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## Fluoroscopic Dose Monitoring and Patient Follow-up Program at MGH

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 MASSACHUSETTS  
GENERAL HOSPITAL

Substantial radiation dose can be delivered to patient skin in fluoroscopic procedures, especially in fluoroscopy guided interventional imaging procedures. Multiple incidents of radiation injury from such procedures have been reported. In Massachusetts, Hospitals are required to have a fluoroscopic dose monitoring program in place. If the skin dose is more than 2 Gy, the case must be reviewed by hospital RSC. Also, hospital must take action for patients whose skin dose is high enough to warrant follow-up.

Although professional organizations such as Society of Interventional Radiology, American College of Radiology, and NCRP have developed guidelines for patient dose monitoring, implementing a working and effective program for a large medical institution is quite challenging.

**The Objectives**

- ✓ *To comply with regulations*
- ✓ *To care patients with potential radiation injury in a timely manner*
- ✓ *To raise the risk awareness by providing feed back to MD*
- ✓ *To provide cumulative dose data for procedure planning*


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There are several objectives we wanted to accomplish with the dose monitoring program. First , we want to make sure that the hospital complies with all regulations. Second , we want to identify and take care of patients with potential radiation injury in a timely manner. Third, we would like to provide the feed back to MDs so that their performance in dose management can be improved , finally, we would like to use the recorded dose data for procedure planning in the future.


### Basic Requirements


- a. *Be able to capture available dose information from **ALL** fluoroscopy exams **regardless of equipment vendor and model**.*
- b. *Be able to identify the cases with **SRDL** (substantial radiation dose level) quickly and reliably.*
- c. *Be automated as much as possible to keep human error to the minimum.*
- d. *Be practical and easy to use.*

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To accomplish above objectives, the program must meet some basic requirements. First, it must be able to capture all available dose information from all fluoroscopy procedures regardless the equipment vendor and the model. This may not be an easy task. Second, the program must be able to identify all cases with SRDL quickly and reliably so that the patient with potential radiation injury can be cared for timely. Third, the program should be automated as much as possible to minimize human errors. And finally, the program must be practical and the dose recording tools should be easy to use such that everyone user is willing to use.

### Major Challenges

<ol style="list-style-type: none"> <li>1. <i>Equipment fleet from multiple vendors. Doses are reported in different ways</i></li> <li>2. <i>Dose formats are not standardized, data analysis difficult</i></li> <li>3. <i>Most dose data are not in DICOM, 100% automation not possible</i></li> </ol>	 <p style="margin-top: 10px;"><math>K_{a,r}</math>: mGy, Gy, R</p> <p style="margin-top: 10px;"><math>KAP</math>: Gy.cm<sup>2</sup>, μGy.m<sup>2</sup>, R.cm<sup>2</sup>, dGy.m<sup>2</sup></p> <p style="margin-top: 10px;"><b>Time:</b> Sec, Min</p>
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There are many challenges with the implementation. For example, our equipment inventory includes 14 interventional systems from Siemens and GE, 8 R/F rooms and 32 mobile c-arms from GE, Siemens, Philips, and many other vendors. Each vendor or each model from the same vendor reports the dose in a different way. The newest interventional systems have Radiation Dose Structured Dose report in DICOM header. The dose information produced by many old systems can only be retrieved from the acquisition station. Once the case is deleted from the acquisition station, all dose data are lost. The first challenge is how to collect the dose data from any fluoro system regardless of equipment vendor and model and put all data in a centralized database and in patient medical record. A second, doses report are in many different formats and units, the challenge is how to process, sort and monitor such incompatible data. Third, since most dose data are not in DICOM header, a 100% automation is not possible. Human error is unavoidable. The challenge is how to detect and correct such error.

## Dose Metrics

**Dose metrics**

- $K_{a,r}$  - **Air Kerma at ref. point**
- $P_{KA}$  - **Air kerma area product**
- $T$  - **Fluoroscopy time**
- # - **Recorded Images**

For isocentric fluoroscopes, the reference point lies on the central axis of the x-ray beam, 15 cm from the isocenter on the x-ray tube side.

