Monitoring Radiation Exposure With DICOM and Splunk

Derek Merck | Director of the Rhode Island Hospital 3D Lab

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Acknowledgements

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Support:
- Splunk4Good (Corey Marshall)
The RIH 3D Lab

- Medical imaging and informatics research
- Post-graduate academic training
- Unique clinical work-ups and procedure planning
Overview

Radiation-based medical imaging
- X-rays and computed tomography
- Responsible radiation use

Dose monitoring with open source tools and Splunk
- DICOM
- Bridging DICOM to JSON
- Network organization
- Effective queries for DICOM tags

Improved Quality Assurance
- Dose dashboards
- Outlier alerts
- Creating an audit trail
- Scaling out to additional devices

Radiology workflow analysis with Splunk
- Device utilization
- Workload prediction using HL7
Radiation-Based Medical Imaging
X-Rays and Computed Tomography

▶ Film x-ray has been around since the late 19th century

▶ Computed tomography was developed in the 1970s
  • Uses x-ray images from multiple angles to estimate x-ray attenuation inside a volume
  • Since different tissue types attenuate x-rays differently, this effectively shows anatomy

Rontgen’s wife’s hand (1896) and a modern 64-slice CT scanner at RIH.
X-Rays and Computed Tomography

70mGy vs. 23mGy exposure for similar studies
ALARA Principle: “As Low As Reasonably Achievable”
Noise and low anatomic differentiation is ok sometimes
More radiation = more precise reconstruction and more useful data for patient care

More radiation = more chance of injuring the patient
- Directly, by burning them
- Indirectly, by raising their risk for cancer

Incident at Cedar-Sinai in 2009 \(^{(3)}\) resulted in new rules

Improperly performed perfusion studies at Huntington, WV, in 2011 \(^{(11)}\) caused focal hair loss.
Hospitals must routinely prove that we are using radiation responsibly.

Otherwise the Joint Commission could reduce how much we are reimbursed for imaging studies. (2)

Currently done by sending “radiation dose reports” for all studies to a third party system:

- American College of Radiologists (ACR) registry provides quarterly summaries, but it's difficult to actually identify outliers.
- Commercial systems provide on-demand analysis, but they cost $100k/year.

A sample ACR report: great if everything is ok, but not very helpful in mitigating problems.
Challenge: Create an inexpensive, effective dose monitoring system that can be managed in-house without a dedicated IT person
Dose Monitoring with Open Source Tools and Splunk
CT scanners generate images and metadata using the woefully archaic DICOM format.

Detailed technology and patient metadata embedded directly in the image header as numeric “tags.”

Also a set of network protocols that allow machines to interoperate.

DICOM-friendly systems are all meant for patient care, not for data analysis.

Need to transform DICOM headers into data.

DICOM format is key/value driven by cryptic numeric tags, only accessible through DICOM viewers.
Orthanc, an open source DICOM server and image database

Accepts data in DICOM

Can be controlled via a REST interface

Still no capability for complex data analytics

But, effectively translates most DICOM tags into JSON (but not dose)

And can be modified to translate dose tags into JSON as well

Same data liberated by replacing numeric tags with intuitive identifiers and transforming format to a generic dictionary structure.
Scanners talk to an Orthanc node

Python script acts as a bridge
  • Requests DICOM dose information from Orthanc in JSON format
  • Pushes JSON to Splunk index

Once data are in Splunk, they can be used for analysis

Network Organization

We index 250 dose reports/day from 12 scanners at 6 sites.
Effective Queries for DICOM Tags

- Need to address the limitations of the data format
  - Normalizing DICOM tags that are used by different vendors in different ways
  - Splitting up multiple radiation events within each dose report
  - Lookup maps between unintuitive data and simple names
    - scanner s/n → location
    - procedure code → body part
Effective Queries for DICOM Tags

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    - procedure code → body part

```ruby
eval RPD=if(RPDField=="Description",
  "\n  StudyDescription,",
  coalesce(RequestedProcedureDescription, "ProcedureCodeSequence\{\}.CodeMeaning; RequestAttributesSequence\{\}.RelatedProcedureDescription\")) |
lookup rpd_map.csv RPD OUTPUT BodyPart Impact |
eval age="adult" |
eval bodypart="head" |
```

