# Automated Framework for Digital Radiation Dose Index Reporting From CT Dose Reports

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**OBJECTIVE.** Radiation exposure from CT studies has increased over the past 30 years in the United States and now constitutes approximately 50% of the radiation dose index administered in the health care setting. Tracking CT dose index (CTDI) is cumbersome because it relies on a manufacturer-generated screen capture, which contains the estimated dose index exposure for the patient. The radiation dose index information is not digital but, rather, is "burned" into the image (i.e., not in numeric form, not as part of the image header or elsewhere associated with the study), making it difficult to automatically share these data with other information systems. The purpose of the dose index reporting application (DIRA) we developed for CT is to extract the radiation dose index information from the CTDI reports to eventually perform automated quality control, promote radiation safety awareness, and provide a longitudinal record of patient-specific health care–related radiation exposure.

**MATERIALS AND METHODS.** A random selection of 518 CTDI reports were processed by the DIRA and the dose index information was extracted. CTDI reports using a standard DICOM C-STORE to the DIRA allow an automated process to compile radiation dose index and patient information in a Web-based framework using a structured query language (SQL) database.

**RESULTS.** Our initial tests showed that the DIRA accurately extracted dose index information from 518 of 518 CTDI reports (100%). Because the extracted CTDI descriptor—dose-length product—is based on standard CTDI measurements obtained using fixed-size cylindric polymethylmethacrylate phantoms, preliminary studies have been performed to correct for patient size by applying correction factors derived from CTDI measurements using a range of phantom sizes from 6 to 32 cm in diameter. Our system provides a way to automatically track CTDI on existing CT scanners and does not rely on the DICOM SR Dose Index Report standard, which is available on only the newest CT scanners.

**CONCLUSION.** A modular and vendor-independent DIRA system can be integrated with any existing CT scanner. This system greatly facilitates digital dose index reporting and makes it possible to provide a longitudinal record of the health care radiation exposure estimate in an individual patient's health record.

**Keywords:** CT, radiation dose, reporting

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Recent adverse events involving inadvertent health care–related radiation overexposure from CT have caused much public concern about the safety of CT based on reports to the U.S. Food and Drug Administration (FDA) [1]. In one instance, eight times the dose index was administered in a hospital for head CT studies of more than 206 patients [1]. In another instance, a 2-year-old child had the same region of his head scanned more than 150 times, lasting more than an hour during the same CT examination [1]. These radiation overexposure events can occur because of various kinds of mistakes including policy errors (e.g., flawed CT protocols), human errors, or machine error. In these reported cases, some of these inadvertent CT radiation overexposures were detected only because of patient symptoms (e.g., erythema, hair loss) or, in the case of the 2-year-old boy, an astute parent who realized that a typical CT study should not exceed 1 hour.

Considerable debate concerning health care–related radiation exposure has been taking place over the past few years in both the medical and lay press. The debate started in large part because of the increase in the use of CT for both diagnostic and screening purposes: CT accounts for approximately 50%

of the radiation dose index administered in the health care setting [2]. The reasons for the increase in CT usage are multifactorial, with demand increasing from both referring clinicians and patients. Improvements in CT scanners in both image quality and computer processing power make these studies extremely easy to perform—a few mouse clicks and a few seconds of scanning. In the United States alone, approximately 70 million CT studies are performed each year [3], which is up from 3 million in 1980 [4], and the average lifetime diagnostic radiation dose index increased sevenfold in the same time period. Even more concerning is the use of CT for imaging pediatric patients—more than 4 million per year—because pediatric patients have been shown to be significantly more sensitive to radiation than adult patients for a given dose index [5]. Controversy also exists about whether certain CT screening procedures should be performed. Recently, government medical experts questioned the FDA's decision to approve CT colonography despite its risk of radiation exposure [6].

Although no studies to date directly implicate CT in cancer-related deaths, recent publications have extrapolated the risk of CT-associated cancer using data from the atomic bomb survivors [3, 7]. One particular atomic bomb survivor cohort of 25,000 people who received an average dose index of 40 mSv, roughly the equivalent of two or three CT studies, showed a significant increase in overall cancer risk and mortality [8]. One commonly cited study estimates that up to 1.5–2% of all current cancers in the United States may be attributed to CT studies [7]; therefore, despite a small individual risk, the risk to the population associated with CT use may be significant [7].

For these reasons, a solution for tracking CT radiation exposure and identifying trends related to CT radiation exposure is needed for the immediate goal of detecting inadvertent radiation overexposure and the long-term goal of better understanding the risks of health care–related radiation exposure.

