

Patient Dose Audit using Interventional and Conventional Radiograph

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Abstract

The Patient Dose Audit allows tracking the cumulative dose of a patient subjected to one or more fluoroscopic as well as conventional x-ray examinations, and analyzing the dose distribution profiles over the irradiated areas of interest, with the aim of optimizing dose delivery. This study is performed in real time using the Ray Safe ionization chamber with the Siemens Fluoroscopy unit at the Georgetown Public Hospital Corporation. The Dose Profile generated from an Intravenous Pyelogram interventional study, indicated a higher dose rate and dose deliverance than that of Conventional examination. The dose profile allowed mapping doses delivered to a particular organ within any specific location of the collimated field. This allows for adjustments of factors which can be added and/or eliminated in tracking doses delivered to specific organs, with and without the presence of the patient. This information from the resulting dose audit would therefore serve as an institutionally based local Diagnostic Reference Levels, which ultimately would better equip Occupationally Exposed Personnel institutionally and by extension across Guyana to be more cautious in dose delivery without compromising diagnostic quality.

Keywords: Radiography; Diagnosis; Fluoroscopy; Angiography

Introduction

In Guyana, medical imaging has been revolutionized to include the incorporation of multi-modality imaging methods using modern technology. Some of the imaging modalities used in diagnostic imaging includes interventional techniques such as Fluoroscopy and Angiography that deliver higher radiation doses to the patient. Due to the high demand and increase in both type and quantity of patient examinations requested over the years, a significant dose of ionizing radiation is unintentionally delivered to the patient. Since patients are also considered members of the public, maintaining their level of radiation to a minimum is now a challenge; a challenge that is not impossible to conquer. Methods to measure the dosage delivered will go a long way to strengthen the modern system of imaging, as well as to optimize dose delivery [1].

Background to the problem

From observation it can be noted that a significant number of examinations that uses ionizing radiation were never monitored as it pertains to radiation imparted on to the patient. The only source of radiation monitoring is to occupationally exposed personnel with the use of thermoluminescent dosimeters (TLD's). Even though modern day equipment (therapy and fluoroscopy) allow selection of the dose before it is delivered to the patient, no cumulative record or traceability exists of patients exposure to ionizing radiation, or when the same patient return for follow up imaging involving conventional and interventional radiography. And interventional radiography delivers more radiation than non-interventional radiography [2].

The problem

Protocols exists, to monitor radiation exposure but there is limited knowledge on whether they are being adhered to. These protocols are implemented to monitor the cumulative dose received by members of the public. Not implementing protocols and, documenting and tracking equipment based as well as institutionally based dose rates for patients can lead to investigation, legal actions and denial of operating license by regulatory authorities.

Purpose of the research

This study aims to conduct a patient dose audit using static repeated

doses information from actual examinations from the fluoroscopy unit at the Georgetown Public Hospital Corporation (GPHC).

Significance of the research

The resulting dose audit would serve as a baseline reference for future research and aids in developing a local Diagnostic Reference Level (DRL) for Guyana firstly by an institutional basis. This in turn would better equip OEPs in Guyana to be more aware and learned in dose delivery without compromising diagnostic quality [3].

Hypothesis

Patient dose received during interventional procedures is higher than that received during conventional procedures.

Research questions

-For hospitals, is there similarity with the equipment being used and doses delivered, what is this similarity?

-Is there any software to track dose delivered? Should the dose be measured with patient and then without patient?

-There are existing protocols of dose optimization in Guyana, but are they being adhered to?

-In order to take the recommendations to the national level, what number of medical institutions in this study?

-Where there are existing protocols in place, are they for static imaging or dynamic imaging?

-How is kVp related to the actual dose profile and dose? Is it an independent or direct relation?

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Literature review

As the number of interventional and conventional radiologic procedures performed in Guyana continues to increase, there is growing concern about patient protection issues. Currently, no national protocol is in place to track a patient's lifetime cumulative dose from medical sources, and questions have arisen regarding the possible threat to public health from the widespread use of these modalities, especially in pediatric patients. The literature review was performed using various key scholarly databases and search engines. For comparison purposes and to estimate the relative risk increase for stochastic effects such as cancer, patient doses are reported as "effective doses," which are measured in Sieverts (Sv) in the International System of Units [4].

