Final report on

"Analysis of the occupational exposure to radiation among health care professionals involved in cardiac and vascular interventional procedures"

An investigative agreement between

Workplace Health, Safety and Compensation Commission and

Memorial University of Newfoundland

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Summary

Motivation.

Existing personal dosimetry methods do not permit pro-active staff management to minimize radiation exposure through staff rotation and procedure optimization. This project was undertaken to determine if a machine-based metric of radiation usage, Reference Point Dose (RPD), could be used to estimate the whole body dose of angiography/ fluoroscopy staff. This sub-set of radiology was chosen because a) exposure times are longer than in conventional x-ray and b) staff, although shielded, are in the room.

Results.

Individual staff doses for the study period were provided as quarterly reports, work roles were indicated as radiologist, nurse, and technologist. The retrospective study was designed to span four years, but Eastern Health was able to provide Reference Point Data for just one year. In addition, they were not able to determine the completeness of the data. As an alternative a patient based metric, Dose Area Product (DAP), data was provided for the period 4th quarter 2016 to second quarter 2021.

Finding 1. RPD data: For the single year RPD data an apparent correlation was noted between average radiologist quarterly dose and total RPD. No correlation was observed with the other staff groups.

Finding 2. A linear regression fit was obtained between the natural log transform of RPD and the natural log transform of DAP. This suggests that a higher order relation exists between the non-transformed variables. The slope was near unity suggesting that the original power series data may have similar exponents. Based on this finding DAP was used as a proxy for radiation usage.

Finding 3. DAP data: No direct correlation was obtained between DAP and staff dose. An observational correlation between episodic DAP peaks and radiologist whole body dose metrics was noted. No correspondence with nurse or technologist dose was noted.

Finding 4. Active room dose measurement during angiography procedures provided a method to translate DAP values to staff exposure estimate on a procedure basis.

Conclusion.

Due to data limitations, this study cannot confirm that RPD, and possibly DAP, can provide a useful estimate of staff dose.

Introduction

Occupational exposure to ionizing radiation is an ongoing concern for public health agencies. Provincial and Federal guidelines limit whole body exposure for nuclear energy workers to 50 mSv per year (estimated dose) above the amount received from natural sources. Other radiation workers, such as those in health care, follow local or regional regulations where the annual permissible dose may be 30 mSv.

Whole body dose is the value that best relates to the incidence of cancer. Numerous studies have established that a 50 mSv annual exposure level carries no significant risk of morbidity or mortality. Nevertheless, provincial and federal agencies have adopted an ALARA (as low as is reasonably achievable) principle for occupational exposure. This means that all reasonable efforts must be made to limit a workers exposure to radiation. Measures taken include wearing protective clothing where appropriate and monitoring whole body and extremity dose using summative personal dosimeters. Radiation workers normally receive quarterly dose reports, although greater and lesser frequencies may also be called for. These dose reports represent the accrued radiation dose for the period.

By its very nature a *post hoc* dose report is not useful for maintaining overall low exposure in the worker cohort, since this would require predictive information. It does not distinguish individual "events" so it isn't useful for identifying and correcting sub-optimal interventional suite procedures. Finally, the summative dosimeter cannot distinguish numerous small doses from an equivalent large dose. **This study was undertaken to determine if the machine variable Reference Point Dose (RPD) available on fluoroscopic and angiographic instruments was a useful addition to and/or proxy for the personal dosimeter.** RPD (mGy) is calculated for each exposure and is summed for all exposures in a view or a study. It is independent of angle or aperture size. It is an estimated air dose determined at a point that often corresponds to the surface of the patient. The literature has previously reported that it is this instrument metric that most closely corresponds to patient Peak Skin Dose (https://www.iaea.org/resources/rpop/health-professionals/interventional-procedures/radiation-doses-in-interventional-fluoroscopy). A second measure provided by the instrument is Dose Area Product (DAP). This value most closely parallels patient whole body estimated dose and as mentioned above this value correlates best with risk of stochastic disease incidence. However, similar DAP values are obtained with high dose and small area or small dose and large area. These conditions alter the scattered radiation and so will result in different staff dose. It is worth noting that patient dose is not directly measured and that there are no regulations requiring measurement of patient dose during fluoroscopic/ angiographic procedures.

Patient dose is the most important input variable in determining occupational dose for workers in interventional/ fluoroscopic suites. The dose to workers in the room arises from radiation scattered by the patient… "second-hand radiation". Relatively more radiation is scattered from the surface than from the interior of the patient. The instrument itself leaks very little radiation and, while some extremity dose (hands) might arise from direct exposure to the x-ray beam, it is very unusual that whole body dose would accrue from direct exposure. Therefore, it is a reasonable thesis that as patient dose increases so too will occupational dose (*ceteris paribus*).

Instrument based measurements are episodic and so provide a great deal of granularity in estimating occupational dose. This is an advantage for two reasons: 1. A dose-contributing event is easily identified and 2. The procedures around such an event can be reviewed and corrected if necessary.

In this study we aimed to establish that RPD correlated with occupational dose and so could preemptively contribute to understanding occupational dose. That is, a certain RPD value would deliver a presumed dose to staff contingent on their role in the interventional suite. This means that staff could be rotated as necessary in a given quarter to maintain overall low exposure in the cohort.

