

Development of an In-House CT Dose Monitoring and Management System Using Open-Source Resources – Pearls and Pitfalls

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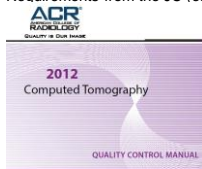
Content of This Talk

- Motivation and design of an in-house CT dose monitoring system
- Steps of implementing such a project
- Pitfalls we went through and lessons we learned

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Background: Dose Concerns and Regulatory Requirements

- The rise of concerns of medically induced radiation
 - CT: #1 dose contributor
 - Waves of articles in lay media
- Requirements from ACR accreditation (effective Dec/2011)
- Requirements from the JC (effective Jul/2015)



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<http://time.com/2011/04/medical-scans-fuel-do-dangers/>
<http://www.forbes.com/sites/jamesconna/2014/12/03/do-not-fear-the-radiation-in-medical-scans/>

JC Requirements

- In a brief summary, hospitals need to
 - Review protocols periodically and keep protocols current with input from interpreting radiologist, medical physicist and lead imaging technologist.
 - Bench mark dose levels with external references.
 - Set up dose thresholds specific to individual exam types.
- These are non-trivial tasks!

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Challenges: Highly Fragmented Data

- An extreme example from a workhorse GE CT750
 - 18 mo. of data, 16587 exams
 - 708 protocols in exam records
 - on average 23.4 exams/protocol
 - A disaster to manually analyze the data
- Protocols fine-tuned & individualized for
 - Advanced features, e.g. dual energy CT, MAR
 - Patient size/age
 - Clinical indication: baseline vs. follow up
- Mixture of old and new data in the exam records
- Fleet of scanners from different vendors and models



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Challenges: The Clash of Names

- Synonyms, abbreviations, and typos exist in protocol names, e.g.,
 - ❑ Abdomen/Pelvis, ABP, Abd/Pel, Abd-Pel
 - ❑ Cancer Follow Up, CA FU, CA-FU, CAFU, CA F/U
 - ❑ Above 300 lbs, > 300 lbs, 300+ lbs, above 300
 - ❑ Without contrast, I-, C-, NON-CON, W/O
 - ❑ Thorax vs. Chest, etc.



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Opportunities

- Great opportunity to solve these problems and to make innovations
- Radiation Dose Structured Report (RDSR) became widely available, thanks to the MITA XR29 initiative



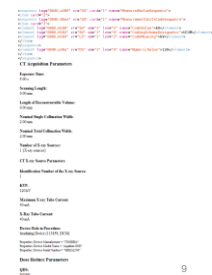
Motivation and the Planning Phase

- Motivation
 - Geeks with enthusiasm in informatics and desire to demonstrate value
 - High level of desired flexibility of the system
 - Supportive department
 - Open source software resources!
- Top level design: two subsystems
 - A light-weight dose information collection system with simple user interface
 - A flexible and evolving data analysis framework for dose tracking and protocol management
- Figure out what data to collect from PACS and other hospital IT systems

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A Good Wealth of Dose Info from PACS

- Four possible sources of CT dose info from PACS
 - Radiation Dose Structured Report (RDSR)
 - Easy to parse
 - Contain info of the entire exam and of individual scan series
 - Dose summary images
 - Scout images
 - Axial images
- Small-footprint data collection
 - RDSR + scout images + dose summary images
 - Several megabytes per exam



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CT Dose Info in RDSR from Multiple Vendor/Models