The outcome of this study hopes to prove that automated methods of radiation dose data collection permit a detailed analysis of radiation dose according to protocol and equipment over time as similar to a study done by Kate MacGregor, et al in August 2015. This is one of the goals of this particular topic since most if not all the CT, Fluoroscopy, Angiography and Direct and/or Computed Radiography are connected through a PACS system and the introduction of the dose tracking monitoring software would be a step in the right path for cumulative patient dose auditing [5].

In this study, one of the most utilized interventional radiography method is Computed Tomography (CT) and it focuses on the methods used in obtaining patient dose to effectively give a reading of that patient cumulative dose. For this to be effective a certain guideline/baseline study from acceptable international recognized limits should be available to refer to, one such committee/organization are the National Radiological Protection Board and European Commission. One method of measuring the Entrance Surface Dose (ESD) is by the use of thermoluminescent dosimeters, which was done by Konstantinos A. Gogos, et al, 2003. An estimated the effective doses from the measured ESD can also be obtained, which was also covered in the same study by Konstantinos, but this was done using paediatric patients [6].

To estimate the dose delivered on adult patients, a formula to measure the Dose-Area Product (DAP) and ESD using an interventional method was referred to. These two measured quantities can be used to measure the effective dose, which involved the use of conversion coefficients that have been determined for specific X-ray views in a mathematical phantom. From published literature done by E Yakoumakis, PhD and colleagues, establish that the calculation procedure suggested that effective dose (E) estimate using the DAP measurements could be more accurate than using just the ESD measurements. This bit of theory can be effectively incorporated in this study to produce a paper of high caliber. However in the absence of appropriate equipment a reliable E should also be achievable from the ESD calculated using the electro-technical factors (i.e. kVp and mAs), this would allow even the low budget and far-fetched departments to perform their own tests, and this was also covered in the same literature by E Yakoumakis [7].

One other way the successful planning and management in dose delivery can be achieved is by developing dose profiles which give the dose rates delivered at strategic locations in the profile. A study carried out by Richard D. Nawfel, et al in July 2000, concluded that by knowing and developing dose profiles by knowing the dose rates were successful in permitting conservative planning in the management of radiation safety and dose delivery in the CT fluoroscopic time [8]. Which would be the ideal aim of this research. Because the hypothesis is saying that interventional procedures would deliver more doses to

patients, the effective patient dose is the dose in focus for this study. A paper by Raoul M. S. Joemai and associates in April 2009 stated that the effective patient dose was derived from the recorded dose-length product, basically it measured the dose delivered during the duration of the interventional study which is ideal and more accurate (Table 1).

Some further reading on a study done by Reena Sharma and associates backed up E Yakoumakis, et al, that the technique factors specific to X-ray technology and patient parameters mainly affect the patient doses and image quality (Table 2). In this study and from general knowledge we can all safely say that the patient dose resulting from an X-ray examination depends on a number of parameters such as energy of the X-ray beam, beam current, exposure duration, type of image recording system, technique of examination and the type of X-ray generator. As such, it is necessary to record these parameters in conducting this study by measuring the doses using the methodology stated above [9].

However, before any patient dose studies on any ionizing radiation equipment, it should be a priority and a requirement that comprehensive quality assurance (QA) tests were carried out. So it would be beneficial to gather information on the frequency and the last time these tests were carried out along with the results and recommendation (if any). These tests should be repeated on quarterly basis for two years. These measures, when adapted to this particular study, leads to increased quality and maintain a standard of results generated. As was done in same study by Reena Sharma and associates [10].

Methodology

Materials

X-ray unit: All the measurements below were taken from the Fluoroscopic unit of the Georgetown Public Hospital Corporation (GPHC) with the following specifications.

Siemens Fluoromat overhead Fluoroscopic X-ray Unit: Energy Range: -0-150 kVp (only functional/operational unit of its kind in Guyana to date.)

-OsiriX Software (retrieval of images), MS 3D paint, MS excel

-Radiation detector

RaySafe Table top Detector with Fluoroscopy/Radiography Attachment sensor (Figure 1)

Auxiliary measuring tools: Measuring Tape, Spirit Level, Meter Rule

Steps

Pediatric examinations were not included in this project.