Methods

NL Health Services supported this investigation by providing the primary information. Two types of data were provided:

1. Reference Point Dose values for those instruments reporting to the dose-monitoring software suite Radimetrics. These data were grouped by procedure. NL Health Services determined that they were unable to provide RPD values for most instruments and instead provided DAP values. Consequently, some 2020 data for which there was both RPD and DAP information was used to determine the relationship between RPD and DAP. A linear relationship was found after log transformation.
   A. The relationship between RPD and quarterly staff dose was investigated for 2020.
   B. The relationship between DAP and quarterly staff dose was investigated for 2016 - 2020.
2. Anonymized quarterly dosimeter readings for interventional staff. These readings were grouped by role (physician, technologist, nurse). The study spanned 2016 to 2021, 443 quarterly readings were provided from a theoretical total of 516. These consisted of 133 quarterly readings (22 missing values, 14.2%) from 9 radiologists, 83 quarterly readings (21 missing values 20.2%) from 10 nurses and 227 quarterly readings (30 missing values, 11.7%) from 18 technologists.

Given the overall sparsity of data statistical inference was limited to simple means and variance. Relationship curves are provided with standard error lines.

Results and Discussion

Appendix Table 1 provides the quarterly dose measurements of the radiologists engaged in fluoroscopy procedures. It is note worthy that none of these staff approached the allowable maximum annual dose (30 mSv). However, there are problems with the data. First, is the large number of missing values (14%) and second is the large number of values reported as “M” that were re-coded as 0 for statistical purposes. It may be noted that significant doses occasionally accrue. Radiologist 8 and radiologist 4 routinely had higher doses than their colleagues. We do not know if this was due to their assignments or their technique.

Appendix Table 2 provides the quarterly dose measurements for nurses. The vast majority of the values are barely above the detection limit. Again, the number of missing values and below minimum values makes statistical comparison difficult. It is worth noting that routine monitoring using whole body dosimeters is only recommended for workers who are likely to achieve an annual dose of 1 mSv. None of the nurses in this study experienced a tenth of this value.

Appendix Table 3 provides the quarterly dose measurements for technologists. The vast majority of the values are barely above the detection limit. Again, the number of missing values and below minimum values makes statistical comparison difficult. As is the case for nurses, most values are zero and these technologists did not experience an annual dose of 1 mSv.

Appendix Tables 1-3 highlight one of the challenges in monitoring occupational exposure to radiation, missing data. Overall, fifteen percent of the data is missing; this may mean that an anomalously high reading is obtained in the following quarter. (Integration over six months instead of three). The second issue is whether the workers need to be monitored. National and local guidelines recommend that workers likely to receive exposures above the publicly allowable level of 1 mSv per year should monitor their exposure using the integrating dosimeters. Angiographic and certain fluoroscopic type examinations are most likely to result in that exposure because staff must be in the room with the patient while the x-ray beam is on. Where practical, all staff step back three paces when the beam is on. This greatly reduces exposures as intensity falls off with the square of the distance. However, during insertion procedures some staff may not be at liberty to step back. The data in this report, although there are gaps, indicate that technologists and nurses on these services do not receive significant whole-body doses. In fact, the data indicates that the most frequent dose report is zero or very close to it. The radiologist group is most likely to be close to the patient during beam on. This is reflected in their generally higher values and fewer incidences of zero readings. Of course, this must be interpreted with caution as again there are many missing values.

From Appendix Table 4 the following values were determined:

Average annual dose:		
	radiologist	1.27±3.63 mSv,
	nurse	0.05± 0.10 mSv
	technologist	0.04± 0.18 mSv
Number of annual doses exceeding 1 mSv over four years:		
	radiologist	7
	nurse	0
	technologist	1
Number of annual doses exceeding 3 mSv over four years:		
	radiologist	5
	nurse	0
	technologist	0

These values indicate that nurses and technologists normally fall below the guidelines for the general public whereas radiologists may not. In the radiologist group, two staff members accounted for all the annual doses above 1 mSv. Further investigation will be required to determine why two members accrue dose while others apparently do not. The possibilities include unequal procedure selection, protocol expertise/ methodology and compliance with badging.

Badges are issued when there is an expectation of regular occupational exposure above the level permitted for the general public. If a decision was made to withdraw badging for nurses and technologists not meeting this criterion, would there be an alternative available to ensure continued low radiation exposure? As stated, this study was undertaken to determine if RPD could act as a proxy for whole body dosimetry. The advantage of using this value is a) it is a direct measure of the radiation used; b) it is independent of the badge use and collection system; 3. It can allow immediate feedback should that prove necessary in those rare instances when the guidance dose (5 mSv) is approached.

Table 1. Mean Reference Point Dose (mGy) versus mean radiologist whole body dose (mSv)

Total Reference point Dose (mGy)	Mean radiologist whole body dose (mSv)	Standard deviation of mean radiologist dose (±mSv)
52932.40	0.09	0.08
68673.60	0.18	0.22
107463.25	0.23	0.29

The investigative approach was to determine if there was a correspondence between this machine generated value and whole body dose. The data in **Table 1** and **Figure 1** correlating RPD and radiologist quarterly dose suggests it might. On there other hand, this apparent relationship was not observed for nurse and technologist staff. However, there are many codicils preventing a firm conclusion: 1. The RPD data were sparse. NL Health services was only able to furnish us with data for one year (2020). The technical reasons for this were not shared. 2. The biased distribution of values for technologists and nurses effectively sets their mean values near zero. 3. NL Health Services was not able to identify which technologists were on duty in the "RPD reporting suites" during the period for which they were able to provide RPD data.

