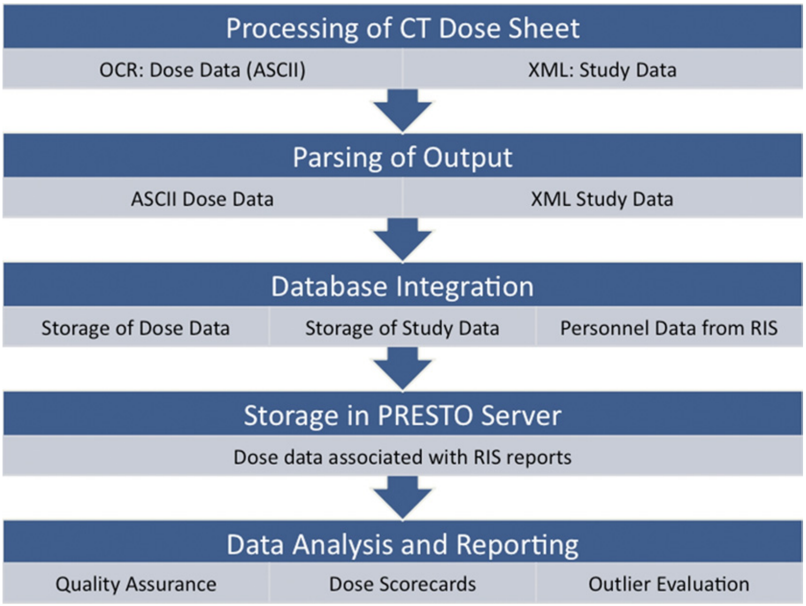


Fig 1. The automated dose extraction pipeline, which combines data from the dose sheet, examination header, and radiology information system to enable analytics and quality assurance.

literature. These observations underlie the need to track and monitor CT-related radiation dose.

Initiatives are under way to standardize the documentation and reporting of radiation dose information. The Digital Imaging and Communications in Medicine (DICOM) Structured Reporting (Dose SR) standard contains dose objects dedicated to storing CT radiation dose information [15,16]. Using these DICOM Structured Reporting objects, the Integrating the Healthcare Enterprise initiative has developed a Radiation Exposure Monitoring profile to assist vendors in the implementation of standardized dose reporting by scanner software [17]. The ACR's Dose Index Registry, part of the National Radiology Data Registry, is also in development to standardize dose reporting via scanner firmware updates, which will allow reporting of radiation dose information directly from scanners for all prospective examinations [12,18]. The Initiative to Reduce Unnecessary Radiation Exposure From Medical Imaging was recently launched by the US Food and Drug Administration [19]. The National Institutes of Health is also making efforts to track and report radiation dose for all patients imaged at the Institutes [20].

However, these endeavors do not address the challenge posed by vast repositories of retrospective CT data that store dose parameters as an image-based dose sheet instead of structured data within the DICOM header. Furthermore, CT scanners currently in use may not have firmware amenable to incorporating radiation dose into image headers.

In the interests of improving compliance with the ALARA principle "as low as reasonably achievable" [21], and acknowledging the increasing spotlight on radiation exposure from CT, we present our work on an automated pipeline for extracting and archiving CT radiation dose information.