Effective Queries for DICOM Tags

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Traditional radiation QA has very high latency (monthly or quarterly)

ACR reports only show that outliers exist
  • Do not identify where/why/how to fix

Now service managers print Splunk dashboards
  • Do identify where/why/how to fix

Even better, they want to use the dashboards interactively for QA
Dashboards
Radiation Exposure Summary

All Adult Head CT by CTDI

All ct scans in ctdi ascending order to view ranking of dose per slice by protocol

<table>
<thead>
<tr>
<th>RPD</th>
<th>count</th>
<th>min CTD</th>
<th>max CTD</th>
<th>avg CTD</th>
<th>avg D LP</th>
</tr>
</thead>
<tbody>
<tr>
<td>CT FACE W IV CONTRAST</td>
<td>4</td>
<td>4.38</td>
<td>12.47</td>
<td>6.79</td>
<td>135.3</td>
</tr>
<tr>
<td>CT FACE WO IV CONTRAST</td>
<td>13</td>
<td>4.02</td>
<td>38.67</td>
<td>13.27</td>
<td>944.5</td>
</tr>
<tr>
<td>CT SINUS WO IV CONTRAST</td>
<td>3</td>
<td>8.28</td>
<td>22.15</td>
<td>16.98</td>
<td>184.7</td>
</tr>
<tr>
<td>CTA ELVO HEAD AND NEC K</td>
<td>205</td>
<td>5.57</td>
<td>69.56</td>
<td>19.84</td>
<td>1,734.3</td>
</tr>
</tbody>
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<td>69.56</td>
<td>9.84</td>
<td>1,743.6</td>
</tr>
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</table>
## Dashboards
### Radiation Exposure Drilldown

<table>
<thead>
<tr>
<th>Count</th>
<th>min CTD Lvol</th>
<th>max CTD Lvol</th>
<th>avg CTD Lvol</th>
<th>avg D LP</th>
</tr>
</thead>
<tbody>
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<td>6.79</td>
<td>135.3</td>
</tr>
<tr>
<td></td>
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<td>13</td>
<td>4.02</td>
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<td>944.5</td>
</tr>
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<td></td>
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<td></td>
<td>1</td>
</tr>
<tr>
<td>3</td>
<td>8.28</td>
<td>22.15</td>
<td>16.98</td>
<td>184.7</td>
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<tr>
<td></td>
<td></td>
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<td></td>
<td>9</td>
</tr>
<tr>
<td>205</td>
<td>5.57</td>
<td>69.56</td>
<td>19.84</td>
<td>1,784.</td>
</tr>
<tr>
<td></td>
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<td></td>
<td></td>
<td>36</td>
</tr>
</tbody>
</table>

- **StudyDateTime**: 2017-08-19T12:10:02
- **StudyDescription**: CTA ELVO HEAD AND NECK
- **StudyID**: 17526
- **StudyInstanceUID**: 1.2.840.113619.2.404.3.2299185167.25.1503118643.704
- **StudyTime**: 121002
- **Unknown Tag & Data**: CT Scanner
- **ValueType**: CONTAINER
- **VerificationFlag**: UNVERIFIED
- **X-Ray Radiation Dose Report**:
  - **CT Accumulated Dose Data**:
    - **CT Acquisition**:
      - **Acquisition Protocol**: 1.8 MULTI-PHASE ELVO CTA Head and Neck
      - **CT Acquisition Parameters**:
        - **CT Acquisition Type**: Spiral Acquisition
        - **CT Dose**:
          - **CTDIfw Phantom Type**: IEC Head Dosimetry Phantom
          - **DLP**: 1472.71
          - **Dose Check Alert Details**:
            - **Dose Check Notification Details**:
              - **Mean CTDivol**: 69.56
          - **Irradiation Event UID**: 1.2.840.113619.2.404.3.2299185167.25.1503118643.717
Data confirms that we *never* go over allowable radiation dose

But there are outliers with higher than expected dose for a given procedure

Now that we can identify outliers, we can automatically generate meaningful reports and alerts

Monthly QA reference reports can go out as PDFs to administration

Real-time alerts can be sent by email, Slack, or Twillio to service managers
Now that we are identifying and responding to outliers, we need an audit trail.

