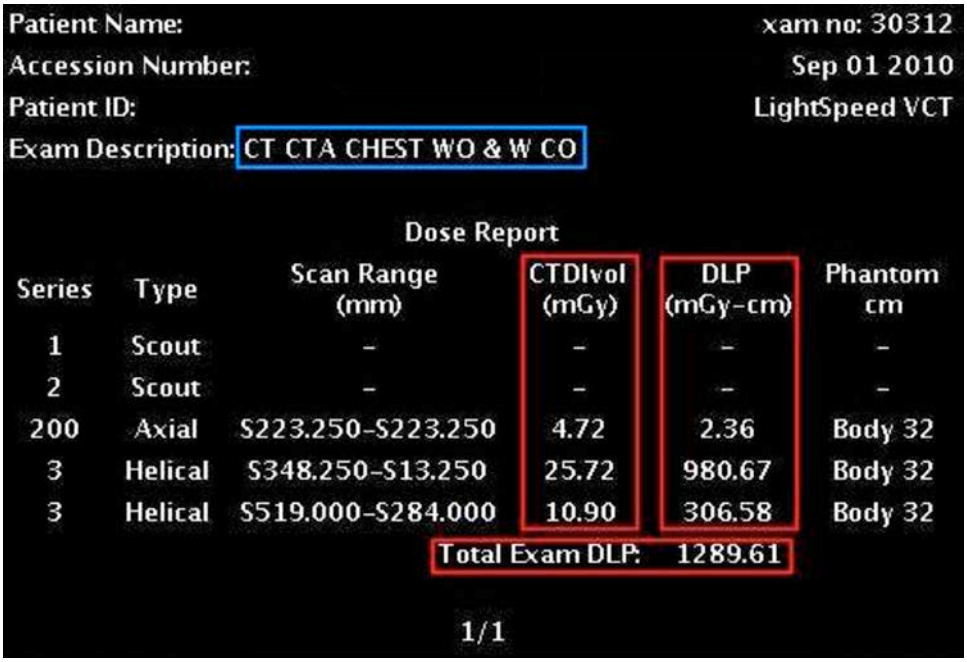
Appendix E1

Exposure Extraction Method

1. Queries are issued to the image archive for information about computed tomographic (CT) examinations.

2. Potential dose report screen captures (hereafter, dose screens) (Fig E1) are identified from these query results on the basis of a combination of dose screen image type and any expected manufacturer-specific series numbers or series descriptions.



Patient Name: xam no: 30312
Accession Number: Sep 01 2010
Patient ID: LightSpeed VCT
Exam Description: CT CTA CHEST WO & W CO