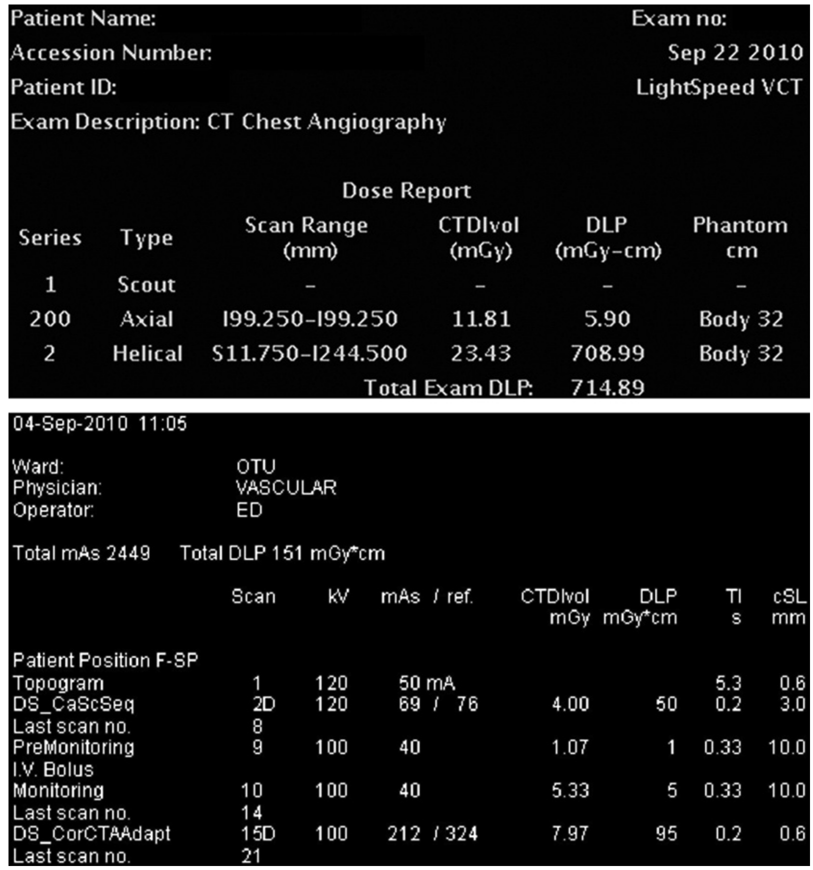
METHODS

To facilitate access to and analysis of radiation dose information, we have designed, implemented, and validated an automated extraction pipeline to query our institutional PACS and extract radiation dose data stored in the dose sheet of every CT examination [22]. The pipeline is summarized in Figure 1.

The pipeline commences with the automatic retrieval of a dose sheet from the PACS. Sample dose sheet images from two different vendors are shown in Figure 2. First, we use an open-source optical character recognition tool to convert the pixel-based information into ASCII text [23]. The DICOM image header is subsequently translated into an extensible markup language file. We then apply a set of internally developed PHP/MySQL scripts to parse each text and extensible markup language file and extract pertinent information about each scan. Extracted dose parameters include the x-ray tube voltage, x-ray tube current, reference tube current, volume CT dose index, and dose-length product. These parameters are stored for each series acquired during the CT examination.

Before being stored in a database, the dose-related parameters extracted from the dose sheet are validated using a set of regular expressions to correct errors in the optical character recognition process. For example, numerical values are inspected to verify that they do not contain nonnumeric characters or spaces. Instances in which an underscore is substituted for a

Fig 2. Sample dose report images from two CT scanners: an abdominopelvic CT scan obtained on a GE scanner (top) and a coronary CT scan (bottom) obtained on a Siemens scanner. Identifiable patient information has been removed for HIPAA compliance.



Patient Name: Exam no:
Accession Number: Sep 22 2010
Patient ID: LightSpeed VCT
Exam Description: CT Chest Angiography

Dose Report

Series	Type	Scan Range (mm)	CTDIvol (mGy)	DLP (mGy-cm)	Phantom cm
1	Scout	-	-	-	-
200	Axial	I99.250-I99.250	11.81	5.90	Body 32
2	Helical	S11.750-I244.500	23.43	708.99	Body 32
			Total Exam DLP:	714.89	

04-Sep-2010 11:05

Ward: OTU
Physician: VASCULAR
Operator: ED

Total mAs 2449 Total DLP 151 mGy*cm

	Scan	kV	mAs / ref.	CTDIvol mGy	DLP mGy*cm	TI s	cSL mm
Patient Position F-SP							
Topogram	1	120	50 mA			5.3	0.6
DS_CaScSeq	2D	120	69 / 76	4.00	50	0.2	3.0
Last scan no.	8						
PreMonitoring	9	100	40	1.07	1	0.33	10.0
I.V. Bolus							
Monitoring	10	100	40	5.33	5	0.33	10.0
Last scan no.	14						
DS_CorCTAAdapt	15D	100	212 / 324	7.97	95	0.2	0.6
Last scan no.	21						

particular letter are also identified and corrected. Errors in the extraction of series names from the dose sheet are also resolved. Derivation of the phantom-based volume CT dose index values is not validated at this time; these values are calibrated during routine maintenance performed by the scanner manufacturer. Once the optical character recognition–extracted data are validated, an estimate of whole-body effective dose is calculated using anatomically based conversion factors published in the literature [24]. For example, the dose estimate for an abdominopelvic CT scan can be computed by multiplying the dose-length product by 0.015.