Company's Name	Model and Serial #	Manufactured Date	Maximum Tube Output
SIEMENS	03345209 409161572	05 – 2015	150 kVp

Table 1: The details of the Siemens Fluoromat overhead Fluoroscopic X-ray Unit.

Examination	Kilovoltage Peak (kVp)	Milliamperes Seconds (mAs)
Barium Meal	83	25
Barium Swallow	87.5	28
Intravenous Pyelogram 1	80	28
Intravenous Pyelogram 2	70	25

Table 2: Examinations and Parameters (electro-technical factors).

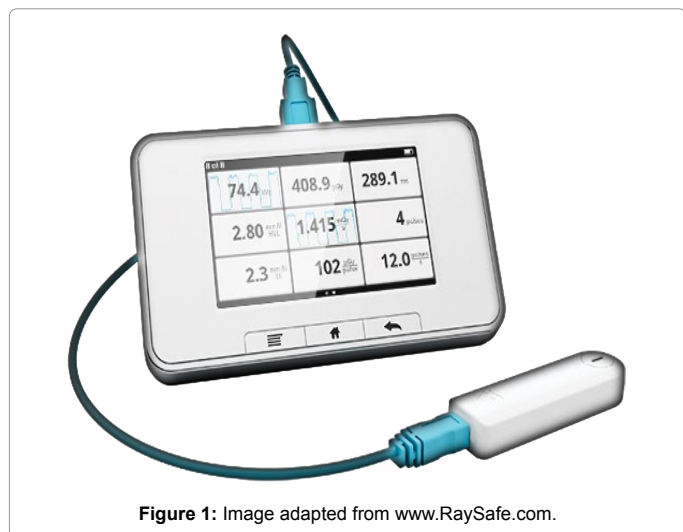


Figure 1: Image adapted from www.RaySafe.com.

A total of four (4) interventional/special examinations of which complete measurements were taken and can be used; two (2) Intravenous Pyelogram (IVPs) and one (1) Barium swallow one (1) Barium meal Parameters including: collimated area, electro-technical factors (kVp, mAs), SID – 115 cm (source to image Distance) were all recorded and documented.

Dose profiles were generated with the use of the RaySafe ionizing chamber being strategically placed at different points within the collimated field. This allowed to see the difference in dose delivered at different points along the field. The spirit level purpose was to ensure tube head is perpendicular to sensitive window of detector while tape measure and meter rule were used to measure SID in both the projected field and standard field at recommended SID [11].

Ensuring sufficient data was recorded, readings were taken at as many points as possible with patients (the edges, midway between the edges, the center of each quadrant and additional points when the examination was over, maintaining the parameters but without unnecessarily exposing the patient).

Within the Ray Safe kit are the R/F unit, the portable unit and a survey meter along with detectors for Computed Tomography readings. These will be used for future work [12].

The R/F RaySafe ionizing chamber was the unit used most frequently and also the one that gathered all the necessary readings without patient present (Table 3-7).

Dose mapping

The image of a Barium examination, it was used to map which organs were exposed at the points the detector took readings and the effective dose of those organs/structures were calculated.

To accurately pin-point where in the image the detector was the measurement of the detector which is known (2 cm/20 mm) was used as reference to identify the other areas and which organs/structures that were exposed and thereby allowing to calculate the organ dose [13].

Knowing the dimensions of the detector and what size of the image corresponds to the same size of detector then it can accurately be used to locate the point on the image was the detector and by knowing the

Reading No.	kVp	Dose (mGy)
1	73.9	0.05364
2	0	0.01661
3	83.3	1.253
4	82.8	1.452
5	83.3	1.141
6	83.1	1.215
7	82.9	1.377
8	82.3	1.52
9	82.2	1.576
10	80.3	1.58

Table 3: Barium meal measurements.

Reading No.	kVp	Dose (µGy)
1	0	17.81
2	81.2	53.35
3	81.8	55.42
4	0	45.8
5	0	8.215
6	88.2	75.6

Table 4: Barium swallow measurements.

Reading no.	kVp	Dose (µGy)
1	76.2	68.83
2	0	10.17
3	76.7	118.6
4	67.9	53.16

Table 5: 1st IVP examination reading.

Reading no.	kVp	Dose (µGy)
1	0	26.52
2	0	21.8
3	0	18.35
4	0	17.11
5	0	21.53
6	0	39.96
7	76.2	61.6
8	72.5	926.1

Table 6: 2nd IVP examination reading.

anatomical location of organs, successfully track the effective dose of that organ/structure knowing their tissue weighting factors with respect to the detector placement.