- Created another form dashboard that allows managers to comment on incidents, mark them open or closed, and print incident logs filtered by different categories.

- Simple, but replaces multiple hand-maintained Excel spreadsheets from different services and hospitals with a unified system.

- 1 year ago I asked the chief technology officer, “How many radiation exposure outliers do we have in a year?” and he said, “Never”.
  - Yes, we never have significant incidents (because our staff is awesome).
  - However, we do have a couple of minor outliers each week that are usually justified (i.e., additional imaging required) or are addressed through engineering or staff education.
  - Now these are logged, rather than dealt with informally.
## Dashboards

### Tracking Exposure Outliers

### Dose Outliers

Review of CT studies with relatively high helical CTDI

<table>
<thead>
<tr>
<th>Accession Number</th>
<th>Reason</th>
<th>Comment</th>
<th>Status</th>
</tr>
</thead>
</table>

Pressing "submit" updates an incident and audit trail immediately. You may need to refresh the incident log manually (rollover button at the bottom) to see status updates and new comments. The same rollover provides a manual download link to create a csv file from the listed events.

### Incident Log

<table>
<thead>
<tr>
<th>Time Range</th>
<th>Institution</th>
<th>Reason</th>
<th>Status</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>AccessionNumber</th>
<th>PatientID</th>
<th>RPD</th>
<th>MaxCTDI</th>
<th>DLP</th>
<th>InstitutionName</th>
<th>Device</th>
<th>OperatorsName</th>
<th>users</th>
<th>reason</th>
<th>comments</th>
<th>status</th>
</tr>
</thead>
<tbody>
<tr>
<td>CT BRAIN WO IV CONTRAST</td>
<td>50.11</td>
<td>1164.88</td>
<td>RIH</td>
<td>ED (Siemens)</td>
<td>Imm</td>
<td>rih</td>
<td>body habitus</td>
<td>327 lbs</td>
<td>closed</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CT CHEST ABDOMEN PELVIS W IV CONTRAST</td>
<td>25.36</td>
<td>1766.11</td>
<td>RIH</td>
<td>Main (GE)</td>
<td>rih</td>
<td>body habitus</td>
<td>closed</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CT BRAIN WO IV CONTRAST</td>
<td>54.04</td>
<td>984.67</td>
<td>RIH</td>
<td>MOC (GE)</td>
<td>rih</td>
<td>body habitus</td>
<td>closed</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CT CHEST ABDOMEN PELVIS W IV CONTRAST</td>
<td>24.92</td>
<td>1610.53</td>
<td>TMH</td>
<td>Main (GE)</td>
<td>mh</td>
<td>combo study</td>
<td>body habitus</td>
<td>closed</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CT ABDOMEN PELVIS WO IV CONTRAST</td>
<td>24.01</td>
<td>1348.83</td>
<td>TMH</td>
<td>ED (Siemens)</td>
<td>LP</td>
<td>mh</td>
<td>body habitus</td>
<td>140 kvp</td>
<td>closed</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Medicare/Medicaid Services (CMS) visited TMH and asked to see a summary of radiation exposure in our fluoroscopic x-ray suites

- "Interventional radiology" is a service that uses real-time x-ray imaging to guide device placement or direct catheters for intravascular procedures

Play the same game

- A little bit of network rerouting
- Normalize the DICOM dose reports
- Change the units on the dashboards...