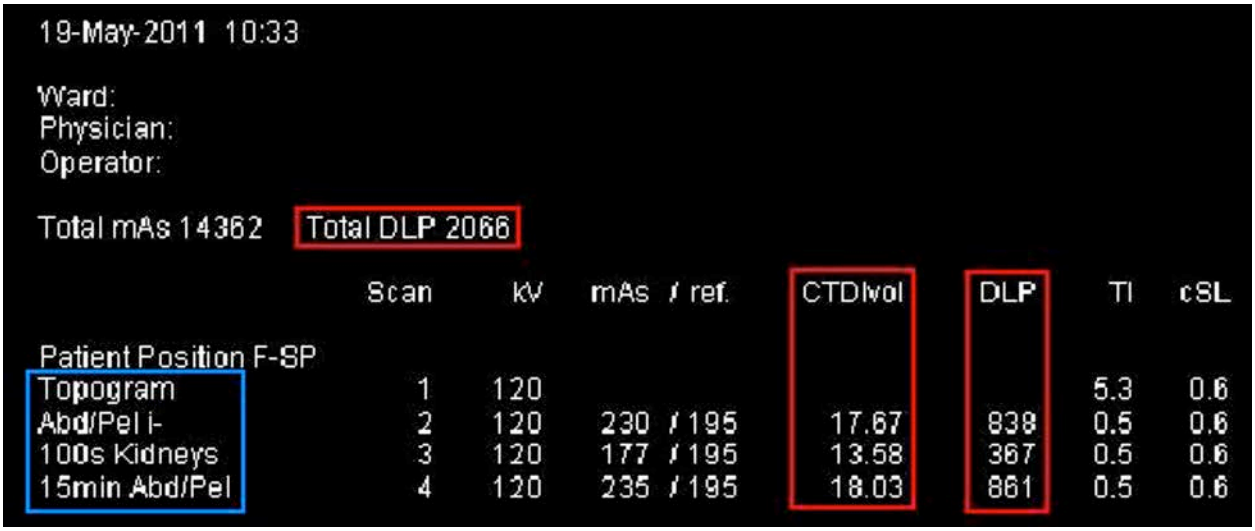
Dose Report

Series	Type	Scan Range (mm)	CTDIvol (mGy)	DLP (mGy-cm)	Phantom cm
1	Scout	-	-	-	-
2	Scout	-	-	-	-
200	Axial	S223.250-S223.250	4.72	2.36	Body 32
3	Helical	S348.250-S13.250	25.72	980.67	Body 32
3	Helical	S519.000-S284.000	10.90	306.58	Body 32

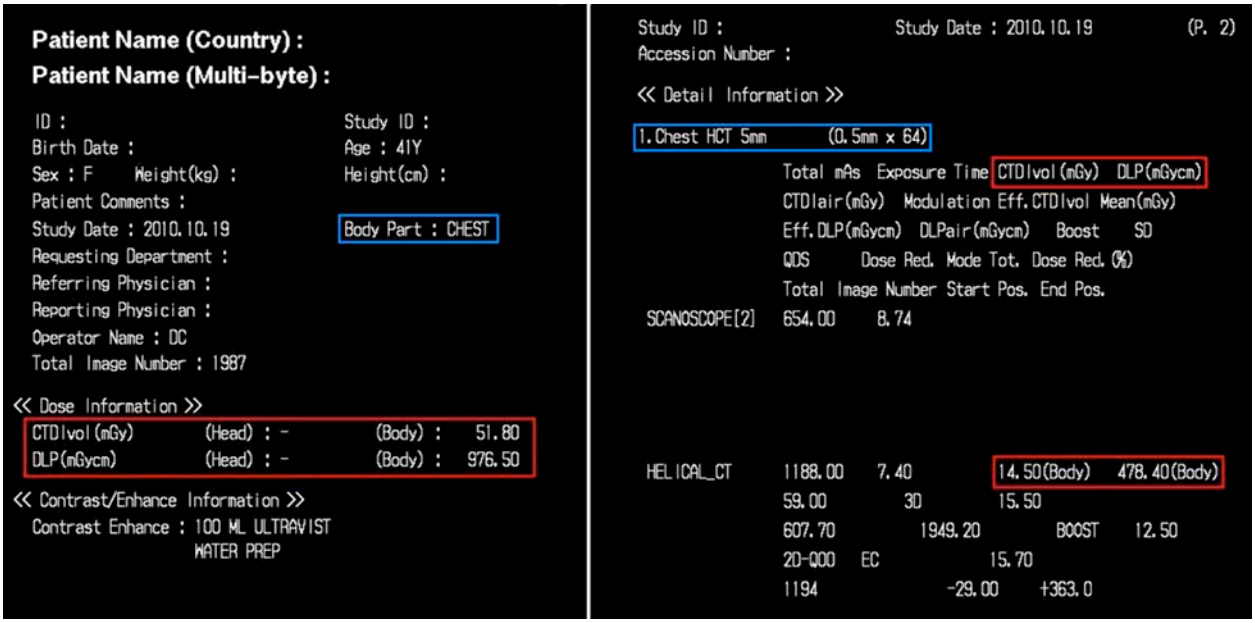
Total Exam DLP: 1289.61

1/1

E1a.


19-May-2011 10:33
Ward:
Physician:
Operator:
Total mAs 14362
Total DLP 2066
Scan kV mAs / ref. CTDIvol DLP TI cSL
Patient Position F-SP
Topogram 1 120 5.3 0.6
Abd/Pel i- 2 120 230 / 195 17.67 838 0.5 0.6
100s Kidneys 3 120 177 / 195 13.58 367 0.5 0.6
15min Abd/Pel 4 120 235 / 195 18.03 861 0.5 0.6

E1b.


