DICOM Structured Report to Track Patient's Radiation Dose to Organs from Abdominal CT Exam

Craig Morioka[*†], Adam Turner[*], Michael McNitt-Gray[*],
Maria Zankl[γ], Frank Meng[†], and Suzie El-Saden[*†]
[†]Department of Radiology, Veterans Affairs (VA) Greater Los Angeles Healthcare System,
11301 Wilshire Blvd, Los Angeles CA 90073
[*]Department of Radiology, University of California, Los Angeles,
924 Westwood Blvd, Los Angeles CA 90024
[γ]Helmholtz Zentrum München, German Research Center for Environmental Health (GmbH),
Institute of Radiation Protection, Ingolstaedter Landstraße 1, 85764 Neuherberg, Germany

ABSTRACT

The dramatic increase of diagnostic imaging capabilities over the past decade has contributed to increased radiation exposure to patient populations. Several factors have contributed to the increase in imaging procedures: wider availability of imaging modalities, increase in technical capabilities, rise in demand by patients and clinicians, favorable reimbursement, and lack of guidelines to control utilization. The primary focus of this research is to provide in depth information about radiation doses that patients receive as a result of CT exams, with the initial investigation involving abdominal CT exams. Current dose measurement methods (i.e. $CTDI_{vol}$ Computed Tomography Dose Index) do not provide direct information about a patient's organ dose. We have developed a method to determine $CTDI_{vol}$ normalized organ doses using a set of organ specific exponential regression equations. These exponential equations along with measured $CTDI_{vol}$ are used to calculate organ dose estimates from abdominal CT scans for eight different patient models. For each patient, organ dose and $CTDI_{vol}$ were estimated for an abdominal CT scan. We then modified the DICOM Radiation Dose Structured Report (RDSR) to store the pertinent patient information on radiation dose to their abdominal organs.

Keywords: CTDI, CT Dose, DICOM Structured Report, Organ Dose

1. INTRODUCTION

Many national and international groups (FDA, American College of Radiology, NIH, International Atomic Energy Agency) are advocating for radiation dose to be recorded and tracked for patients. In 2012, California State Bill 1237 requires hospitals and clinics that use CT X-ray systems for patient scanning to record, if the CT system is capable, the dose of radiation on every CT exam [1]. However, the only information currently recorded by CT scanners is the dose to a standardized phantom, known as the CT Dose Index (CTDI), which is not patient dose [2]. The focus of this research is to provide information about a patient's radiation dose received from abdominal CT exams. $CTDI_{vol}$ (Computed Tomography Dose Index) does not provide information about the patient's organ dose. The $CTDI_{vol}$ is a standardized measure of radiation output of a CT system. The dose output of $CTDI_{vol}$ is based on a cylindrical acrylic phantom (16 cm or 32 cm) that allows users to gauge the amount of emitted radiation and to compare the dose efficiency between different scan protocols or scanners. Additional calculations are required to convert scanner output to patient dose, taking into account the patient's size and the scan range. We recently reported on a method to determine $CTDI_{vol}$ normalized organ doses using a set of organ specific exponential regression equations [3-4]. These were used together with measured $CTDI_{vol}$ to calculate organ dose estimates from abdominal CT scans for eight different patient models (from GSF – German National Research Center for Environment and Health). We then developed a database schema based on DICOM Supplement 127; CT Dose Reporting to store the pertinent patient information on organ dose. Furthermore, we can export the database information as a DICOM SR (Structured Report) which can then be sent to a DICOM compliant PACS system for storage or to a DICOM SR report viewing workstation. In addition, we have integrated our Radiology Imaging

Medical Imaging 2011: Advanced PACS-based Imaging Informatics and Therapeutic Applications,
edited by William W. Boonn, Brent J. Liu, Proc. of SPIE Vol. 7967, 79670X · © 2011 SPIE
CCC code: 1605-7422/11/$18 · doi: 10.1117/12.878277

Workstation with a web page that contains the pertinent patient's organ dose based on the image study's accession number. The clinician can view both the image study and the CT organ dose for the patient at any radiology image review workstation.