All the data collected was then tabulated and images marked with graphical analysis on each of the examination.

Dose calculation

The ESD at a given tube potential was estimated from the measured radiation output of the tube, the relevant exposure factors and a mathematical model of the human body used to estimate radiation backscatter. The following equation can therefore be used: (Appendix 1), however, was not needed but can be referenced if the ionization chamber is not available for future studies [14].

Study design

The study is set-up to be experimental, using static images repeated in a series and scout (conventional dose) with relatively little

retrospective study being consulted. Actual patients and their recorded doses during the examination. Permission was sought and granted by institution and patients in the form of a signed consent form and finally an analytical standpoint (Figure 2) [15].

Data collection was displayed in tabulated form which aided in the figures being easily compared to each other as interventional dose delivered against conventional. Dose Profiles as well as an average dose delivered per patient was developed graphically which can allow for comparison amongst other analytical approaches (Figure 3). Setup for this is seen below:

Results

Following figures and diagrams depicts images from the examinations mention above along with graphical analysis of the scout (conventional doses) and the series of combined doses after each examination was completed then lastly a graphical dose profile of that examination after the completed series [16] (Figure 4-13).

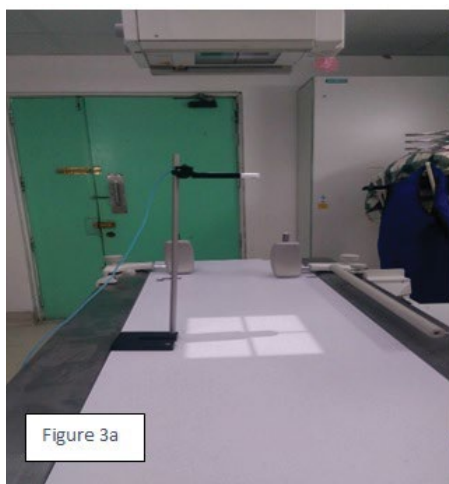
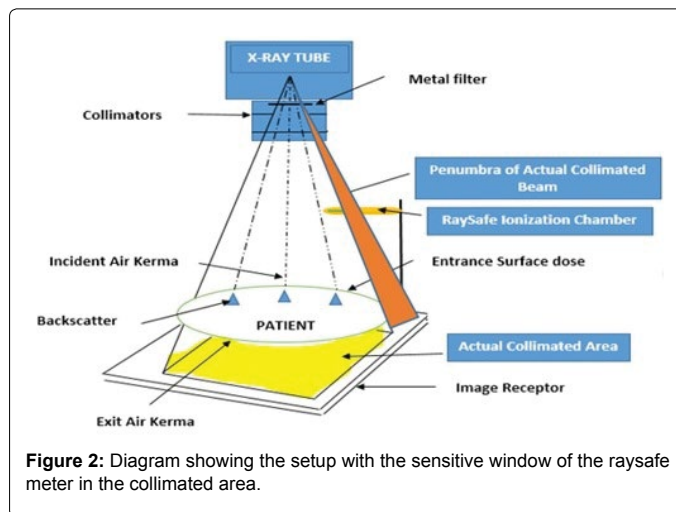
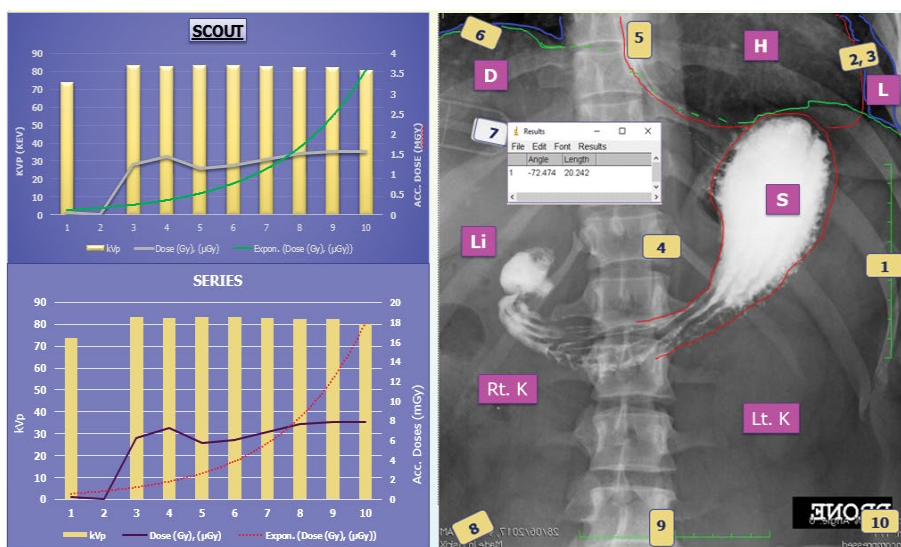