NL Health services provided DAP data instead of RPD data. Their rationale was that they had DAP data for the study period. There is a relationship between DAP and RPD but it is not straightforward. Dose Area Product values are calculated on a procedure basis, not on an exposure basis. Equal DAP values may arise from a high dose and small area or small dose and large area. It is not possible to know from the DAP value alone what were the relative contributions. Clearly this has implications for scattered radiation.

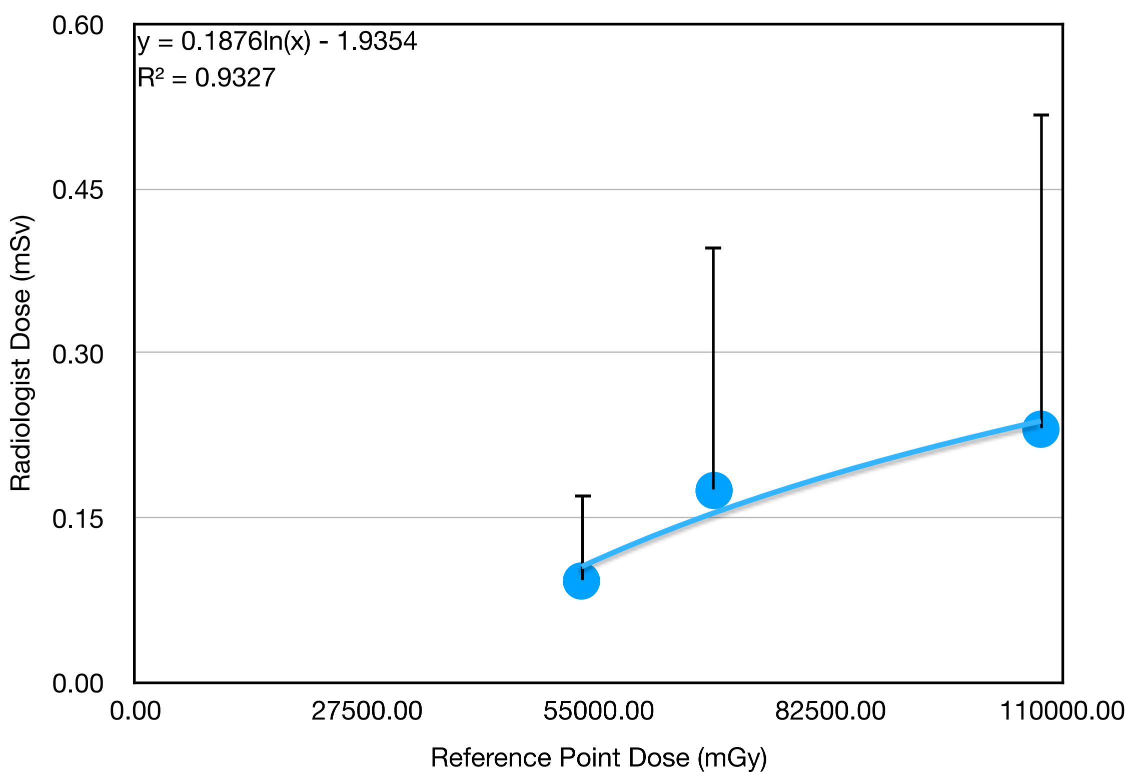

Figure 1. Radiologist whole body dose (mSv) versus reference point dose (mGy). The reference point dose from all procedures in a three month period was summed then grouped in blocks of 10,000 mGy. This provided three group values, the mean of these groups is entered in the table. The corresponding whole-body dose for all radiologists in the period was calculated as a mean value.

Nevertheless, the relationship between DAP and RPD was investigated. Since we had DAP and RPD data for 2020, we examined their quantitative relationship.

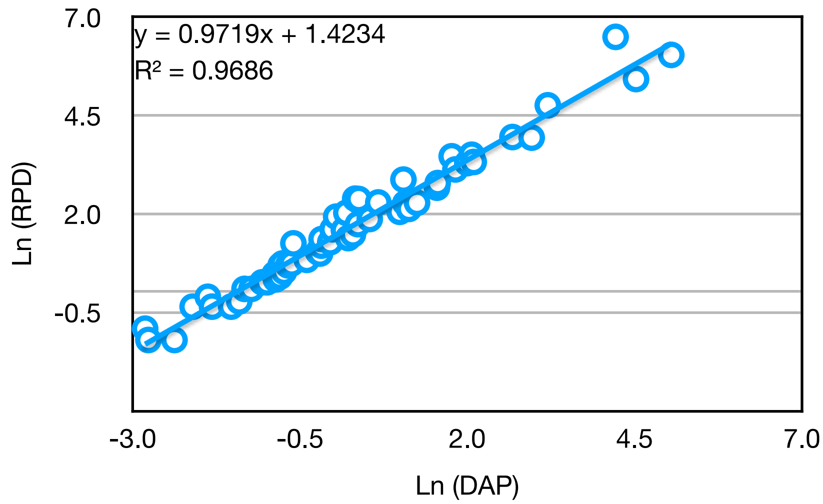

Figure 2. ln Reference Point Dose versus ln Dose Area Product .