Additional information attached to the study, such as examination date, scanner manufacturer and model, reporting radiologist(s), performing provider (eg, technologist), and responsible modality section, is parsed from the extensible markup language file or queried from the radiology information system to enable more robust analysis of the radiation dose information. These data as well as the dose-related data (including the estimated whole-body effective dose in millisieverts) are stored in a MySQL database. This database can be queried by the pathology and radiology enterprise search tool developed at our institution [25] to enable the real-time generation of patient dose profiles.

The pipeline can process both retrospective and prospective CT studies to make dose information available for all CT examinations at our institution, as well as examinations acquired at other institutions provided for review or reevaluation. The system is capable of interpreting CT dose sheets from multiple vendors, including Siemens, GE, Toshiba, and Philips.

We demonstrate some of the analysis made possible by our automated extraction pipeline as applied to all CT examinations performed at our institution during the first quarter of 2010, as well as to a subset of all CT examinations performed at our institution since 2003.

RESULTS

Using the data extracted via the automated pipeline, we are able to analyze a variety of factors associated with estimated radiation dose from CT examinations. For example, studies within each departmental section that exceed a certain dose threshold can be identified using this approach (Figure 3). In addition, we can also examine estimated radiation dose according to scanner and study type. Figure 4 illustrates the average (blue) and maximum (red) dose estimates in January and February 2010 for a variety of CT examinations (anonymized as "CT001" through "CT006") for 5 different scanner

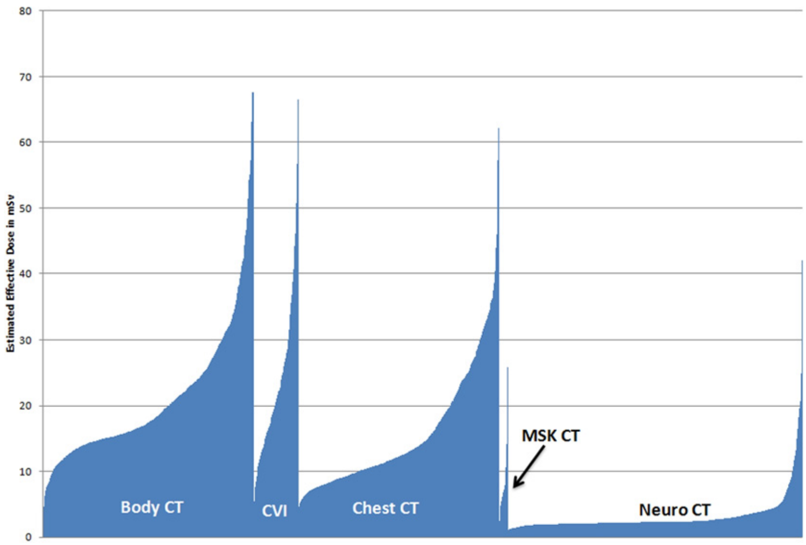
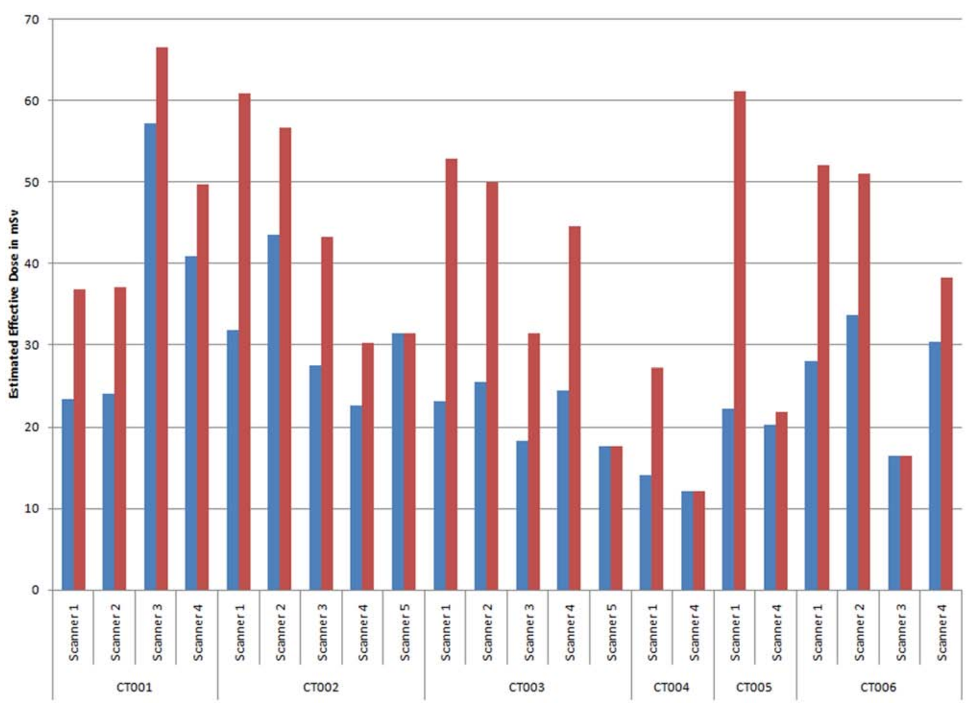