| Model | GE CT780 HD, VCT | GE LB16 Pro | Toshiba A-Prime | Toshiba A-One | Siemens Def AS, Biograph 64 |
|-----------------------------------|----------------------------|----------------------------|----------------------------|----------------------------|-----------------------------|
| Scanner protocol name | (Injection Protocol) | (Injection Protocol) | (Injection Protocol) | (Injection Protocol) | (Injection Protocol) |
| Radical or Adult | (CT Acquisition Type) | (CT Acquisition Type) | (CT Acquisition Type) | (CT Acquisition Type) | (CT Acquisition Type) |
| Body region | Whole Patient | Whole Patient | Whole Patient | Whole Patient | Whole Patient |
| About dose reduction techniques | Whole Patient | Whole Patient | Whole Patient | Whole Patient | Whole Patient |
| Dose reduction tech | (Dose Reduction Tech) | (Dose Reduction Tech) | (Dose Reduction Tech) | (Dose Reduction Tech) | (Dose Reduction Tech) |
| Noise index or SD | (Noise Index or SD) | (Noise Index or SD) | (Noise Index or SD) | (Noise Index or SD) | (Noise Index or SD) |
| Per-series Acquisition Parameters | | | | | |
| Exposure time | Exposure Time | Exposure Time | Exposure Time | Exposure Time | Exposure Time |
| Scan length | Scan Length | Scan Length | Scan Length | Scan Length | Scan Length |
| Scan begin z location | (Z Location of Scan Begin) | (Z Location of Scan Begin) | (Z Location of Scan Begin) | (Z Location of Scan Begin) | (Z Location of Scan Begin) |
| Scan end z location | (Z Location of Scan End) | (Z Location of Scan End) | (Z Location of Scan End) | (Z Location of Scan End) | (Z Location of Scan End) |
| Scan thickness? | (Scan Thickness) | (Scan Thickness) | (Scan Thickness) | (Scan Thickness) | (Scan Thickness) |
| Collimation | Collimation | Collimation | Collimation | Collimation | Collimation |
| Filter | Filter | Filter | Filter | Filter | Filter |
| Single or dual source | Single or Dual Source | Single or Dual Source | Single or Dual Source | Single or Dual Source | Single or Dual Source |
| KVP | KVP | KVP | KVP | KVP | KVP |
| Max mA | Max mA | Max mA | Max mA | Max mA | Max mA |
| Average mA | Average mA | Average mA | Average mA | Average mA | Average mA |
| Rotation time | Rotation Time | Rotation Time | Rotation Time | Rotation Time | Rotation Time |
| Displayed CTDIv | Displayed CTDIv | Displayed CTDIv | Displayed CTDIv | Displayed CTDIv | Displayed CTDIv |
| Phantom type | Phantom Type | Phantom Type | Phantom Type | Phantom Type | Phantom Type |
| DLP | DLP | DLP | DLP | DLP | DLP |
| About Total Radiation | | | | | |
| Total DLP | Total DLP | Total DLP | Total DLP | Total DLP | Total DLP |
| Total # of exposures | Total # of Exposures | Total # of Exposures | Total # of Exposures | Total # of Exposures | Total # of Exposures |

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CT Dose Info Not Globally Available

| Model | GE CT780 HD, VCT | GE LB16 Pro | Toshiba A-Prime | Toshiba A-One | Siemens Def AS, Biograph 64 |
|-----------------------------------|----------------------------|----------------------------|----------------------------|----------------------------|-----------------------------|
| Scanner protocol name | (Injection Protocol) | (Injection Protocol) | (Injection Protocol) | (Injection Protocol) | (Injection Protocol) |
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| Body region | Whole Patient | Whole Patient | Whole Patient | Whole Patient | Whole Patient |
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| Dose reduction tech | (Dose Reduction Tech) | (Dose Reduction Tech) | (Dose Reduction Tech) | (Dose Reduction Tech) | (Dose Reduction Tech) |
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| Scan thickness? | (Scan Thickness) | (Scan Thickness) | (Scan Thickness) | (Scan Thickness) | (Scan Thickness) |
| Collimation | Collimation | Collimation | Collimation | Collimation | Collimation |
| Filter | Filter | Filter | Filter | Filter | Filter |
| Single or dual source | Single or Dual Source | Single or Dual Source | Single or Dual Source | Single or Dual Source | Single or Dual Source |
| KVP | KVP | KVP | KVP | KVP | KVP |
| Max mA | Max mA | Max mA | Max mA | Max mA | Max mA |
| Average mA | Average mA | Average mA | Average mA | Average mA | Average mA |
| Rotation time | Rotation Time | Rotation Time | Rotation Time | Rotation Time | Rotation Time |
| Displayed CTDIv | Displayed CTDIv | Displayed CTDIv | Displayed CTDIv | Displayed CTDIv | Displayed CTDIv |
| Phantom type | Phantom Type | Phantom Type | Phantom Type | Phantom Type | Phantom Type |
| DLP | DLP | DLP | DLP | DLP | DLP |
| About Total Radiation | | | | | |
| Total DLP | Total DLP | Total DLP | Total DLP | Total DLP | Total DLP |
| Total # of exposures | Total # of Exposures | Total # of Exposures | Total # of Exposures | Total # of Exposures | Total # of Exposures |

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Steps of Implementation: Data Collection

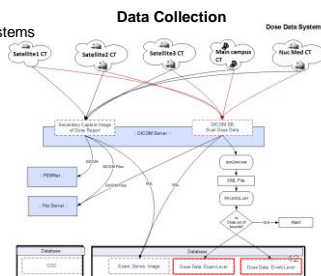
- Planning
- Implementation of major sub-systems