Scaling Out to Additional Devices

Many image-guided procedures are done under constant x-ray exposure, called “fluoroscopy”
# Dashboards

## Radiation Exposure in Fluoroscopy Procedures

### All VIR Procedures with breakdown of dose, fluoro time, and dap

<table>
<thead>
<tr>
<th>RPD</th>
<th>Accession Number</th>
<th>name</th>
<th>vir_dose</th>
<th>vir_fluoro_time</th>
<th>vir_dap</th>
</tr>
</thead>
<tbody>
<tr>
<td>IR TRANS CATH/EMBL ART/VEN HEM SI</td>
<td></td>
<td>RIH VIR Room 1 (Tohiba)</td>
<td>4,201.56</td>
<td>32.250 mi</td>
<td>1,337.899 mgY · cm²</td>
</tr>
<tr>
<td></td>
<td></td>
<td>TMH VIR Room 1 (unk)</td>
<td>3,402.00</td>
<td>36.000 mi</td>
<td>2,605,300 mgY · cm²</td>
</tr>
<tr>
<td></td>
<td></td>
<td>RIH VIR Room 1 (Tohiba)</td>
<td>3,342.13</td>
<td>8 mgY</td>
<td>788,948 mgY · cm²</td>
</tr>
<tr>
<td></td>
<td></td>
<td>RIH VIR Room 2 (Philips Bi-Plane)</td>
<td>3,122.90</td>
<td>9 mgY</td>
<td>285,529 mgY · cm²</td>
</tr>
<tr>
<td></td>
<td></td>
<td>RIH VIR Room 1 (Tohiba)</td>
<td>2,273.80</td>
<td>18.483 mi</td>
<td>96.181 mgY · cm²</td>
</tr>
<tr>
<td></td>
<td></td>
<td>TMH VIR Room 1 (unk)</td>
<td>2,155.00</td>
<td>34.700 mi</td>
<td>1,474,100 mgY · cm²</td>
</tr>
<tr>
<td></td>
<td></td>
<td>RIH VIR Room 2 (Philips Bi-Plane)</td>
<td>2,127.52</td>
<td>8 mgY</td>
<td>256,099 mgY · cm²</td>
</tr>
<tr>
<td></td>
<td></td>
<td>RIH VIR Room 3 (Philips)</td>
<td>2,107.04</td>
<td>3 mgY</td>
<td>517,312 mgY · cm²</td>
</tr>
<tr>
<td></td>
<td></td>
<td>RIH VIR Room 2 (Philips Bi-Plane)</td>
<td>1,854.03</td>
<td>31.750 mi</td>
<td>232,822 mgY · cm²</td>
</tr>
</tbody>
</table>

### All VIR Procedures by RPD with breakdown of room, dose, fluoro time, and dose area product

- **IR TRANS CATH/EMBL ART/VEN HEM SI**
- **BRTO**
- **IR ANGIOMGRAM VISCERAL SELECTIVE**
- **IR VERTEBROPLASTY L-SPIKE PERC W/O IV BX SI**
- **Bilateral Biliary Tubes**
- **IR TRANS CATH/EMBL FOR TMRS/URE SI**
Radiology Workflow Analysis with Splunk
An unforeseen side-effect of the system is the ability to do deep utilization analysis.

1 year ago I asked the chief tech officer, “How many CT scans do we shoot in a year?” and we could only ballpark answers.

- Now we know about every scan and which machine each was done on (all 60k/year across 10 scanners at 3 hospitals).
- We can even estimate which machines may need x-ray source replacements next.

The CT manager wants to know why the ED was complaining about long wait times for imaging on a particular day.

- We plot number of studies per hour on that day on the ED scanners vs. average number of studies they handle and show that utilization vastly exceeded capacity.
- Now we have evidence that only way to fix those wait times is to order another scanner or to divert…
Dashboards

Device Utilization

Count by procedure over time
Next, the CT manager wants to predict what those wait times are going to be, so that we can mitigate problems before they occur.

Dose reports only tells us what was done, not what is ordered.

Then, we need to integrate another data feed from the hospital order system.

- The ordering system uses another archaic format: HL7.

Once the parser and logic is in place, we can predict utilization patterns based on ordering patterns with an hour of lead time.
1. Domain data is amenable to Splunk workflows

2. Splunk is a great replacement for under-performing, over-engineered solutions

3. Linking heterogeneous data sources = unforeseen possibilities for systemic optimization

Key Takeaways
App is on GitHub
http://www.github.com/derekmerck/DIANA
References


8. Rees v Cedar-Sinai Medical Center. 2014.


Thank You

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