In today's computationally sophisticated world it should be possible to digitally capture the dose index reporting in CT. The challenge lies with our inability to systematically track and assess radiation exposure from each CT study because of limitations in the way the modality manufacturers have been providing this information. Digital CT dose index (CTDI) reporting is currently quite cumbersome for most CT scanners, utilizing a manufacturer-generated screen capture that contains the estimated dose index exposure. Except with the newest CT scanners, the radiation dose index information is "burned" into the image (i.e., not in numeric form, not as part of the DICOM image header or elsewhere associated with the study). Even if a hospital owns one of the newer CT scanners in which the radiation dose index is contained in the DICOM header information, the PACS software must also be able to use and store that information. As a result of these limitations, it is difficult to provide automated quality control for inadvertent radiation overexposure and to share radiation dose index data with other information systems, which may provide better ways to minimize health care–related radiation exposure such as increasing education and awareness.

Our study presents a novel way to automate the tracking of CTDI information that can work on all generations of CT scanners (old and new) and can be integrated into virtually any health care information technology (IT) infrastructure. Moreover, the application we describe here does not rely on future enhancements from manufacturers or other standards such as DICOM SR Dose Index Reporting [9] to be consistently implemented, both of which may take years. Others have reported similar methods to track radiation dose index [10]. In addition to tracking CT modality–generated dose index reports, our dose index reporting application, which we refer to as "DIRA," attempts to correct for patient size with the goal of yielding more accurate patient-specific CTDI estimates for tracking dose over time.

## Materials and Methods

Our dose index reporting application, which we refer to as "DIRA," was built using a Linux server (Ubuntu server 10.04, Ubuntu) running customized software with an automated workflow for digital CTDI reporting. DIRA performs image processing to extract the dose information in the CT dose report and adjusts the standard phantom–based dose on the basis of patient size, thereby creating a patient-specific dose. The current automated workflow (Fig. 1) obtains the CT dose report images by either an automated DICOM push from the CT modality or by an automated DICOM Query-Retrieve command from the imaging archive (PACS). The CT dose report contains all the important information for creating a patient-specific dose including patient age, sex, and weight. When the dose report arrives, image processing is used for dose extraction and patient-size adjustments are made to the dose values, which we describe later in this article. The radiation dose estimates and patient information are stored in a structured query language (SQL) database with Web-based framework for user access.

In the following sections, we describe the automated workflow.

### *Send Dose Index Reports*

The CT modalities have been programmed to deliver each dose index report immediately after the examination to the DIRA via a standard DICOM C-STORE. This automated DICOM C-STORE is protocol-specific, which requires a one-time manual adjustment to each protocol. In addition to standard patient information (e.g., name, age, sex), patient weight and height are sent to the DIRA by means of the electronic health record to the radiology information system (RIS) as part of a health level 7 (HL7) orders feed produced locally in conjunction with our vendor. Our RIS contains fields for patient weight and height that can be populated by this custom HL7 feed. Once in our RIS, the patient weight and height information is propagated to the CT modalities, where it becomes part of the DICOM header information.

### *Image Processing*

Extracting dose index information from CT images is a limited instance of a more general problem called "text information extraction" [11]. Our DIRA relies on a connected components algorithm to segment out the text from the CTDI report. The steps of this process are shown in Figure 2. Figure 2A is an example of the dose index report sent directly from a CT scanner. Figure 2B shows the text information extraction applied to the "burned" image of the CTDI report. After text information extraction and a string search, the dose-length product (DLP) value is extracted from the burned image and converted into the numeric form that can be easily processed. The same technique has been used for extracting other clinically useful information, such as patient names (Kennedy D et al., presented at the 2008 annual meeting of the Radiological Society of North America).

### *Patient-Size Dose Index Adjustment*

The manufacturer-generated CTDI report is based on standard-sized polymethylmethacrylate (PMMA) phantoms, which do not reflect differences in patient size. To correct for patient size, we followed a two-step procedure. For the first step, we used the published relationships between patient weight and size [12, 13] to derive the equivalent cylindric phantom diameter based on patient weight. Take an abdominal CT study for an example: 103 abdomen examinations were measured to generate relationships between patient weight and patient dimensions in the anteroposterior (AP) and