□ Data collection

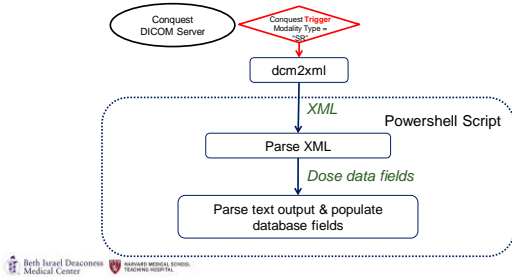
□ Data mining

- Exam level vs. Event level

- Event level: about individual scans
 - E.g., kVp, mAs, per-series CTDIv
- Exam level: about the entire exam
 - E.g., total DLP, total mAs, etc.



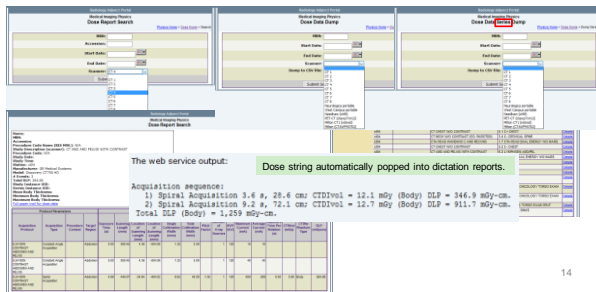
Data Collection: Processing of RDSR



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HTML-Based User Interface of the Data Collection System



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Need for Automated Data Selection

- With the wealth of data (5000+ exams per month at my institute), how to smartly select the right data to answer various questions is the key.



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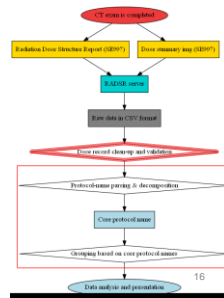
Data Mining: Cleansing, Validation, and Classification

Data cleansing and validation against

- ❑ Non-patients CT scans
- ❑ Duplicated records

Parse and normalize protocol names

- ❑ To solve the "clash of names"
- ❑ To build classifiers for the dose data
- ❑ To group data for presentation



Candidates of Standardized Imaging Procedure Names

Scan protocol names

- ❑ The protocols that techs can choose on scanners
- ❑ The targets for the protocol review
- ❑ E.g., C- Chest, AAA, LYMPH/GEN ABD/PEL

Study description

- ❑ Orderables or billing code names
- ❑ Pulled by CT from RIS/ordering system
- ❑ Available on all scanners
- ❑ E.g. CT CHEST W/CONTRAST, CT 3D RENDERING W/POST PROCESSING
- ACR-DIR allows both as local exam names to be mapped to standardized exam names (RadLex Playbook or ACR Common)

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Data Mining: Protocol Name Normalization

A protocol name usually contains

- ❑ The "core protocol name", i.e., text representing the essential meaning of the protocol
- ❑ Many descriptive phrases
 - Some can be removed without losing essential information
 - ❑ E.g. revision date/time
 - You can decide what other parts to be included in the normalized names



Key Points of Implementing the Data Mining Framework

- Modular design (OOP) of data selection and presentation
- Script-driven
 - Explore data interactively
 - Prepare for data presentation in batch-processing
- Build flexible data selection criteria using regular expressions for including and excluding desired patterns
 - (inclusion_regex, exclusion_regex), (INC, EXC), (INC, EXC), ...

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Some Results: Interactive Exploration of Dose Data

- Example: tentative search for "Chest Pain"
 - ▢ Results include protocols covering diff body parts
 - ▢ I want to exclude the ABP exams in this search

```
0015 dcr = DoseCrossCompare(target_pain_name,
0016                          naming_scheme="scan_protocol_name",
0017                          prev_dose_name="napap_pain_list[('chest:pain', '1')]",
0018                          CT_list=['CT-1',
0019                                  'CT-2',
0020                                  'CT-3',
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0022                                  'CT-5',
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```

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Some Results: Interactive Exploration of Dose Data

- A refined search of "chest pain"
 - Excluded all "ABP" exam types
- Note the script driven query and processing
 - Easy to run in batch mode

```
0016 ddc = DoseCrossCompare(target_path, genome,
0017                          naming_scheme='scan_protocol_name',
0018                          prot_in_dir=os.path.join('CT-lists',
0019                                                    'CT-1'),
0020                          CT='CT-1',
0021                          CT-2='CT-2',
0022                          CT-3='CT-3',
0023                          CT-4='CT-4',
0024                          CT-5='CT-5',
0025                          CT-6='CT-6',
0026                          CT-7='CT-7',
0027                          NewScan='CT-1',
0028                          study_date_from=str('2016-01-01'),
0029                          study_date_to=str('2016-06-30'),
0030                          bool_verbose=False)
0031 ddc.display_dose_summary('all')
```