In **Figure 2** a linear relationship was found between ln transformed DAP and ln transformed RPD values. It may be noted that: a. The fit is quite good and b. apart from a constant offset (1.42) the relationship is nearly stoichiometric. The slope value suggests that these power series data may have similar exponents. However, what is important is if this relationship holds for room dose (arising from x-rays scattered by the patient) since that is what contributes to staff dose.

Figure 3 suggests that it does. Data were collected using a digital detector positioned approximately 2 meters from patients undergoing various cardiac procedures. The dosimeter was not shielded. The curve, in theory, provides a method to estimate staff doses from DAP values at various location given the known relationship between radiation intensity and distance from source (Appendix Figure 1).

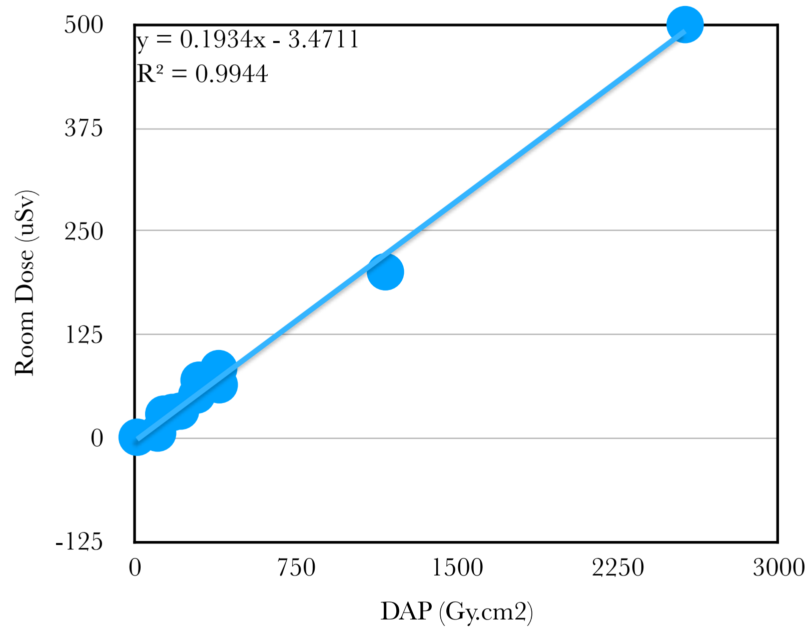

Figure 3. Room dose (uSv) versus DAP (Gy.cm^2)

Since it appeared that DAP values might serve the intended purpose, we examined the relationship between patient DAP values and staff exposure over the observation period.

In **Figure 4** the quarter by quarter DAP values are compared with the corresponding doses to radiologists, technologists and nurses. For this figure, those procedures performed more than thirty times over the observation were included. It was reasoned that rarely performed protocols may have a higher chance of anomalous exposure. Radiologist

8 had an anomalously high exposure in the first quarter of 2018. This value was eliminated from the calculation of total dose for the period.