2. METHODS

We have developed a method to determine $CTDI_{vol}$ normalized organ doses using a set of organ-specific exponential regression equations [4] of the form:

$$A * e^{Bp} \tag{1}$$

(A,B fitting parameters, p=patient perimeter). The exponential regression equation together with the $CTDI_{vol}$ measurements were used to calculate the organ dose for the stomach, liver, and colon from abdominal CT scans. Eight different patient models developed by German National Research Center for Environment and Health were used to estimate the dose. For each patient, organ dose and $CTDI_{vol}$ (to a 32 cm diameter phantom) were estimated for an abdominal CT scan. The International Commission on Radiological Protection (ICRP) recommendations for tissues to be observed in Publication 103 have been added as fields in our rendition of DICOM Supplement 127. Currently, we can model the adrenals, colon, gall bladder, kidney, liver, pancreas, spleen, and stomach (see Figure 1). The tissues that we are planning to include in the ICRP Publication 103 are the following: bone surfaces, urinary bladder, breast, gonads, lungs, esophagus, red bone marrow, skin, and thyroid [5].

Table 1. Age, Gender, and Size information on eight GSF patient models (Wt=weight, Ht=height, BMI=Body Mass Index).

GSF Model	Age (yr)	Gender	Wt. (kg)	Ht (cm)	BMI (kg/m^2)	Perimeter (cm)
Baby	8 wks	F	4.2	57	12.9	36.3
Child	7	F	22	115	16.4	59.7
Irene	32	F	51	163	19.2	66.5
Donna	40	F	79	170	27.3	95.0
Helga	26	F	81	170	28.0	106.2
Golem	38	M	69	176	22.2	87.4
Frank	48	M	95	174	31.3	124.5
Visible Human	39	M	103	180	30.9	106.2

The DICOM Structured Report is based on DICOM Part 16, and its predecessor Supplement 127: CT Radiation Dose Reporting (Dose SR) [6-7]. We utilize DICOM Supplement 127 to store mandatory fields for the templates that comprise the CT Radiation Dose SR: TID10011-CT Radiation Dose, TID1002-Observer Context, TID 10012-CT Accumulated Dose Data, and TID 10013-CT Irradiation Event Data. The templates for the CT Radiation Dose SR were the basis for the database schema used to store the pertinent study information (Figure 2). Clinicians can view the calculated organ dose from our commercial PACS system through an embedded web browser in our Radiology Review workstation software (AGFA, Ridgefield Park, NJ). We utilize version 6.2 of the Agfa IMPAX Radiology image viewing client software that allows URL integration. The URL contains parameters that include the user and study accession number. Obtaining the patient's organ dose for the current scan requires no modifications to the clinician's workflow. The user first logs into the IMPAX client and chooses the image study they want to review from the patient worklist. The results are then displayed, with the images displayed on the right side (not shown) and the study worklist on the left side of the display along with a window containing the patient's organ dose (see Figure 4).

3. RESULTS

Table 1 provides detailed information about the 2 pediatric, 3 adult male and 3 adult female GSF models. Perimeter values were obtained using a graphics software package that featured a semi-automated segmentation tool. A contour was placed around the outside of the patient and its path length was recorded. Table 2 depicts the results of organ dose estimates for 3 organs measured for our 8 GSF patients (AF= adult female, AM=adult male). From Table 2 each patient, their organ dose (adrenals, colon, gall bladder, kidney, liver , pancreas, spleen, and stomach) and $CTDI_{vol}$ were estimated for an abdominal CT scan (see Figure 1).

4. DISCUSSION

Figure 1 shows the effect of patient size on radiation dose and the feasibility of correcting for it to obtain estimates of organ dose normalized by $CTDI_{vol}$ for abdomen scans performed with fixed tube current. These results were obtained by first simulating abdominal scans for each of the GSF models with fixed tube current. The dose for each abdominal organ (on a per mAs basis) that is fully contained within the scan region was tallied in the simulation. This organ dose

Table 2. Shows $CTDI_{vol}$, stomach, liver, and colon organ dose estimates for eight GSF patient models.