Fig 3. Departmental snapshot of estimated radiation dose (in millisieverts) during January and February 2010. This type of analysis can help identify outlier examinations for more careful analysis.

models at our institution (all produced by the same manufacturer). This type of analysis is helpful in identifying potential differences in study protocols that may be leading to increased radiation dose on some scanners compared with others. For example, there is a clear dose difference between scanners 3 and 4 for examination type CT001 compared with scanners 1 and 2, suggesting that further protocol optimization for dose reduction is necessary for studies performed on scanners 3 and 4. The identification of outliers is also facilitated by this analysis, which reveals that scanner 5 results in higher average estimated radiation dose for examination type CT003 compared with other models.

Extracted dose information can be used to survey the estimated radiation dose for a particular examination type within the department, as shown in Figures 5 and 6. Figure 5 shows the estimated radiation dose for all chest CT examinations performed between January and March 2010 at our institution. Using this analysis, we can determine how the range of dose estimates at our institution compares with the average reported dose for a chest CT examination in the published literature [26]. Examinations with dose estimates greater than 1 to 2 standard deviations above the reported mean can be examined more closely to identify possible explanations for the increased dose.

Fig 4. Radiation dose estimate (in millisieverts) during January and February 2010 on different scanner models according to examination type. Columns in blue online (light gray in print) indicate average dose and red columns online (dark gray in print) indicate maximum dose for a particular examination type on a particular scanner model. This analysis can identify protocol issues that can potentially be leading to higher doses (eg, dose estimate on scanners 1 and 2 for examination code CT001 vs for scanners 3 and 4).



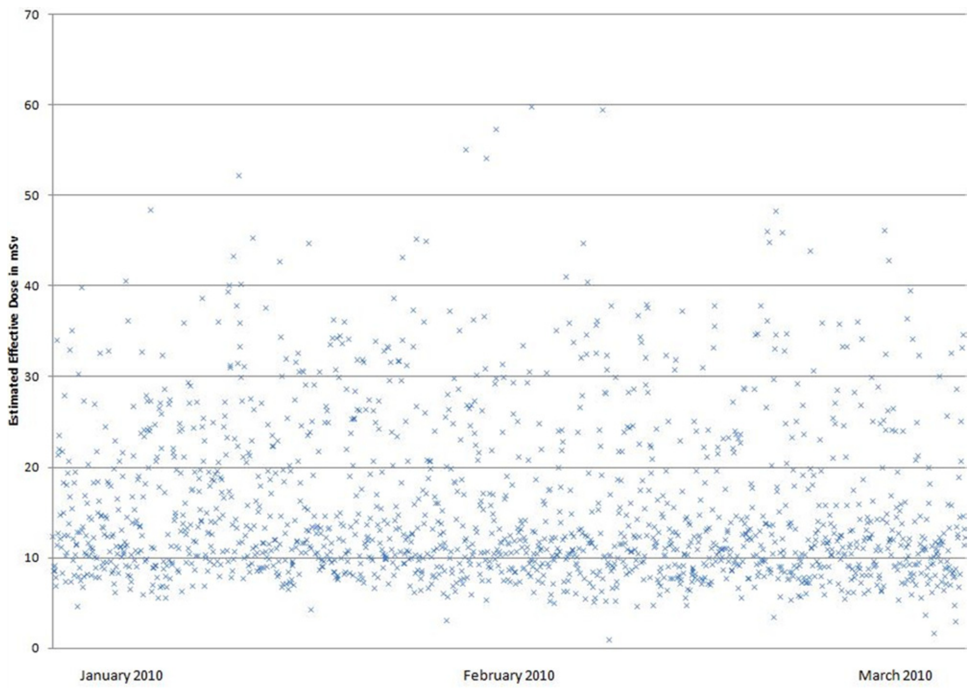


Fig 5. Estimated radiation dose (in millisieverts) for all chest CT examinations performed from January to March 2010. This analysis can be used to identify outlier examinations for closer inspection.