Figure 3: (a) Image showing setup of R/F detector at a projected field height. (b) Image showing setup of the portable R/F detector at tabletop.



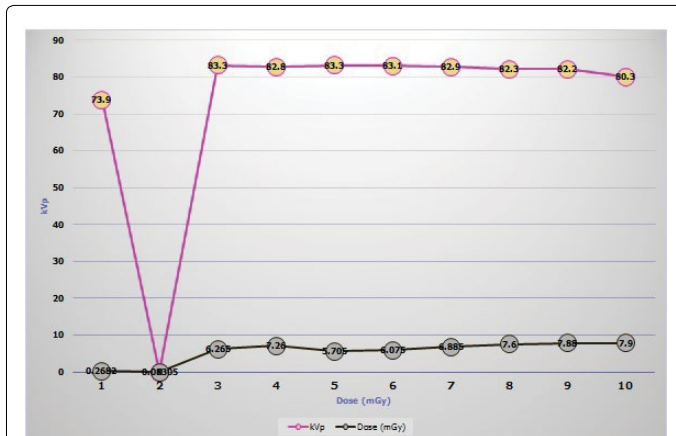


Figure 5: Graph depicting the dose profile of Figure 4 after completed examination.

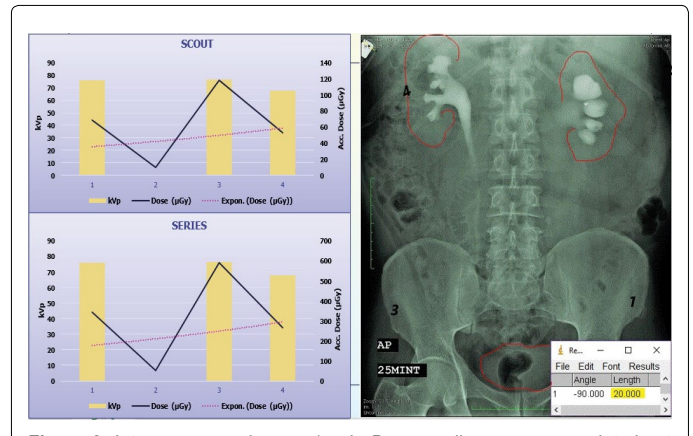


Figure 8: Intravenous pyelogram 1. n.b: Dose readings are accumulated not averaged.

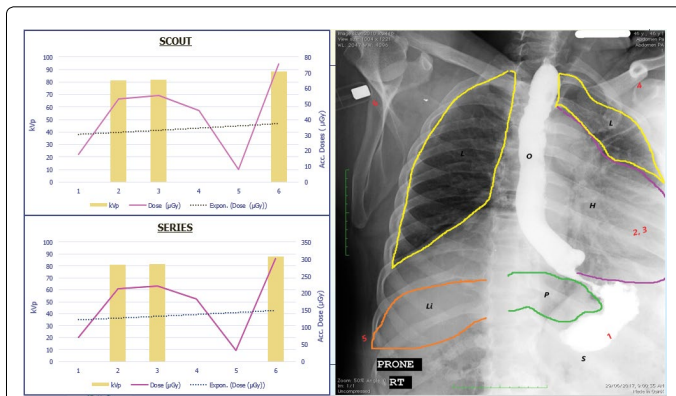


Figure 6: Barium swallow. n.b: Dose readings are accumulated not averaged.