GSF Model	***CTDI$_{vol}$* (mGy)**	**Stomach (mGy)**	**Liver (mGy)**	**Colon (mGy)**
Baby	5.6	14.0	13.8	12.3
Child	8.0	15.4	14.9	13.8
AF1 (Irene)	11.7	20.7	19.9	18.6
AF2 (Donna)	13.0	16.6	15.7	15.3
AF3 (Helga)	16.5	18.6	17.4	17.2
AM1(Golem)	13.0	18.1	17.2	16.6
AM2 (Frank)	16.5	19.3	18.1	17.8
AM3 (Visible Human)	16.5	15.1	13.9	14.2

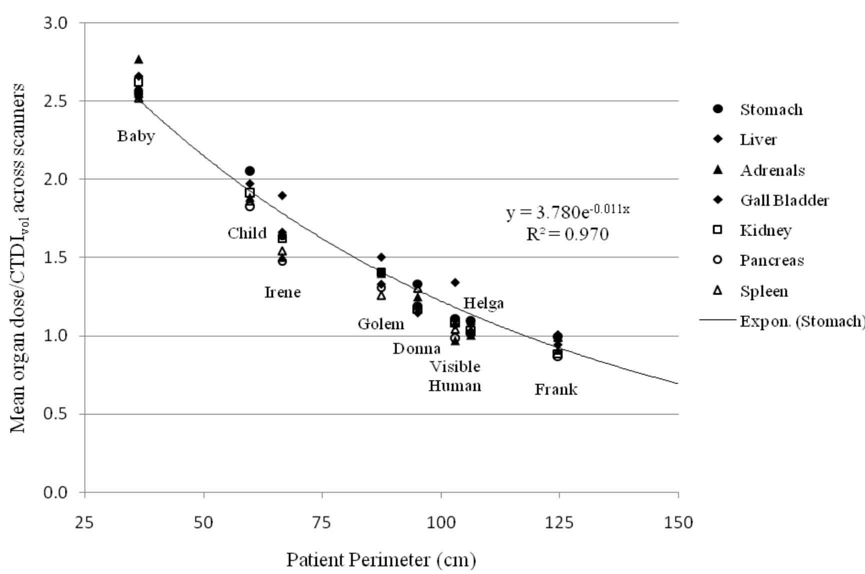

Figure 1. Data showing organ doses normalized by $nCTDI_{vol}$ ($CTDI_{vol}$ normalized by mAs) values resulting from simulated abdomen scans [from 4]. Scans were simulated for each GSF patient model (described above). Results were plotted as a function of patient perimeter. For each organ, exponential regression models were determined as a function of patient size in the form :

$$(\text{Organ Dose}/ \text{nCTDI}_{vol}) = A * e^{(B*\text{perimeter})} \quad (2)$$

was normalized by the $CTDI_{vol}$ value (also on a per mAs basis) obtained under the same operating conditions (scanner manufacturer and model, bowtie filter, kVp, collimation, pitch, etc...). It should be noted that this also normalizes out the effects of mAs. The figure caption gives an example of how this could be used to estimate organ dose for patients of different sizes if the patient perimeter, $CTDI_{vol}$ and mAs is known. Table 2 depicts the importance of patient size: even when the scanner output is reduced (lower $CTDI_{vol}$), a smaller patient absorbs a relatively larger organ dose compared to a larger patient who shows greater $CTDI_{vol}$ value. The difference is due to the patient's size (smaller patients receive a higher dose because they have less attenuating mass surrounding their organs) and the amount of radiation that is transmitted through the patient (i.e. the quantity and quality of x-ray photons that travel from the entrance to the exit surfaces of the patient).

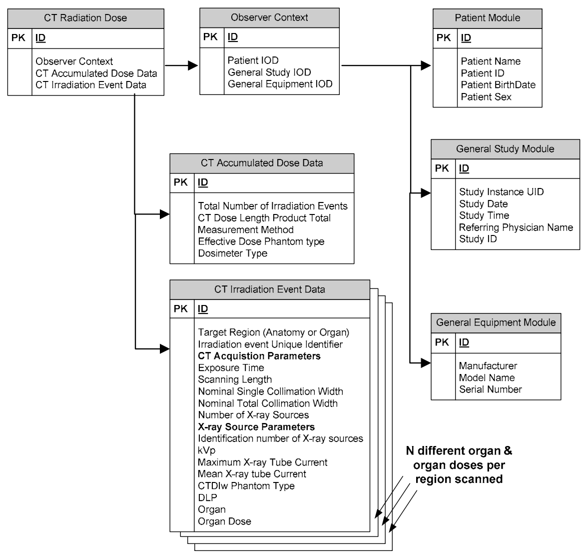

Figure 2. Database Schema for CT organ dose.