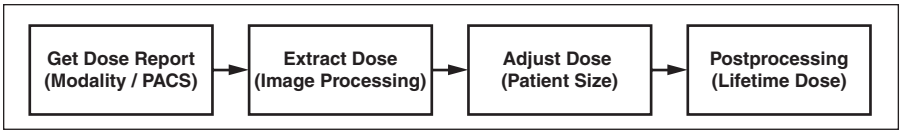



**Fig. 1**—Diagram shows automated workflow for radiation dose index reporting application.

lateral (LAT) directions [12]. These relationships were used to calculate the equivalent cylindric phantom diameter using the following formula:

$$\sqrt{AP \times LAT \times C}$$

where $C$ is the correction factor that takes into consideration the difference in the density of soft tissue (≈ 1.0 g/cm$^3$) and acrylic PMMA phantom material (at 1.19 g/cm$^3$).

$$C = 1.0 / 1.19 = 0.84.$$

For the second step, we calculated the correction factor based on the estimated phantom size from the previous step. For each CT scanner, the volume CT dose index ($CTDI_{vol}$) was measured using a range of cylindric acrylic phantoms with diameters of 6–32 cm, as shown in Figure 3. Because the effect of phantom size on the CTDI has been studied [14, 15], correction factors based on the derived equivalent phantom size can be applied to the displayed $CTDI_{vol}$ for each CT scanner (Fig. 4). The same correction factor can also be applied to the other dose index descriptor in the manufacturer CTDI report—DLP (the product of $CTDI_{vol}$ and scan length). In our preliminary studies, we decided to extract the DLP as the primary dose index descriptor because it includes both the $CTDI_{vol}$ and the scan length. From DLP, effective dose can be estimated using published conversion factors [16]. We used the conversion method described by the European Commission [16] that allows the DLP value to be converted into effective dose using a conversion factor that is specific for various regions of body such as 0.019 for pelvic CT, 0.015 for abdominal CT, 0.017 for chest CT, 0.0054 for neck CT, and 0.0023 for head CT.

### *Postprocessing*

Postprocessing of this CTDI currently includes tabulating a lifetime CT radiation exposure dose estimate and estimating effective dose and other radiation-related measures.

## Results

Our initial tests showed that DIRA accurately extracted dose index information from 518 of 518 CTDI reports (100%). Since then, hospitalwide deployment of the DIRA in early 2010 has resulted in its processing of over tens of thousands CTDI reports, many of which have been sampled to ensure the dose index information remains accurate. Currently, patient-specific dose index adjustments based on patient size are being made for abdominal CT studies, but implementation of this adjustment will likely expand to other types of studies (e.g., chest).

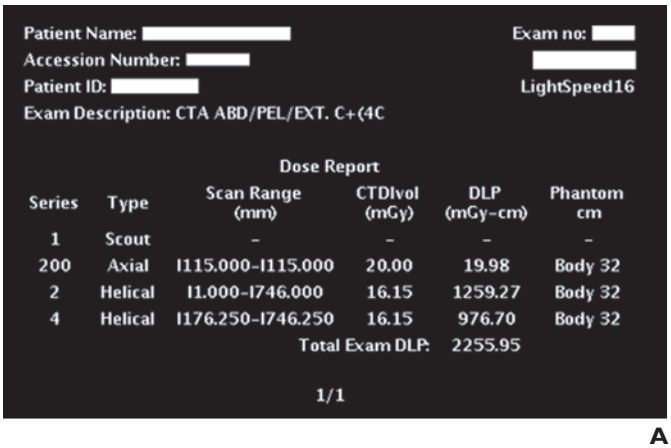
## Discussion

Campaigns promoting radiation safety and awareness, such as Image Gently [17], and the color coding of pediatric low-dose index protocols by vendors to increase compliance [18] have increased awareness of both the public and medical world about this issue. However, despite these efforts, it is still currently difficult to know the extent of radiation overexposure because of the difficulty in tracking the CTDI.

Our system provides a way to automatically track the CT radiation dose index on existing CT scanners and does not rely on dose index information in the image DICOM headers or on the DICOM SR Dose Index Report standard [9], which is available on only the newest CT scanners. Because DIRA is manufacturer-independent, it can be deployed immediately in almost any health care IT infrastructure. Although patient height and weight information may be nontrivial to automatically populate depending on the IT infrastructure and RIS, this information can be manually entered at the time of CT study by the technologist (e.g., which is routinely done by MR technologists because Patient Weight is a required field).

We assume that eventual improvements will make dose index reporting much easier, but the typically slow-moving health care industry and lengthy equipment upgrade cycle periods may make a system such as DIRA a reasonable medium-term solution for the next several years. In addition, DIRA can be used to process dose index information from archived CT studies in PACS, which cannot benefit from dose index reporting improvements available in the newest generation of CT scanners, to incorporate patient-specific radiation dose index estimates into their medical record.