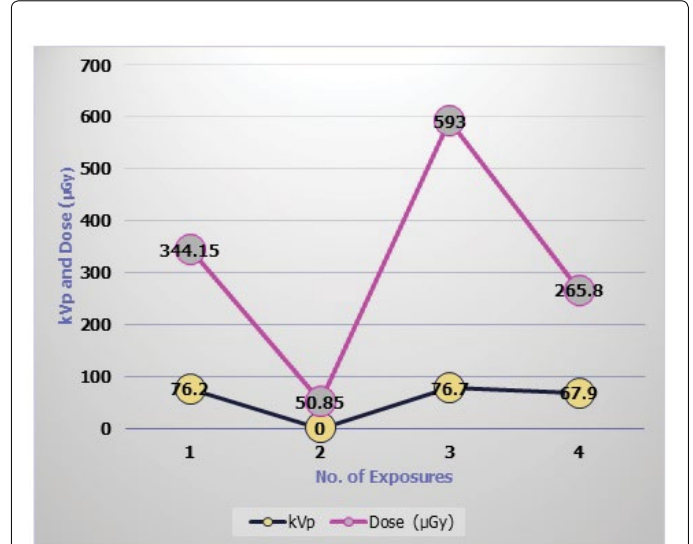


Figure 9: Graph depicting the dose profile for Figure 8 of the 1st IVP completed examination.



Figure 7: Graph depicting the dose profile for Figure 6 of a completed barium swallow examination.

Conversions

- 1 Gray (Gy) = 1000 millisievert (mSv)
- 1 milligray (mGy) = 1 millisievert (mSv)
- 1 microgray (µGy) = 0.001 millisievert (mSv)

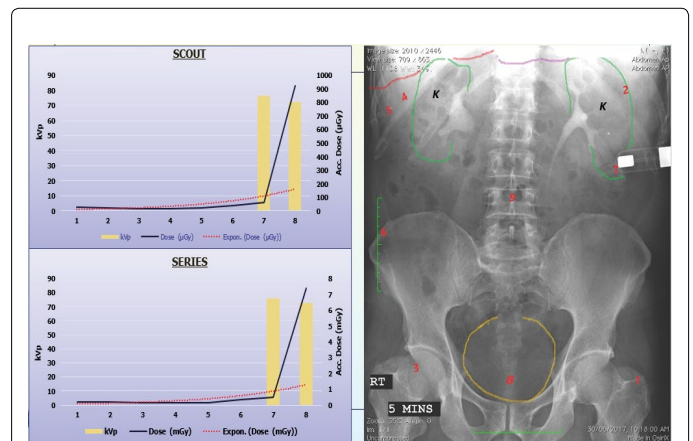


Figure 10: Intravenous pyelogram 2. n.b: Dose readings are accumulated not averaged.

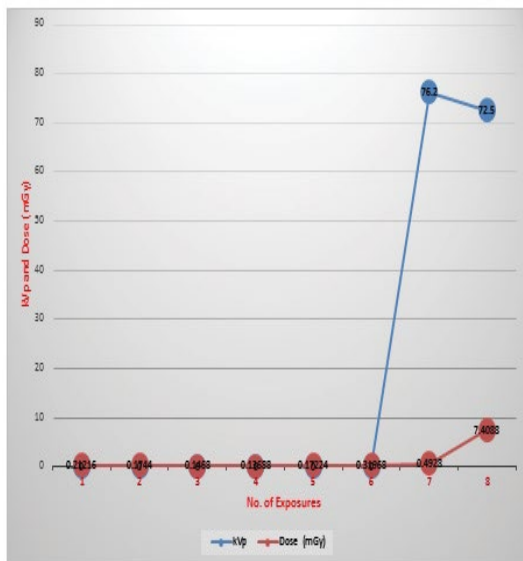


Figure 11: Graph depicting the dose profile for Figure 10 of the 2nd IVP examination.

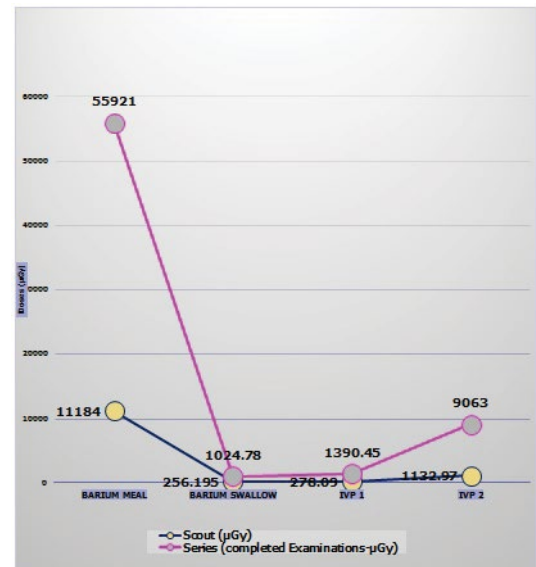


Figure 12: Graph showing the comparisons of the doses scout static images against the doses of the completed series of images.