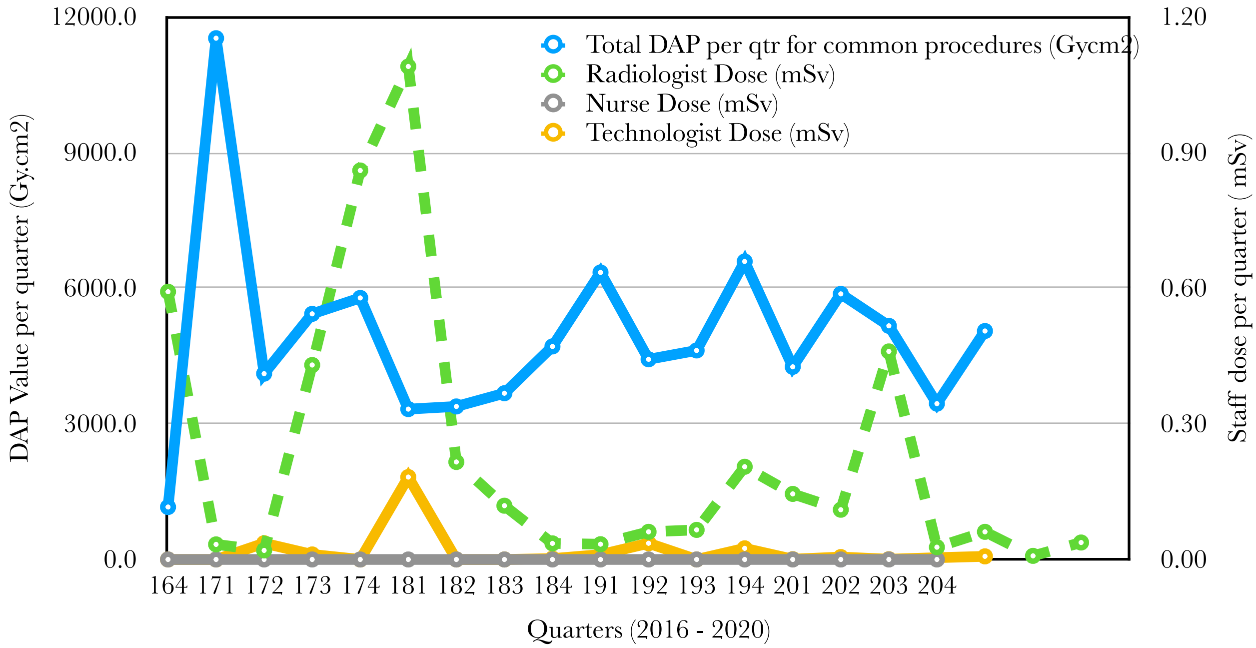

Figure 4. Temporal adjacency of DAP values (Gy.cm²) and staff dose values (mSv).

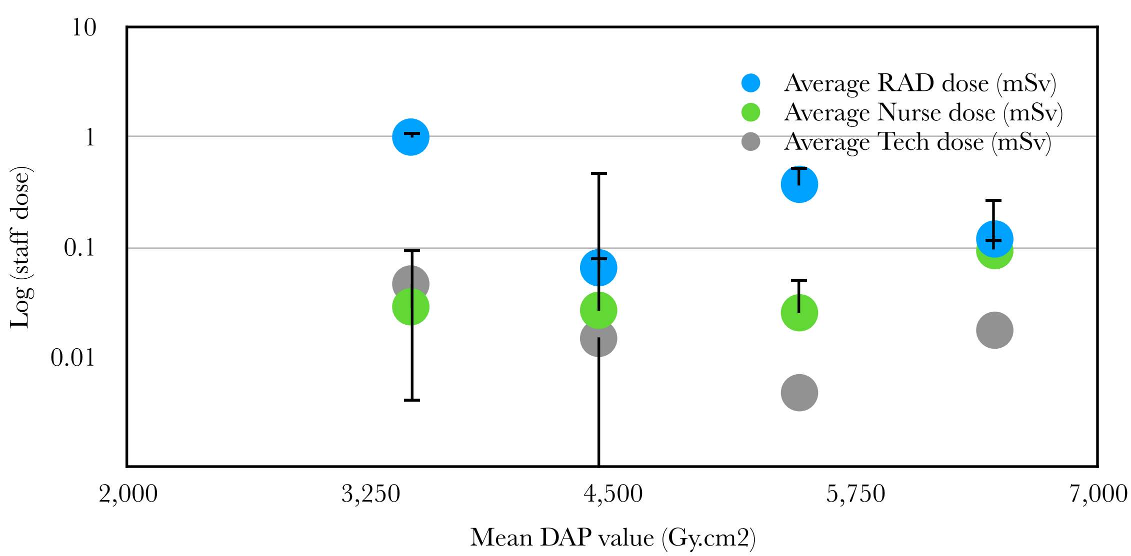

Figure 5. Log Mean Staff dose (mSv) versus mean total DAP (Gy.cm²).

The following observations are offered:

1. There appears to be a temporal hysteresis in that spikes in DAP ratings are reflected in subsequent dose reports (**Figure 4**). This is understandable since the quarters assigned for DAP are based on calendar date while the quarters assigned for staff dose are based on when the dosimetry badge was submitted for reading. In some cases, submissions were one or two quarters late (inferred from missed readings).
2. From **Figure 4** it may be noted that any dose the technologist group experienced was amplified in the radiologist group.
3. It may be inferred from **Figure 4** that some relationship between total DAP value (per quarter) and radiologist (possibly technologist) dose exists. Radiologists accrue small doses due to their proximity to the patient when the beam is active.
4. There is no apparent correlation between mean DAP values and mean nurse estimated dose (**Figure 5**). During the observation period, and this included the pandemic slowdown, nurses did not record any appreciable dose (<0.2 mSv/ quarter in aggregate!) It is questionable if this group requires dosimetry badges.
5. There is no apparent correlation between mean DAP values and mean technologist estimated doses (**Figure 5**). Technologists occasionally recorded a small dose, but again this group most likely does not require dosimeter-based monitoring; they normally do not individually approach the levels permitted for the general public (1 mSv/ year).
6. There is no apparent correlation between mean DAP values and mean radiologist estimated dose (**Figure 5**).
7. The lack of correspondence between DAP and dosimeter may be due to the very low exposure rate experienced by staff. Staff dosimeters are worn beneath the protective gown reducing exposure by a factor of ten. From **Figure 3** a DAP of 2500 Gy.cm^2 results in a 500 uSv air dose. Shielding will reduce this to 50 uSv or 0.05 mSv. Given that this radiation is on average spread over a number of staff, many will fail to meet the reporting threshold. This biases the data towards 0 and impairs a simple examination of dose versus DAP.

For at least two of the radiologists, those that often accrue doses above the detection limit, the personal dosimeter badge provides a reasonably fiducial record of exposure. In contrast, any small dose technologists and nurses accrue for the most part is not available since it appears to be

Table 2. Procedure Description with Frequency, Average and Standard Deviation of the patient radiation estimate.