Our method of performing patient-specific dose index adjustments based on patient size should also enhance the ability to provide


Patient Name:
Exam no:
Accession Number:
Patient ID:
LightSpeed16
Exam Description: CTA ABD/PEL/EXT. C+(4C

Dose Report

| Series | Type | Scan Range (mm) | CTDIvol (mGy) | DLP (mGy-cm) | Phantom cm |
|---|---|---|---|---|---|
| 1 | Scout | – | – | – | – |
| 200 | Axial | I115.000-I115.000 | 20.00 | 19.98 | Body 32 |
| 2 | Helical | I1.000-I746.000 | 16.15 | 1259.27 | Body 32 |
| 4 | Helical | I176.250-I746.250 | 16.15 | 976.70 | Body 32 |
| | | | Total Exam DLP: | 2255.95 | |

1/1

A

B

**Fig. 2**—Example of typical CT dose index (CTDI) report.
**A,** Example of "burned" image of manufacturer's CTDI report.
**B,** This figure shows text information extraction applied to "burned" image of manufacturer's CTDI report.

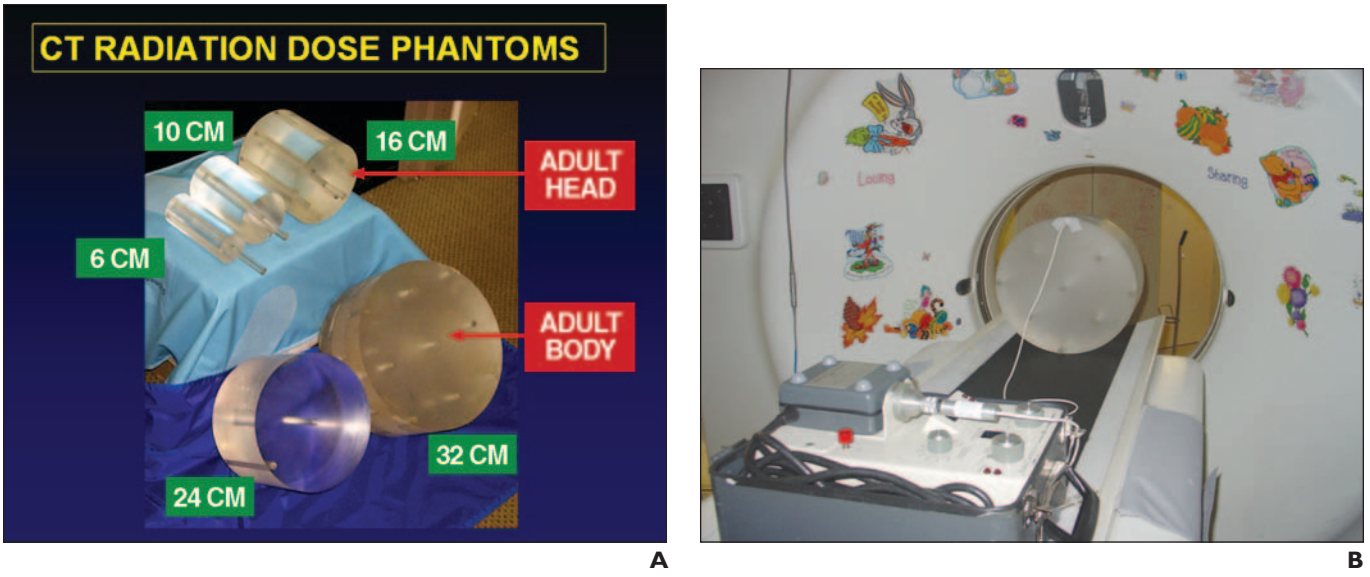



**Fig. 3**—CT dosimetry phantoms and setup.
**A,** Photograph shows group of CT dosimetry phantoms made of polymethylmethacrylate with diameter ranging from 6 to 32 cm.
**B,** Photograph shows setup for CT dose index (CTDI) measurements with phantom on one of CT scanners used for study.

a more accurate record for the patient because the current dose index estimates from the CT modalities are based on standard-sized PMMA phantoms. Consequently, the errors in these dose index reports are significant when the patient differs greatly from the "standard" size. This is especially true for pediatric patients for whom the reported dose indexes may be erroneously low. The patient-specific dose index adjustments (i.e., adjusted $CTDI_{vol}$) have been verified by phantom measurements [14, 15]. In our future work, we will continue to validate this method: first on anthropomorphic phantoms in sizes ranging from neonates to adults and then on real clinical cases using optically stimulated luminescence dosimeters (MicroStar, Landauer).