Y/N	Tag	Attribute Name	VR	VM	Value
☑	>>(0040,A040)	ValueType	CS	1	CONTAINER: X-Ray Source Parameters
☑	>>(0040,A730)	ContentSequence	SQ	8	
☑	>>>ITEM 1				
☑	>>>(0008,0100)	CodeValue	SH	1	CONTAINS
☑	>>>(0008,0102)	CodingSchemeDesignator	SH	1	NUM
☑	>>>(0008,0104)	CodeMeaning	LO	1	Identification Number of X-ray Sources= 106819
☑	>>>ITEM 2				
☑	>>>(0008,0100)	CodeValue	SH	1	CONTAINS
☑	>>>(0008,0102)	CodingSchemeDesignator	SH	1	NUM
☑	>>>(0008,0104)	CodeMeaning	LO	1	kVp = 80
☑	>>>ITEM 3				
☑	>>>(0008,0100)	CodeValue	SH	1	CONTAINS
☑	>>>(0008,0102)	CodingSchemeDesignator	SH	1	NUM
☑	>>>(0008,0104)	CodeMeaning	LO	1	Maximum X-ray Tube Current = 200 mA
☑	>>>ITEM 4				
☑	>>>(0008,0100)	CodeValue	SH	1	CONTAINS
☑	>>>(0008,0102)	CodingSchemeDesignator	SH	1	NUM
☑	>>>(0008,0104)	CodeMeaning	LO	1	Mean X-ray Tube Current = 160 mA
☑	>>>ITEM 5				
☑	>>>(0008,0100)	CodeValue	SH	1	CONTAINS
☑	>>>(0008,0102)	CodingSchemeDesignator	SH	1	CODE
☑	>>>(0008,0104)	CodeMeaning	LO	1	CTDIw Phantom Type = IEC Body Dosimeter Phantom
☑	>>>ITEM 6				
☑	>>>(0008,0100)	CodeValue	SH	1	CONTAINS
☑	>>>(0008,0102)	CodingSchemeDesignator	SH	1	NUM
☑	>>>(0008,0104)	CodeMeaning	LO	1	DLP = 28.9 mGy*cm
☑	>>>ITEM 7				
☑	>>>(0008,0100)	CodeValue	SH	1	CONTAINS
☑	>>>(0008,0102)	CodingSchemeDesignator	SH	1	CODE
☑	>>>(0008,0104)	CodeMeaning	LO	1	ORGAN = STOMACH
☑	>>>ITEM 8				
☑	>>>(0008,0100)	CodeValue	SH	1	CONTAINS
☑	>>>(0008,0102)	CodingSchemeDesignator	SH	1	NUM
☑	>>>(0008,0104)	CodeMeaning	LO	1	ORGAN DOSE = 4.8 mGy
☐	>>>ITEM 9				
☐	>>ITEM 6				
☐	>ITEM 7				

Figure 3. Portion of DICOM SR object for X-ray Source Parameters for GSF Baby (8 weeks, female, perimeter 36.3 cm) based on DICOM Supplement 127: CT Radiation Dose Reporting.

Table 2 also shows that $CTDI_{vol}$ is not the same as a particular patient's organ dose. Ideally, we should be tracking organ dose and not CTDI. Previous work [4] has shown the importance of patient size in estimating radiation dose and has demonstrated the feasibility of converting standard scanner output metrics (CTDI) to patient organ dose when patient size and scan region information are available.

To demonstrate the feasibility of tracking patient organ doses, figure 3 shows a portion of the X-ray source parameter template of DICOM Supplement 127 for capturing the following information: number of x-ray sources, kVp, mA, CT dose phantom type, dose length product (DLP), and stomach organ dose information for a baby undergoing an abdominal CT scan. The DICOM SR report generated from our database allows export of the DICOM object to our DICOM compliant PACS infrastructure. The database allows us the ability to deploy our CT organ dose findings throughout our hospital. Any clinician can view the CT dose for a particular patient through an embedded web browser on the local radiology review workstation distributed throughout our healthcare infrastructure.

Figure 4. URL integration of patient's CT organ dose into Commercial PACS worklist.

5. ACKNOWLEDGEMENT

The authors would like to acknowledge Matt Kecko from AGFA whose technical expertise was vital in the development of the URL integration of the Impax client to our web server.

6. REFERENCES

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