Patient Name (Country) :
Patient Name (Multi-byte) :
ID :
Study ID :
Birth Date :
Age : 41Y
Sex : F Height(kg) :
Height(cm) :
Patient Comments :
Study Date : 2010.10.19
Body Part : CHEST
Requesting Department :
Referring Physician :
Reporting Physician :
Operator Name : DC
Total Image Number : 1987
<< Dose Information >>
CTDIvol(mGy) (Head) : - (Body) : 51.80
DLP(mGycm) (Head) : - (Body) : 976.50
<< Contrast/Enhance Information >>
Contrast Enhance : 100 ML ULTRAVIST
WATER PREP
Study ID :
Study Date : 2010.10.19
(P. 2)
Accession Number :
<< Detail Information >>
1.Chest HCT 5mm (0.5mm x 64)
Total mAs Exposure Time CTDIvol(mGy) DLP(mGycm)
CTDIair(mGy) Modulation Eff.CTDIvol Mean(mGy)
Eff.DLP(mGycm) DLPair(mGycm) Boost SD
QDS Dose Red. Mode Tot. Dose Red.(%)
Total Image Number Start Pos. End Pos.
SCANOSCOPE[2] 654.00 8.74
HELICAL_CT 1188.00 7.40 14.50(Body) 478.40(Body)
59.00 3D 15.50
607.70 1949.20 BOOST 12.50
2D-QDD EC 15.70
1194 -29.00 +363.0

E1c.

E1d.

Figure E1: Sample screen capture dose reports for **(a)** GE Healthcare, **(b)** Siemens Healthcare, **(c)** Toshiba Medical Systems, and **(d)** Philips Healthcare. Contents and formatting differ, but all contain the x-ray tube output metrics $CTDI_{vol}$ and DLP, outlined in red boxes. Each separate row containing values of these metrics represents a distinct dose event, while all of the component dose events on a dose screen belong to the same CT encounter. The blue boxes contain series or scan descriptions that may aid anatomy determination. In **d**, the dose report content within a private DICOM attribute is included to the right.

3. Potential dose screens and the first image in every non–dose screen series are retrieved.

4. Optical character recognition (OCR) is used to convert dose screen images to text. Manufacturer-dependent regular expressions and logic rules are applied to capture exposure metrics, including dose-length product (DLP) and volume CT dose index ($CTDI_{vol}$), and table start and stop positions.

5. Additional potentially useful image-level information is gathered from the Digital Imaging and Communications in Medicine (DICOM) attributes, including protocol name and series description. These image-level data are matched to dose events.

6. A combination of data from steps four and five is used to assign anatomic regions to dose events by using a manufacturer-dependent strategy that is described later in this Appendix.

7. Dose information and image level data are stored in a relational database (SQL Sever 2005; Microsoft, Redmond, Wash) for subsequent analysis.

Anatomy Assignment Strategy

The algorithms used to assign anatomy are complex, not only because of the extremely variable format and content of exposure events reported by the different manufacturers, but also because of the variable fidelity of potentially available anatomic descriptors. The basic strategy used is to favor use of more specific dose event–level descriptions, when available, instead of the typically less specific protocol-level descriptions. The event-level descriptions correspond to the series description on the Philips Healthcare (Best, the Netherlands) private DICOM dose sequences and the range name on the Siemens Healthcare (Forcheim, Germany) dose screens. Dose screens from GE Healthcare (Piscataway, NJ) and Toshiba Medical Systems (Tokyo, Japan) do not include explicit event-level descriptions, so protocol descriptions are used with additional anatomy mapping definitions used for the most common protocols comprising multiple dose events. For example, the entire scanning range is divided equally into thirds for common chest/abdomen/pelvis studies. These definitions and additional logic rules assign anatomy based on available table positions or relative scan lengths. It is also necessary to match dose events to images to use the image- or series-level anatomic descriptions or other DICOM attributes found only at the image level (as opposed to the dose screens).