Examination with organs	Equivalent dose Scout - series		Tissue weighting factor	Scout (conventional) effective dose	Completed series effective dose
Barium Meal	mGy			mSv	
Stomach	1.452	7.26	0.12	0.174	0.871
Lung	1.253	6.265	0.12	0.15	0.751
Heart	1.141	5.705	0.12	0.136	0.684
Liver	1.377	6.885	0.04	0.055	0.275
Pancreas	1.452	7.26	0.12	0.174	0.871
Bone	1.576	7.88	0.01	0.0157	0.078
Total					3.53
Barium Swallow	µGy			mSv	
Stomach	17.81	71.24	0.12	0.0021	0.0085
Pancreas	17.81	71.24	0.12	0.0021	0.0085
Liver	8.215	32.86	0.04	0.00032	0.0013
Lung	45.8	183.2	0.12	0.0055	0.022
Esophagus	53.35	213.4	0.04	0.0021	0.0085
Heart	55.42	221.68	0.12	0.0067	0.0089
Bone	75.6	302.4	0.01	0.00076	0.003
Total					0.0607
1 st IVP	µGy			mSv	
Kidney	53.16	265.8	0.12	0.0064	0.032
Adrenal gland	53.16	265.8	0.12	0.0064	0.032
Bone	118.6	593	0.01	0.0012	0.0059
Gonads	68.33	344.15	0.08	0.0055	0.028
Sml. Intestines	53.16	265.8	0.12	0.0064	0.032
Bladder	118.6	593	0.04	0.0047	0.024
Spleen	10.17	50.85	0.12	0.0012	0.0061
Prostate	118.6	593	0.12	0.0064	0.032
Total					0.192
2 nd IVP	µGy			mSv	
Kidney	26.52	212.16	0.12	0.0032	0.025
Adrenal gland	21.8	174.4	0.12	0.0026	0.021
Bone	39.96	319.68	0.01	0.0004	0.0032
Liver	17.11	136.88	0.04	0.0007	0.0055
Bladder	926.1	7408.8	0.04	0.037	0.3
Gonads	926.1	7408.8	0.08	0.074	0.6
Sml. Intestine	26.52	212.16	0.12	0.0032	0.025
Spleen	21.8	174.4	0.12	0.0026	0.021
Prostate	926.1	7408.8	0.12	0.11	0.89
Total					1.8907

Table 7: Showing the calculations of effective doses of individual organs that fall within examinations and from the completed series doses by multiplying their respective tissue weighting factors (ICRP 103 issue) then converting wherever necessary.

Tissue weighting factors according to ICRP 103 (ICRP 2007)

Tissue	Tissue weighting factor wT	ΣwT
Bone-marrow (red), colon, lung, stomach, breast, remaining tissues(*)	0.12	0.72
Gonads	0.08	0.08
Bladder, oesophagus, liver, thyroid	0.04	0.16
Bone surface, brain, salivary glands, skin	0.01	0.04
Total		1.00

(*) Remaining tissues: Adrenals, extrathoracic region, gall bladder, heart, kidneys, lymphatic nodes, muscle, oral mucosa, pancreas, prostate (♂), small intestine, spleen, thymus, uterus/ovis (♀).

Figure 13: ICRP table of tissue weighting factors.

Discussion

Figure 4 shows the result of the barium meal examination. From the scout conventional static image, the highest dose was just less than 2 mGy, however, after a series of 5 images including follow through, the dose doubled. The respective dose profile saw almost equal consistency as it pertains to kVp and dose, even to the ones that didn't had no kVp readings. The exponential aspect shows an increase should more images be taken. Reason for these doses being so high than the other examinations was due to the fact that the detector was able to be placed directly and well within the collimated field [17-20].