Procedure	Frequency	Average DAP (Gy.cm2)	StDev
Insertion hemodialysis	755	3.0	66.1
Change hemodialysis	503	20.2	74.7
Insertion portal catheter	493	1.6	16.0
AV dialysis	272	15.9	53.5
Change biliary catheter	148	4.2	64.9
Arteriogram neuro	144	215.2	90.8
Trans-hepatic drainage	139	12.4	66.0
Insertion hemodialysis TE	127	2.0	67.0
Insertion drainage single	115	2.6	20.7
Insertion suprapubic catheter	105	3.8	20.5

below the devices 0.01 mSv threshold. As a result, these staff have no exposure information. Therefore, a model that estimates dose from radiation used would be a useful for the very low dose cohort and a useful adjunct for managing the radiation exposure of the radiologist group.

How would this work: The x-ray usage date in this report is grouped by quarter in order to correspond with the quarterly dosimeter readings for staff. However, it might also be grouped by procedure. This type of grouping would provide average exposure values for a procedure and might be used to anticipate the dose to personnel. For example **Table 2** indicates the average DAP used in the top ten most frequent procedures. Each of these procedures is represented more than 100 times so the average value might be a reasonable approximation for predictive purposes. However, given that occupational risk should reflect an abundance of caution, predictions might be based on the 95 percentile dose; in the case of the first example in the table this would be 69.1 $Gy.cm^2$.

Applying the room dose equation from **Figure 3** estimates the whole body dose to staff located two meters from the patient at 0.01 mSv for the procedure. A study of the position of various staff during these procedures would allow a more precise estimate of dose. Having said that, the technologist operates the equipment from a fixed know position in the room approximately two meters from the patient (source). The nurses and other persons attending are instructed to step back three steps (about 2 meters) when the x-ray beam is on. The current room estimate may fairly reflect their exposure. Where staff must remain closer to the patient during beam on or where the patient is not of the (average) size used for the room measurements, staff may expect a higher or lower dose (see Appendix figure 1).

In conclusion, our thesis was that Reference Point Dose (mGy) could be used to estimate staff dose obviating the need for or augmenting the information from personal dosimeters. These preliminary results suggest that the thesis is valid. For the limited RPD data at our disposal a correspondence between RPD and radiologist whole body estimated dose was inferred. No correspondence was noted with nurse or technologist doses. Statistical validation will require a more robust dataset.

For technical reasons within NL Health Services (formerly Eastern Health), the anticipated RPD data was not available over the complete observation period. Instead DAP values were provided. Since DAP values at a selected beam energy are a product of two factors (beam intensity and cross sectional area) they are not necessarily unique (changes in each factor can produce similar values). Although this was not ideal, we determined that there was an excellent correlation between the DAP and RPD values we had. The quarterly comparisons were made between DAP and personal dosimeter readings.

We noted a correspondence, with temporal hysteresis, between DAP events and radiologist whole body dose. Dosimeter reporting frequency and threshold contributed to the apparent disconnect between radiation in use and staff dose.

Challenges encountered in prosecuting this investigation.

1. Availability of data. Before applying for support the principal investigator met several times with the Eastern Health corporate radiation safety officer and the director of radiology service to solicit assistance in obtaining data. This was provided and a letter of support accompanied the application. However, more than a year elapsed before the limited data we did obtain was provided.
2. The principal investigator fell ill and remains on extended medical leave.

Remaining opportunities.

Financial services indicated that approximately $35,000 remains from the original allocation. These funds were initially allocated for an Eastern Health research assistant; instead they opted to perform the work with existing resources. This money might be used to fund a second graduate student to extend the study and to focus on collecting Reference Point Dose data as originally intended.

There are two factors that suggest data access may have improved: 1. The formation of the NL Health Services Research and Innovation section under the leadership of Dr. Liam Kelly. We have met with Dr. Kelly and he noted that some of his staff are available to facilitate data extraction, especially where a clear benefit to NL Health Services is evident. 2. Health Accord advocates are anxious to demonstrate that NL Health Services are interested in delivering all aspects of best-quality service in the most cost-effective manner. Should these findings survive a more extensive investigation the resources (financial and human) that are devoted to radiation monitoring could be replaced by instrument-based automated measurements.

Appendices

Appendix Table 1. Radiologist quarterly dose measurements (mSv).