The anatomy assignment algorithms are described later in the Appendix for each dose screen manufacturer. Each line represents a matching attempt that uses a string of text from the specified source to match anatomic concepts in a DICOM CT anatomy dictionary, which are defined by the Systemized Nomenclature of Medicine Reference Terminology, or SNOMED-RT. Most concepts in the dictionary contain a list of synonyms, including commonly used abbreviations and other variants (eg, CAP for chest/abdomen/pelvis). The longest string is favored during matching. The matching algorithm is terminated once a match is found.

Two manufacturers' dose screens (Philips Healthcare and Siemens Healthcare) often contain useful dose event–level descriptions, in which case anatomy matching is attempted directly at the dose event level. In contrast, the other two manufacturers (GE Healthcare and Toshiba Medical Systems) have no dose event–level descriptions, so matching is initially performed by using protocol-level descriptions to obtain an overall anatomic concept for the entire protocol and is followed by a secondary process to map individual dose events within the protocol (Fig E2).

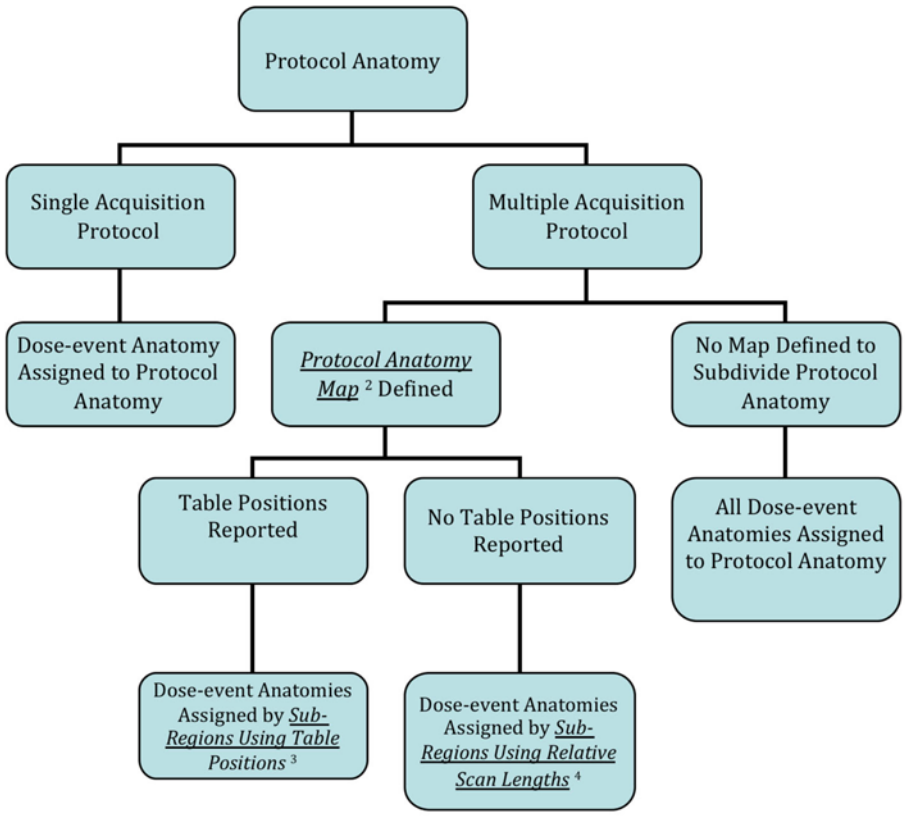


Figure E2: Flowchart shows how anatomy is assigned to each component dose event on the basis of overall protocol anatomy, number of acquisitions, and availability of anatomy map definition and table positions.

The CT anatomy method (described later in this Appendix) takes a DICOM attribute list as an argument and inspects the attributes in a certain order. It attempts a string match by using the value of each attribute and stops when the first match is found.

Once all matching has been performed, anatomy matches are checked for possible elongation. If the scan length (explicitly specified by table positions in the dose screens or otherwise derived by dividing DLP by $CTDI_{vol}$) is greater than 30 cm for abdominal or pelvic anatomy, the anatomy is elongated to the abdomen and pelvis. Similarly if a chest and abdominal or abdominal and pelvic anatomy scan length is greater than 60 cm, it is elongated to chest, abdomen, and pelvis. This was necessary because descriptions for many dose events do not accurately describe the entire body region imaged (eg, abdominal and pelvic scans are often described as *abdomen* in CT protocols). To make this correction more robust for pediatric patients, a look-up table based on average height by age could be implemented in place of fixed thresholds that are used for all patients.