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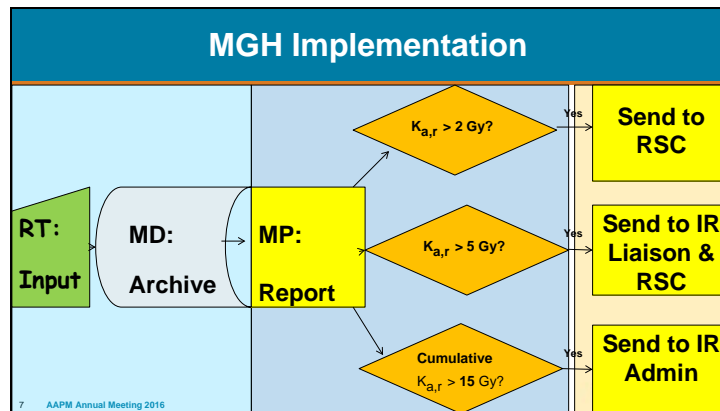
One of the objectives is to identify the cases with SRDL to skin, a dose metric which is a good indicator of the skin dose should be used for monitoring. Modern fluoroscopy system typically reports 4 dose related metrics: Air kerma at the reference point, air kerma area product, fluoroscopy time in minutes and the number of record images. Some old systems may just report the fluoroscopy time. Which metric should be used to detect SRDL cases? The fluoroscopy time and the number of images have been indentified as poor indicators of the skin dose. Air kerma product is considered a good metric for stochastic effect evaluation, but a poor indicator of the deterministic effect because the same air kerma a rea product may be produced by a high skin dose and a small field or a low skin dose and a large field. Air kerma at the reference point is considered a reasonable indicator of the patient skin dose . This is the dose metric we used to identify SRDL cases. For iso centric systems , such as C-arms in most interventional radiology suites, the reference point is located on the central axis of the x-ray beam, and 15 cm from the iso center on the x-ray tube site.

Thresholds for Patient Follow-up	
Parameter	Threshold
Peak skin dose (PSD)	3,000 mGy
Reference point air kerma ( $K_{a,r}$ )	5,000 mGy
Kerma-area-product ( $P_{KA}$ )	500 Gy · cm <sup>2</sup>
Fluoroscopy time (FT)	60 min

**Recommended by SIR and NCRP**

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To trigger the patient follow-up process, a threshold of the dose metric must be established. If  $K_{a,r}$  is selected for dose monitoring, SIR and NCRP have recommended 5 Gy as the threshold for patient follow-up.



In collaboration with our IS team and IR team, we developed an semi-automatic fluoroscopic dose monitoring and patient follow-up program. The program has 3 major components: The first component is the data collection and archiving. These tasks are performed by RTs and MDs. The second component is the data processing, analysis and reporting which is conducted by the physicists, and the third component are actions based on the findings from the reports. Radiologists, physicists and IR management may be involved.

Let's describe each component in more detail

### Data Collection & Archiving

1. ***RT enters dose in custom fields in dictation software through web form***
2. ***MD dictates the case, by clicking a Macro button, dose info populated in patient medical record and sent to SQL server***

```
graph TD
    subgraph "Physician dictation system"
        P[Procedural information and findings] --> R[Radiology report]
        T[CD, DAP, no. of images, fluoroscopy time] --> C[Custom fields]
    end
    R --> RIS[RIS]
    R --> PACS[PACS]
    C --> MS[MS SSAS OLAP Cube]
    MS --> MAP[MAP]
    MAP --> PIVOT[Pivot table report and export into XML]
    subgraph "MS SQL database server"
        MS
    end
```

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We use a web form to collect dose data from any fluoro system and store the data in text format temporarily in the custom fields of the dictation software. When a physician dictates the case and clicks a button, a macro will populate the dose information to the medical report and also send the dose data along with other patient demographic and examination related information to a SQL database.

By this mechanism, we are able to collect the dose information from any fluoroscopy systems and store dose information in patient medical record regardless of equipment vendor and model. The disadvantage of this method is possible human error when the dose information is entered by hand.



### Dose Data Processing & Analysis

1. *MP processes and analyzes doses weekly*
2. *Data are standardized*
3. *Data are checked for consistency*
4. *Data are sorted and classified*

*Raw Data*

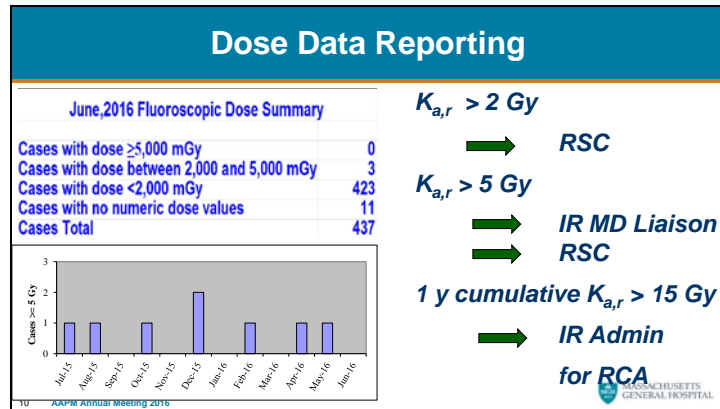
Exam	Rm	Ka,r (mGy)	P <sub>KA</sub>	Unit	Min	Img
FLAB	RF3E2	183.76	20.98	Gy.cm <sup>2</sup>	2.5	7
FLP.MJT	RF1Y6	1	14	μGy.m <sup>2</sup>	0.1	5
FL.XS	RFOR14	0.52 R	98.05	R.cm <sup>2</sup>	2.21 S	4