Participant	Q4 2016	Q1 2017	Q2 2017	Q3 2017	Q4 2017	Q1 2018	Q2 2018	Q3 2018	Q4 2018	Q1 2019	Q2 2019	Q3 2019	Q4 2019	Q1 2020	Q2 2020	Q3 2020	Q4 2020	Q1 2021	Q2 2021	Q3 2021
RAD001	-	0.1	0	0.13	0	0.11	0.03	0.03	0.01	0.03	0	0.11	0.01	0.09	0.14	0.02	0	0	-	-
RAD002							0.01	0	0	0	0	0	0	0	0	0	0	0.05	0	0.01
RAD003							0	0	0	0	0	0	-	0	0.01	0	0	0.03	0	0
RAD004	2.96	0	0.1	0	4.29	6.45	1.54	0.66	0	0	0.07	0.34	1.22	1.04	0.84	1.91	0.17	0	-	-
RAD005	0	0	0	0	0	0	0	0.03	0.03	0.02	0.02	0	0	0	0	0.01	0	0	0.02	-
RAD006				-	0	0	0.07	0.12	0.06	-	0	-	-	0.03	0	0	0.02	0	0	0
RAD007	0	-	0	0	-	0	0.01	0	0	0	0	0	0	0	0	0				0.14
RAD008	0	-	-	2.45	0.87	19.0	0.27	0.23	0.2	0.22	0.46	-	-		0	2.2	-	-	-	-
RAD009	0	-	0	0	0	0	0.01	0	0.02	0	0	0	0	0	0	0	0	0	0.02	-
Average (mSv)	0.59	0.03	0.02	0.43	0.86	3.66	0.22	0.12	0.04	0.03	0.06	0.07	0.21	0.15	0.11	0.46	0.03	0.01	0.01	0.04
StDev	1.32	0.06	0.04	0.99	1.72	7.20	0.50	0.22	0.06	0.08	0.15	0.13	0.50	0.36	0.28	0.91	0.06	0.02	0.01	0.07
Max (mSv)	2.96	0.10	0.10	2.45	4.29	19.0	1.54	0.66	0.20	0.22	0.46	0.34	1.22	1.04	0.84	2.20	0.17	0.05	0.02	0.14
Count GT min	1	1	1	2	2	3	7	5	5	3	3	2	2	3	3	4	2	2	2	2
Count	5	3	5	6	6	7	9	9	9	8	9	7	6	8	9	9	7	7	5	4
Count All	6	6	6	7	7	7	9	9	9	9	9	9	9	8	9	9	8	8	8	9
Missing values	1	3	1	1	1	0	0	0	0	1	0	2	3	0	0	0	1	1	3	5

A dash symbol (-) signifies a missing value. That is, the staff member was on service but the badge was not submitted for reading. A blank value indicates the staff member was not on service. A zero reading indicates the returned value was “M”, indicating below detectable threshold (0.01 mSv). Mean values and standard deviation of the mean exclude missing values.

Appendix Table 2. Nurse quarterly dose measurements (mSv).

Participant	Q4 2016	Q1 2017	Q2 2017	Q3 2017	Q4 2017	Q1 2018	Q2 2018	Q3 2018	Q4 2018	Q1 2019	Q2 2019	Q3 2019	Q4 2019	Q1 2020	Q2 2020	Q3 2020	Q4 2020	Q1 2021	Q2 2021	Q3 2021
RN001	0.00	-	0.00	0.00	0.00	-	0.00													
RN002			0.00	0.00	0.00	0.00	0.00	-												
RN003					0.19	0.15	0.01	-	0.09	0.05	0.00	0.09	0.29	0.03	-	0.00				
RN004	0.00	-	0.00	0.00	0.00	0.00	0.19	0.04	0.03	0.06	0.03	0.02								
RN005					0.12	0.00	0.00	0.11	0.07	0.03	0.00	0.00								
RN006			0.11	0.00	0.11	0.00	0.01	0.09	0.08	0.06	0.00	0.00	-	0.02	0.05	0.02	0.03	-	-	-
RN007	0.00	-	0.00	0.00	0.00	0.00														
RN008	0.00	-	0.00	0.00	0.00	0.00	0.00	0.00												
RN009	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	-	0.01	0.00	0.00	0.00	-	-	-	-	-	-	-
RN010			0.00	0.00	0.00	0.00	0.02	0.01	-											
Average (mSv)	0.00	0.00	0.01	0.00	0.04	0.02	0.03	0.04	0.07	0.04	0.01	0.02	0.15	0.03	0.05	0.01	0.03			
StDev	0.00		0.04	0.00	0.07	0.05	0.06	0.05	0.03	0.02	0.01	0.04	0.21	0.01		0.01				
Max (mSv)	0.00	0.00	0.11	0.00	0.19	0.15	0.19	0.11	0.09	0.06	0.03	0.09	0.29	0.03	0.05	0.02	0.03	0.00	0.00	0.00
Count GT min	0.00	0.00	1.00	0.00	3.00	1.00	4.00	5.00	4.00	5.00	1.00	2.00	1.00	2.00	1.00	1.00	1.00	0.00	0.00	0.00
Count	5.00	1.00	8.00	8.00	10.0	9.00	9.00	6.00	4.00	5.00	5.00	5.00	2.00	2.00	1.00	2.00	1.00	0.00	0.00	0.00
Count All	5.00	5.00	8.00	8.00	10.0	10.0	9.00	8.00	6.00	5.00	5.00	5.00	3.00	3.00	3.00	3.00	2.00	2.00	2.00	2.00
Missing values	0.00	4.00	0.00	0.00	0.00	1.00	0.00	2.00	2.00	0.00	0.00	0.00	1.00	1.00	2.00	1.00	1.00	2.00	2.00	2.00

A dash symbol (-) signifies a missing value. That is the staff member was on service but the badge was not submitted for reading. A blank value indicates the staff member was not on service. A zero reading indicates the returned value was “M”, indicating below detectable threshold (0.01 mSv). Mean values and standard deviation of the mean exclude missing values.

Appendix Table 3. Technologist quarterly dose measurements.