Anatomy Assignment Algorithms

Philips Healthcare

Dose-event anatomy assignment.—

a. Series description (Philips Healthcare private exposure sequence DICOM attribute)

b. Series description (image DICOM attribute, matched[1P] by acquisition date and time)

c. Protocol name (image DICOM attribute, matched[1P] by acquisition date and time)

d. Series description (image DICOM attribute from temporally associated studies, matched[1P] by acquisition date and time or by series number)

e. Protocol name (image DICOM attribute from temporally associated studies, matched[1P] by acquisition date or time or by series number)

f. Prior dose event (in same exposure sequence)

g. CT anatomy method[5] (dose screen DICOM attribute list)

Siemens Healthcare

Dose event anatomy assignment.—

a. Range name (dose screen OCR)

b. Series description (image DICOM attribute, matched[1S] by acquisition number)

c. Protocol name (image DICOM attribute, matched[1S] by acquisition number)

d. Prior dose event (on same dose screen)

e. Study description (dose screen DICOM attribute)

f. CT anatomy method[5] (dose screen DICOM attribute list)

Toshiba Medical Systems

Protocol anatomy assignment.—

a. Protocol name (image DICOM attribute, matched[1T] by acquisition number and protocol name OCR)

b. Protocol name (image DICOM attribute from temporally associated studies, matched[1T] by acquisition number and protocol name OCR)

c. Protocol name (dose screen OCR)

d. CT anatomy method[5] (from image DICOM attribute list of examination and temporally associated studies, matched[1T] by acquisition number and protocol name OCR)

e. CT anatomy method[5] (dose screen DICOM attribute list)

Protocol anatomy to dose event anatomy mapping.—

Please see Figure E2.

GE Healthcare

Protocol anatomy assignment.—

a. Protocol name (image DICOM attribute, matched[1G] by series number)

b. Protocol name (image DICOM attribute from temporally associated studies, matched[1G] by series number)

c. CT anatomy method[5] (dose screen DICOM attribute list)

Protocol anatomy to dose-event anatomy mapping.—

Please see Figure E2.

[1] Matching Dose Events to Image-Level Data

To use anatomic information specified at the image level, it is necessary to match dose events to images. The strategies used to accomplish this differ by manufacturer, as indicated.

[1P] Philips Healthcare.—

The acquisition date and time from the Philips Healthcare private DICOM attribute exposure sequence is used to match the image-level acquisition date and time DICOM attribute for this manufacturer, if present. If absent, the potentially less specific series number from both the exposure sequence and the image-level series number DICOM attribute is used.

[1S] Siemens Healthcare.—

The acquisition number is specified on the Siemens Healthcare dose screens and is used to match the image-level acquisition number.

[1T] Toshiba Medical Systems.—

The implicitly derived acquisition number based on order of appearance from Toshiba Medical Systems dose screens and the protocol name (from OCR of the dose screen) is used to match the protocol name and acquisition number DICOM attributes at the image level. It is necessary to include the protocol name because

multiple protocols can be present on one dose screen and because acquisition numbers reset for each protocol, causing duplicates. Inexact string matching of the protocol name is permitted due to imperfect OCR.

[1G] GE Healthcare.—

The algorithm implemented for GE Healthcare units matches the series number of the dose event on the dose report and the image-level series number DICOM attribute. A potential problem with this matching strategy is occasional inconsistent numbering of the two series numbers.

[2] Protocol Anatomy Map Definitions

1. Chest/Abdomen/Pelvis (CAP)

2. Neck/CAP

3. Neck/Chest

4. Abdomen/Pelvis

5. Chest/Abdomen

[3] Subregions Using Table Positions

For dose reports containing dose event table positions (those obtained with GE Healthcare units and some obtained with Toshiba Medical Systems units), the overall examination scan range is defined from the full combined range of the subcomponent dose event table positions. Anatomic subregions are defined as follows for common combination examinations covering more than one anatomic region. Each dose event is assigned to one of these anatomic subregions by the following rules:

1. Assign all protocol anatomy subregions that are at least 75% covered by the dose event.

2. If no subregions are assigned by the above rule, assign the single subregion with the largest fraction covered by the dose event.