*Processed Data*

Exam	Rm	Ka,r (mGy)	P <sub>KA</sub>	Unit	Min	Img
ARTDIA	RF1L4	4846	1369	Gy.cm <sup>2</sup>	80	485
EMBINT	RF1L4	4619	262	Gy.cm <sup>2</sup>	112	121
ARTINT	RF6G2	4526	703	Gy.cm <sup>2</sup>	50	234

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The physics team extracts the dose data from SQL server on a weekly basis. The raw data need to be processed because they are in text format and many math operation cannot be performed. Here is an example of the raw data. The air kerma at the reference point and KAP may be reported in different units by different system. A program was written to convert Kerma, KAP, time and # of images to numerical value. The data format and units are also standardized. Here is an example of the processed data. Then, the data consistency is checked to detect any possible error from the manual inputting process. Although we do not KAP, fluoroscopy time and number of images directly to identify SRDL cases, we do use all available information to check the reliability of Kerma at the reference point. For example. The x-ray field size at the reference point has a limited range, dividing KAP by the lower and the upper limits can produce the range of Kerma at the reference point. These values are used to check the data consistency. After data processing and consistency checking, data are sorted and classified.




Here is an example of MP’s dose report to RSC and to IR liaison who is coordinating all activities related to patient follow-up. The report lists the number of case with Kerma above 5 Gy, number of cases with Kerma between 2 Gy and 5 Gy, the number of cases with Kerma under 2 Gy. It also has a graph showing the number of the cases with Kerma above 5 Gy each month over the last 12 months.

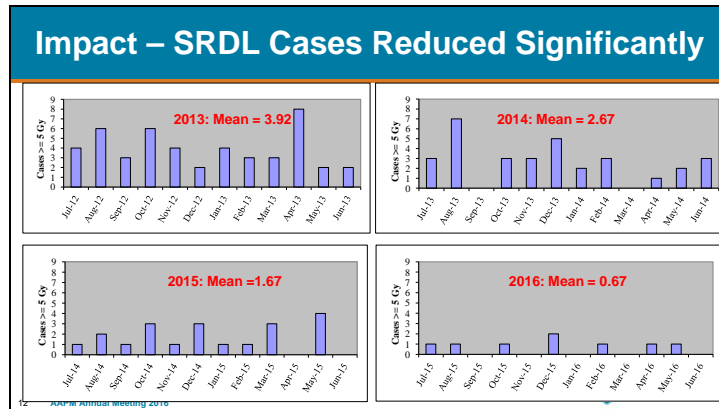
All cases with Kerma above 2 Gy are reported RSC to review per MA regulation.  
 All cases with Kerma above 5 Gy are reported IR liaison for patient follow-up and are also reported to RSC to verify the follow-up  
 All cases with cumulative Kerma above 15 Gy within one year are reported to IR management and patient safety office for root course analysis.

### Follow-Up for Patients with $K_{a,r} > 5$ Gy

1. *IR liaison MD contacts the performing MD*
2. *Performing MD reviews the case and signs follow-up letter to **referral MD** and **RSC***
3. *Referral MD or IR MD or dermatologist sees patient*
4. *# of SRDL cases in MP report and the follow-up letters from MD at RSC must **match***

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Once a SRDL case is identified and reported, the IR liaison MD will notify the performing MD to conduct patient follow-up. The performing MD reviews the case and sends a letter to notify the referral MD and RSC that the follow-up will be performed. The referral MD or IR MD or dermatologist will see the patient. The # of SRDL cases in MP reports and # of the signed letters from IR MDs are reviewed at monthly RSC meeting. Two numbers must match. This follow-up process has provided useful feed back to all performing MDs and has encouraged them to improve their dose performance.



Our dose monitoring program not only makes our hospital in full compliance with the state regulations, but also has a major impact on our patient dose management. This impact is reflected in the number of SRDL cases per month. Here are the numbers of cases with Ka,r more than 5 Gy per month for the last 4 years. In 2013, the mean is 3.92 cases per month. In 2014, the mean is 2.67 per month. For 2015, the mean is 1.67 per month and in 2016, the mean is 0.67 cases per month. The mean number per month has been reduced by a factor of nearly 6 over the last 4 years.

### Summary

- ❑ *The program is integrated in the clinical workflow seamlessly. RT, MD and MP collaborate well.*
- ❑ *The program is able to capture dose from any fluoroscopy system and save data in patient medical record*
- ❑ *The program is able to identify SRDL cases promptly & has played an important role in reducing # of SRDL cases.*

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In summary, we have developed a comprehensive dose monitoring and patient follow-up program for fluoroscopy procedures. The program was integrated into the clinical workflow seamlessly. It has been used by technologists, radiologists and physicists on a daily basis. The program is able to capture dose information from all fluoroscopy systems regardless of equipment vendor and model. The program is able to identify the patient with SRDL quickly and reliably so that such patients are treated in a timely manner. Our patient follow-up procedure has provided useful feedback to MDs. This mechanism has played an important role in reducing # of SRDL in our hospital. Thanks for your attention.