```

17:8
Use protocol name: 'NON GATED CHEST PAI'
Number of exams: 29
CTDIvol: 18.0 mGy
CTDIw: 4.3 mGy
DAP: 324.3 mGy*cm
Rt DAP: 164.1 mGy

NonHodgCt:
Use protocol name: 'NON GATED CHEST PAI (PL)', 'NON
Number of exams: 229
CTDIvol: 5.7 mGy
CTDIw: 1.4 mGy
DAP: 418.0 mGy*cm
Rt DAP: 281.8 mGy

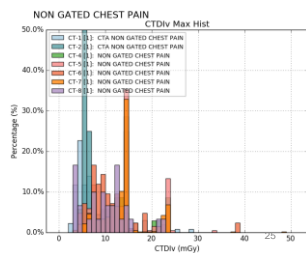
-----
Rose info for the all CIs together
-----
Generate name from all scanners:
CTA NON GATED CHEST PAI
NON GATED CHEST PAI
NON GATED CHEST PAI (PL)
NON GATED CHEST PAI (DUAL/CI/STIC/CI)
DUAL/CI/STIC/CI (NON GATED CHEST PAI)

Number of exams: 1371
CTDIvol: 12.2 mGy
CTDIw: 3.1 mGy
DAP: 484.5 mGy*cm
Rt DAP: 242.1 mGy

```

Graphical Exploration of Dose Data: Histogram

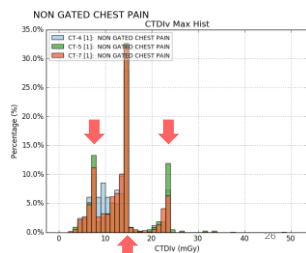
- Histogram: checking consistency of dose behavior across multiple CTs
 - Messy with too many scanners' data
 - Hint of protocol differences



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Graphical Exploration of Dose Data: Histogram

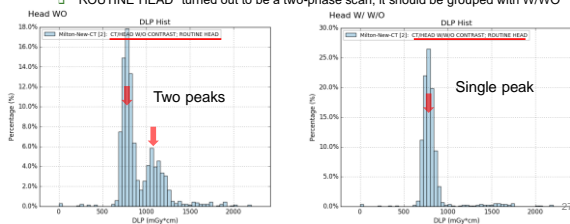
- Similar distribution observed from 3 GE 750 scanners
- Size-specific protocols: 3 BMI groups, 3 peaks



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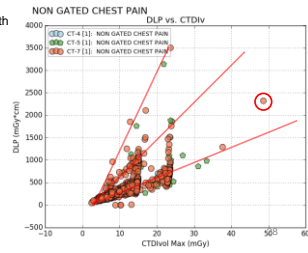
Graphical Exploration of Dose Data: Histogram

- Histogram also helps avoid errors in protocol classification
 - Left figure: "CT/Head W/O CONTRAST" and "ROUTINE HEAD" were grouped together
 - "ROUTINE HEAD" turned out to be a two-phase scan; it should be grouped with W/O



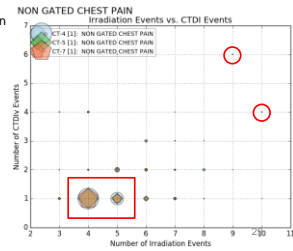
Graphical Exploration of Dose Data: Scatter Plot

- Scatter plot of DLP vs. CTDiv gives sense of total scanned length (and repeated scans)
- Approximately, $DLP/CTDiv \sim \text{scan length}$



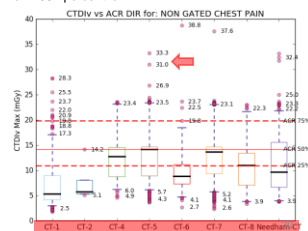
Graphical Exploration of Dose Data: Scatter Plot

- Scatter plot of scan events and "irradiation" events gives sense of how many irradiation events are made
 - E.g., most exams of Non-Gated Chest Pain
 - 1 true CT scan
 - 4-5 total irradiation events
 - CT scan
 - Scout views
 - Monitoring phases
 - Note: marker size \propto # of occurrence



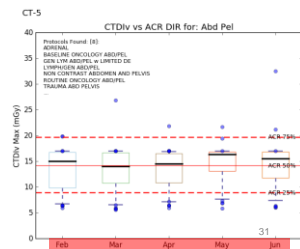
Graphical Exploration of Dose Data: Box Plot

- Boxplots is very useful for comparison across CT scanners
 - Outliers marked when then falling < 5th or > 95th percentile