Participant	Q4 2016	Q1 2017	Q2 2017	Q3 2017	Q4 2017	Q1 2018	Q2 2018	Q3 2018	Q4 2018	Q1 2019	Q2 2019	Q3 2019	Q4 2019	Q1 2020	Q2 2020	Q3 2020	Q4 2020	Q1 2021	Q2 2021	Q3 2021
RT001														0	0	0	0	0	0	0
RT002															0	0	0	0	0	
RT003	0	-	0	0.1	0	0.14	0	0	0	0.01	0	0				0	0	0	0	-
RT004			0	0	0	1.4	0	-	-	0.04	0	0	0.01	0.01	0.01	0	-	0	-	-
RT005	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-
RT006								0	0	0	0	0	0.29	0	0	0	0	0	0	0
RT007	0		0	0	0	0	0	0	0	0	0.42	0	0	0	0	0	0	0	0	0
RT008			0.1	0	0					0	0	0	0	0	0	0	0	0	-	-
RT009	0	-	0.26	0	0	0.1	0	-	-	0.02	0	0	0	0	0.02	0	0	0	0.01	-
RT010	0	-	0	0	0	0	0	0	0.01	0.04	0	0	0	0	0	0	0	0	0.02	-
RT011	0	-	0	0	-	0	0	-	0	0	0	0	0	0	0	0	0	0	0	-
RT012	0	-	0	0	0	0	0	-	0.01	0.01	0	0	0	0	0	0	0	0	0.02	-
RT013																				0
RT014	0	-	0	-	0	0	0	-	-	-	-	0	0	0	0	0	0	0	0	0
RT015							0	0	0	0	0	0	0	0	0	0	0	0	0	0
RT016							0	0	0	0	-	0	0	0	0	0	0	0.03	0.28	0.03
RT017	0																			
RT018							0	0	0	0.02	0.01	0	0.02	0	0.05	0.01	0.06	0.08	0.02	0.03
Average (mSv)	0.00	0.00	0.04	0.01	0.00	0.18	0.00	0.00	0.00	0.01	0.04	0.00	0.02	0.00	0.01	0.00	0.00	0.01	0.03	0.01
StDev	0.00		0.08	0.03	0.00	0.46	0.00	0.00	0.00	0.01	0.12	0.00	0.08	0.00	0.01	0.00	0.02	0.02	0.07	0.01
Max (mSv)	0.00	0.00	0.26	0.10	0.00	1.40	0.00	0.00	0.01	0.04	0.42	0.00	0.29	0.01	0.05	0.01	0.06	0.08	0.28	0.03
Count GT min	0	0	2	1	0	3	0	0	2	6	2	0	3	1	3	1	1	2	5	2
Count	9	1	10	9	9	9	12	8	10	13	12	14	13	14	15	16	15	16	14	8
Count All	9	7	10	10	10	9	12	13	13	14	14	14	13	14	15	16	16	16	16	16
Missing values	0	6	0	1	1	0	0	5	3	1	2	0	0	0	0	0	1	0	2	8

A dash symbol (-) signifies a missing value. That is the staff member was on service but the badge was not submitted for reading. A blank value indicates the staff member was not on service. A zero reading indicates the returned value was "M", indicating below detectable threshold (0.01 mSv). Mean values and standard deviation of the mean exclude missing values.

Appendix Table 4. Annual staff dose (mSv)

ID	2017	2018	2019	2020	Doses > 1 mSv	Doses > 3 mSv
RAD001	0.23	0.18	0.158	0.25	0	0
RAD002	0	0.01	0	0	0	0
RAD003	0	0	0	0.01	0	0
RAD004	4.39	8.65	1.63	3.96	4	3
RAD005	0	0.06	0.04	0.01	0	0
RAD006	0	0.25	0	0.05	0	0
RAD007	0	0.01	0	0	0	0
RAD008	3.32	19.76	0.68	2.2	3	2
RAD009	0	0.03	0	0	0	0
RN001	0	0	0.00	0.00	0	0
RN002	0.00	0	0.00	0.00	0	0
RN003	0.19	0.25	0.43	0	0	0
RN004	0	0.26	0.11	0.00	0	0
RN005	0.12	0.18	0.03	0.00	0	0
RN006	0.22	0.18	0.06	0.1	0	0
RN007	0	0.00	0.00	0.00	0	0
RN008	0	0.00	0.00	0.00	0	0
RN009	0.00	0.01	0.01	0	0	0
RN010	0.00	0.03	0.00	0.00	0	0
RT001	0	0	0	0	0	0
RT002	0	0	0	0	0	0
RT003	0.1	0.14	0.01	0	0	0
RT004	0	1.4	0.05	0.02	1	0
RT005	0	0	0	0	0	0
RT006	0	0	0.29	0	0	0
RT007	0	0	0.42	0	0	0
RT008	0.1	0	0	0	0	0
RT009	0.26	0.1	0.02	0.02	0	0
RT010	0	0.01	0.04	0	0	0
RT011	0	0	0	0	0	0
RT012	0	0.01	0.01	0	0	0
RT013	0	0	0	0	0	0
RT014	0	0	0	0	0	0
RT015	0	0	0	0	0	0
RT016	0	0	0	0	0	0
RT017	0	0	0	0	0	0
RT018	0	0	0.05	0.12	0	0

Appendix Figure 1. Stylized angiography suite showing the exponential decrease in radiation intensity with distance from the source (patient).