With the ability to perform digital CTDI reporting, our short-term goal is to use DIRA to promote radiation safety awareness for both patients and clinicians. For patients, we hope to provide this radiation dose index information in both their hospital's electronic medical records and also their personal health records (e.g., Microsoft HealthVault) for those who wish to have easier access to this information. We would also like to work with the Image Gently campaign, which aims to increase awareness about radiation safety for children. DIRA will enable patients (or parents) to keep a patient-specific record of their (or their child's) health care–related radiation exposure.

More work is under way to improve DIRA to automatically calculate a patient-specific dose index on the basis of patient age, sex, and size [14, 15, 19–21]. For clinicians, we hope to eventually build a feedback mechanism for when they order CT studies to reduce redundant or unnecessary examinations. Additionally, these dose index records can be used to enhance the education of clinical staff about radiation safety and can help determine whether imaging practices for a hospital or an imaging center are within the national standards.

Our long-term goal is to provide patients with a longitudinal record of their health care–related radiation exposure estimates. Studies about radiation-induced cancer have been performed and some researchers believe that the effects of radiation may be cumulative throughout a patient's lifetime [22, 23].

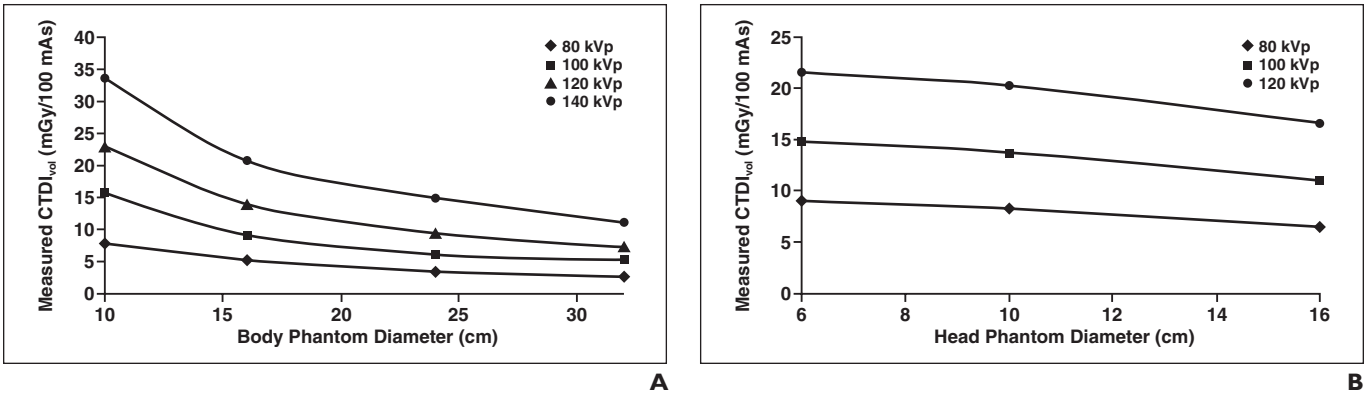



**Fig. 4**—Volume CT dose index ($CTDI_{vol}$) measurements made on 16-MDCT scanner (Sensation, Siemens Healthcare) during body and head scanning. Same measurements were made for each scan.
**A** and **B,** Graphs show relationships of $CTDI_{vol}$ versus phantom size for body scans (**A**) and head scans (**B**).

Therefore, the history of exposure estimates of an individual patient is of great need. Also important for the long-term will be the ability for researchers to better study the effects of health care–related radiation exposure.

We are currently testing an automated quality control module in our DIRA to verify that each CT study's patient-specific dose index falls within an established range of expected dose index values for that particular type of examination [24] to catch inappropriate protocols or to detect system errors. Any outliers are automatically flagged, and an alert is immediately sent by e-mail to our department's safety and quality team so prompt action including educating staff can be taken. We hope automated quality control will greatly reduce the time and effort involved in ensuring that the appropriate CT protocols and techniques are being used.

Automated quality control will likely become extremely important when more quality and pay-for-performance measures are used for reimbursement. Indeed, the Centers for Medicare & Medicaid Services has already instituted a Physician Quality Reporting System reporting of radiation exposure or exposure time during radiology fluoroscopy procedures [25]. Such measures may eventually be extended to include CT and other diagnostic imaging studies with ionizing radiation.

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