 - Compare against ACR DIR



Graphical Exploration of Dose Data: Box Plot

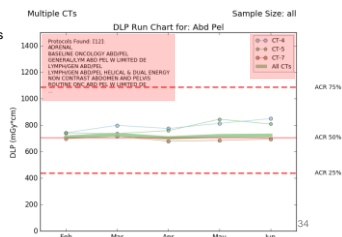
- Boxplots can also be used to show the changes over time
 - ABD/PEL exam from one scanner
 - Combined result from 8 protocols



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Graphical Exploration of Dose Data: Run Chart

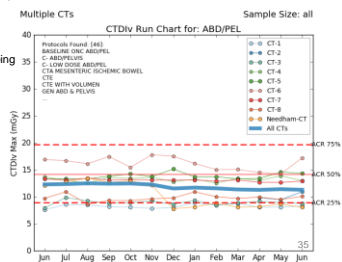
- Run-charts can also be used to show the changes over time, across scanners
 - ABD/PEL exam from 3 scanner
 - Combined result from 12 protocols



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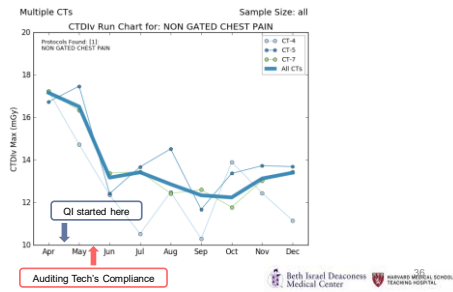
Graphical Exploration of Dose Data: Run Chart

- When combining data from many scanners
 - High level summary
 - 9 scanners, 46 ABP protocols
 - Work with lead tech to verify grouping
 - Very busy figure



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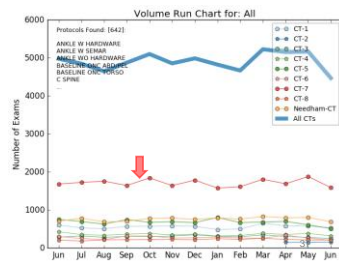
Use Run Chart to Show the Effect of a CT QA Project



Graphical Exploration of Dose Data: Run Chart of Volume

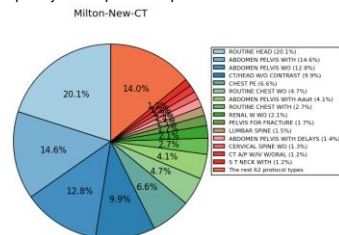
- When combining all protocols from many scanners together

- Trending of volume over time
- 9 scanners, 642 protocols



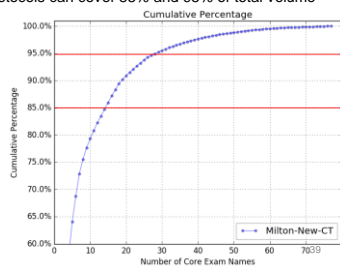
Graphical Exploration of Dose Data: Pie Chart

- Pie charts for evaluating the complexity of the protocol space



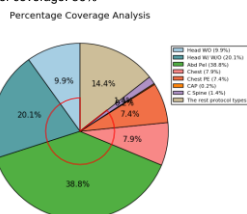
From Pie Chart to Cumulative Percentage

- Examine how many major protocols can cover 85% and 95% of total volume



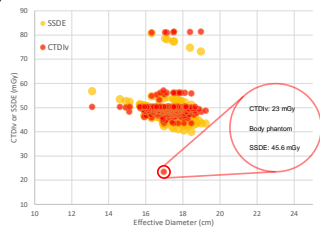
Graphical Exploration of Dose Data: Pie Chart

- Pie charts also useful to show the coverage of a protocol review session
 - CTQA review for a satellite facility, percentage of coverage: 86%



Caveats: SSDE Can Automatically Rule Out Some Outliers

- Head CT with extremely low CTDIv (body-phantom CTDIv value reported in head exam)



Conclusions/Comments

- With freely available software and some local expertise, a highly flexible and usable dose management system can be configured.
- There are non-trivial challenges in terms of data fragmentation, non-standard lexicon, and inconsistencies in the adoption of RDSR capabilities across vendors and platforms.
- The data-rich review process can be very helpful for CT dose and protocol optimization.

Thank you for your attention!