Modality-specific examination of dose estimates is also useful, as illustrated in Figure 6, which examines the estimated radiation dose for all coronary CT examinations performed at our institution between 2003 and 2010. Not only is outlier identification possible, but changes in radiation dose with time and the addition of new scanner models can also be analyzed.

We are also able to generate radiation dose report cards for technologists, reporting providers, and referring physicians. These not only serve as quality assurance measures but are valuable as educational tools to inform radiologists as well as nonradiologists of the estimated radiation dose for a particular study. Radiologists can use this information to implement dose-reduction protocols, while nonradiologist referring physicians can make informed choices about the type of imaging study to order for a patient's condition. Technologists will be able to receive feedback about how specific protocol decisions,

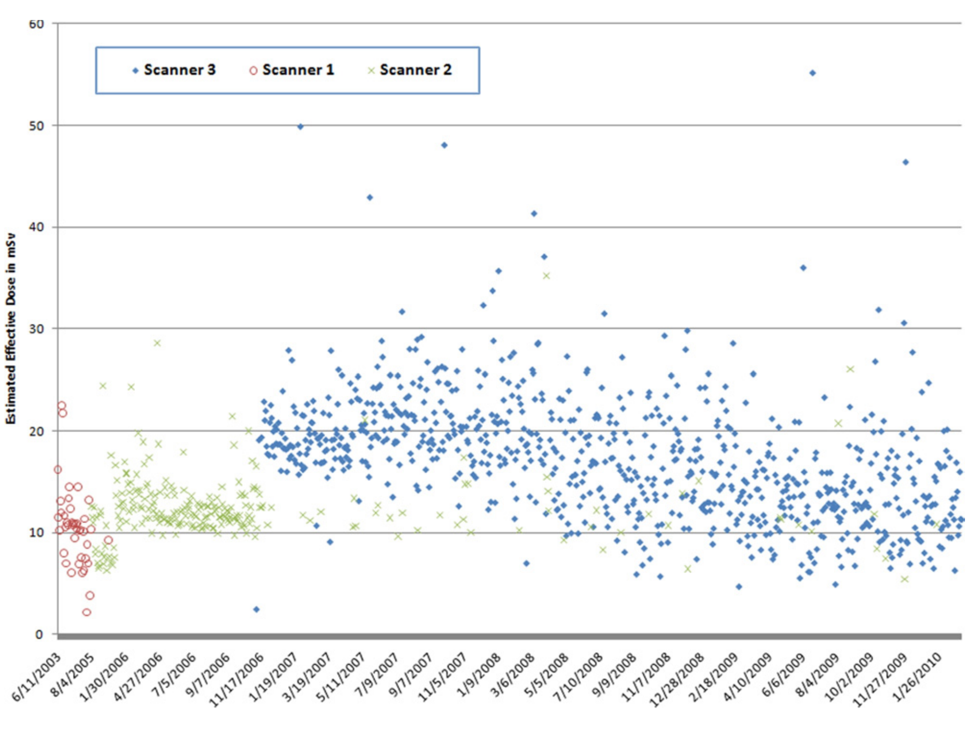


Fig 6. Radiation dose estimates (in millisieverts) for all coronary CT examinations performed at our institution (2003-2010), analyzed according to scanner model. This analysis not only provides historical perspective on the evolution of radiation dose but also allows us to identify outlier examinations and variations between scanner models that may be contributing to increased patient radiation dose.