3. If the table is stationary (as for monitoring scans), assign the subregion containing the fixed table position.

These anatomic region maps use the overall protocol scan range from all component dose events and define anatomic subregions based on the dose-event table positions with the following rules:

Anatomic subregion definitions for common combination examinations.—

1. Chest/Abdomen/Pelvis (CAP)

    a. Each subregion assigned one-third of total scan length

2. Neck/CAP

    a. CAP = caudal four-fifths of total scan length (then subdivided by using the CAP map)

    b. Neck = cranial one-fourth of total scan length

3. Neck/Chest

    a. Chest = caudal three-fourths of total scan length

    b. Neck = cranial half of total scan length

4. Abdomen/Pelvis

    a. Abdomen = cranial half of total scan length

    b. Pelvis = caudal half of total scan length

5. Chest/Abdomen

    a. Chest = cranial half of total scan length

    b. Abdomen = caudal half of total scan length

[4] Subregions Using Relative Scan Lengths

These algorithms are used when there are no table positions available (Philips Healthcare, Siemens Healthcare, and sometimes Toshiba Medical Systems unit examinations). Dose event scan lengths are approximated as DLP divided by $CTDI_{vol}$ (neglecting z overscanning). Each component dose event is assigned a relative scan length, defined as the dose event scan length divided by the longest dose event scan length present by using the following rules:

1. CAP

    a. Two dose events

        i. Abdomen/pelvis = larger relative scan length

        ii. Chest = smaller relative scan length

        iii. CAP = equal relative scan lengths

    b. More than two dose events

        i. CAP = relative scan length ≥80%

        ii. Abdomen/pelvis = relative scan length ≤80% and >50%

        iii. Chest = relative scan length ≤50% and >30% and no chest anatomy yet assigned

        iv. Abdomen = all above rules failed to trigger

2. Neck/CAP

    a. Two dose events

        i. Neck = smaller relative scan length

        ii. CAP = larger relative scan length

    b. Three dose events

        i. Abdomen/pelvis = largest relative scan length

ii. Neck = smallest relative scan length

iii. Chest = median relative scan length

c. More than three dose events

i. Neck/CAP assigned to all

3. Neck/Chest

a. Two dose events

i. Neck = smaller relative scan length

ii. Chest = larger relative scan length

b. More than two dose events

i. Chest = largest relative scan length

ii. Neck = all others

[5] CT Anatomy Method

This method is used only if the more specific potential sources of anatomic information failed to match. It takes a DICOM attribute list from a dose screen or CT image and uses the value of each DICOM attribute in the following order to match concepts in the CT anatomy dictionary, stopping when the first anatomic match is found:

1. Anatomic region sequence

2. Body part examined

3. Image comments

4. Series description

5. Protocol name

6. Performed procedure code sequence

7. Performed procedure step sequence

8. Procedure code sequence

9. Study description

Bolus tracking dose events.—

Monitoring scans (such as bolus timing scans) are assigned to the next recognized anatomic area, or to an anatomic subregion if table position is provided.

Temporally associated studies.—

Temporally associated studies are defined as all CT studies obtained in the same patient (determined by matching patient identifier DICOM attribute) with a study start date and time DICOM attribute equal to the reference examination.

One difficulty with trying to match image data to dose data occurs when dose reports are stored under a different study than the images. For example, for a chest/abdomen/pelvis examination performed in two acquisitions, the chest and abdomen/pelvis portions can be archived as separate studies, but the dose screen may be sent to either study or both studies. If no match between dose-event data and image-level data within the same study is found, then we attempt to match the dose-event data to image-level data by using all temporally associated studies. Also, duplication checks are performed to prevent counting identical dose events more than once if different versions of the same dose screen had been sent multiple times or if the same dose screen had been sent to multiple studies.