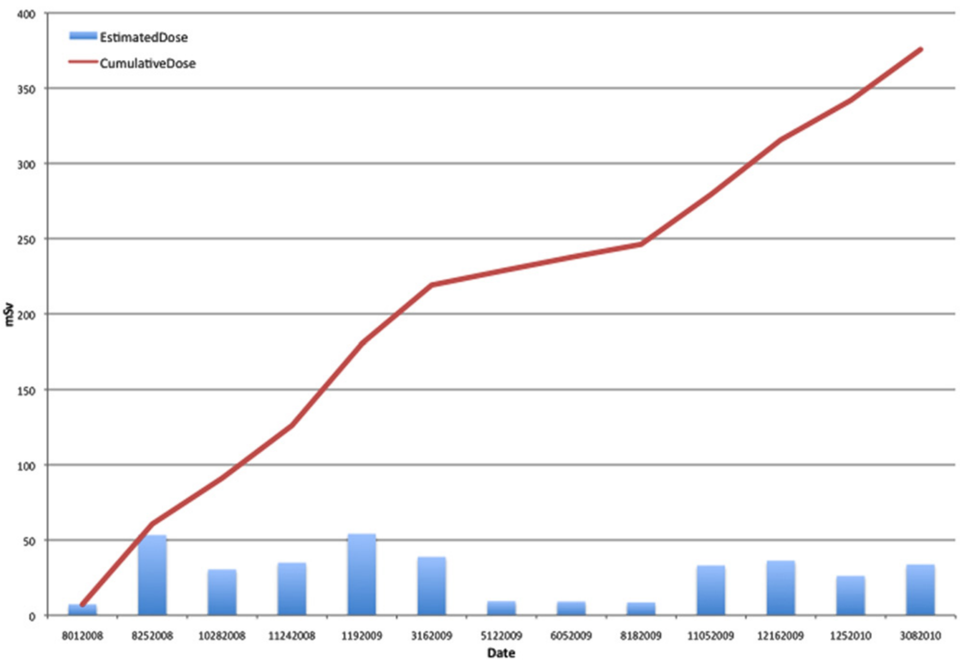


Fig 7. Radiation dose estimates (in millisieverts) for all CT examinations undergone by a patient at our institution. The columns indicate doses for individual studies performed on the indicated date, while the line represents the cumulative estimated whole-body dose (in millisieverts).

particularly dose reduction measures, affected a particular study.

The goal of extracting and analyzing radiation dose information is to assess patient exposure to radiation from CT. By storing radiation dose information both retrospectively and prospectively, we can generate dose report cards for patients indicating their estimated lifetime radiation dose for all studies obtained at our institution (Figure 7). This information is important not only for patient disclosure but also to involve patients and their physicians in medical decision-making for future imaging studies.

DISCUSSION

Extracted radiation dose information can be used to perform a variety of analyses aimed at quality assurance and patient safety. For example, a cumulative patient radiation dose estimate for all CT examinations performed at our institution can be generated. In addition, we can compare actual radiation dose estimates resulting from studies at our institution with average expected doses published in the literature [26]. Furthermore, an equipment-based analysis of radiation dose can be performed to determine if certain scanners routinely result in higher doses than others. Analysis of attempts at dose reduction and the success of those measures is also possible, as is an individualized report for each technologist, resident, and attending physician in the department, detailing the radiation dose estimate for each study performed and interpreted and identifying any outliers compared with published as well as departmental standards. Furthermore, examination of radiation dose by modality section can be used to tailor protocols for specific studies to implement and optimize dose minimization strategies. These reports not only increase awareness of radiation dose experienced by our patients but also serve to educate technologists and radiologists of the need for careful implementation of dose reduction techniques and to inform referring physicians of the radiation dose received by their patients as a result of repeated imaging and guide future ordering patterns.

Archived radiation dose information can serve not only as a quality assurance metric but also as a tool for increasing awareness among health care providers. Integrating retrospective dose information into the patient electronic medical record at our institution and developing decision support modules for order entry will inform and guide referring physicians as to the estimated dose for a particular examination as well as the cumulative dose estimate for a patient on the basis of CT examinations already performed at our institution. As the implementation evolves, we intend to incorporate dose information from fluoroscopic and interventional studies to provide a more robust and accurate assessment of cumulative patient radiation dose.

Admittedly, the primary limitation of this work is that we cannot use information extracted from CT dose sheets to accurately quantify the effective whole-body dose received by a patient for a given examination. The effective dose computed from the volume CT dose index and dose-length product data in the dose report image provides an estimated dose based on the imaging of phantoms [27]. These estimates have been shown to be inaccurate because they do not account for patient gender or body habitus. Specifically, radiation dose to women and patients of smaller build is routinely underestimated, while dose to larger patients is often overestimated [28]. Nevertheless, the dose estimates extrapolated from CT dose report images still serve as a starting point for trend evaluation and outlier identification, both of which are valuable in adhering to the principle of "as low as reasonably achievable." The automated extraction pipeline for radiation dose information allows us to be compliant with the ACR's reporting guidelines and to be more cognizant of radiation dose to our patients, thus resulting in improved patient care and management.

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