The barium swallow examination showed a maximum reading of 70 µGy on the scout image while after a series of 4 images shows an increase of 300 µGy, an increase of about 4 times. The resulting dose profile one dose reading stood out, one without any kVp reading, this measurement can be determined as the scatter leaving the patient and compared to the actual accumulated dose shows a percentage of 3.2% of the total accumulated dose.

The first IVP examination gave a maximum of dose of 118.6 µGy on the scout image while after a series of 5 images the maximum dose increased to 593 µGy, while its lowest was 50.85 µGy, an increase of over 10. Even with most of the measurements being taken just inside and on the periphery of the collimated field yet a dose in excess of 5 times the scout or conventional dose was still achieved. The second IVP examination depicts low doses even when no kVp reading was recorded, since the detector was placed outside of the collimated area so as to not interfere with the image. In the scout image the highest recorded reading was 926.1 µGy while after a series of 8 exposures saw an increase of dose being delivered to as much as 8 times the conventional dose. Any medical doctor/physician would find this very useful in terms of how to get the same diagnostic image without increasing the patient dose. And if (e.g.) a series of 5 examinations is necessary or less [21-24].

Although there was zero kVp recorded in some examinations it did not mean that the examinations were done at zero kVp, the device was just placed outside the collimated area. However the relationship between the kVp and doses across the different examinations would be dependent because of the different tissue densities and therefore the change and variation in doses delivered and recorded on the different examinations.

Comparison of scout doses (conventional) against the repeated series of images in the completed interventional study: The graph shows a significant difference in the barium meal doses compared to the other examinations, however this was so because of the detector position within the field as compared to the position of the detector in the other examinations. Increases by as much as 8 times more than the dose delivered in the scout conventional image was recorded,

immediately signaling the need for optimization, however, this project will serve as a baseline study to be used as references for future project that would be similar in nature for comparison.

Effective doses of individual organs and by examination (organ-dose mapping): The organs of interest in the barium meal and barium swallow examination were organs that have mucous lining (squamous epithelium cells), which are most radiosensitive and therefore of interest in this study. The stomach, esophagus, lung, heart and liver had effective dose readings as follows 0.871 mSv, 0.0085 mSv; 0.0085 mSv (Barium swallow); 0.751 mSv, 0.022 mSv; 0.684 mSv, 0.0089 mSv; 0.275 mSv, 0.0013 mSv respectively. Each of these organs have a tolerance level and these are given by stomach (50-60 Gy), esophagus (57-60 Gy), lung (20-38 Gy), heart (58-61 Gy), and liver (42-46 Gy) [24,25]. Knowing 1 Gy = 1000 mSv, can safely conclude that the interventional series of exposures are well below the tolerance level for all the organs, however, it is the measured patient's accumulated effective dose over time that is one of this study's main objectives and now that can be possible [25].

Looking at the 1st and 2nd intravenous pyelogram examinations, the organs of interest here are the kidneys, bladder, prostate gland, bone (marrow), adrenal glands, small intestines and gonads. Each of which produced the following effective dose readings of 0.032 mSv, 0.025 mSv; 0.024 mSv, 0.3 mSv; 0.0059, 0.0032 mSv; 0.032, 0.89 mSv; 0.032, 0.021 mSv; 0.032, 0.025 mSv; 0.028, 0.6 mSv respectively. The tolerance of the kidney is (41-46 Gy) and since the adrenal glands are accessory to this organ, they would share the same exposure, the bladder (54-64 Gy) and the prostate and gonads are all adjacent to the bladder and share the same exposure and the small intestines (45-50 Gy). All the readings were well below the recommended dose limits, however, there is no telling how many times a patient would need to visit the imaging department, so keeping these figure and tolerance in mind will prove to be very instrumental in tracking any patient's accumulative dose [26].

Limitations of the Research

Scientific graphing software to create 3D surface mesh plot of dose profile

Percentage errors of equipment, human errors and systematic errors

Workload of Institution

Placement of detector as it shows up on the image and thus limiting the researcher in placing it directly in the collimated field with patient present.

Conclusions

The study was able to plot and measure accumulative doses patients received during 4 interventional procedures (barium meal, barium swallow and two intravenous pyelograms). Scout images and doses delivered to those scout images was used as reference for the conventional additional comparison for this study. This showed an increased in doses delivered by as much as 8 times that of a conventional dose, which would see the need for optimization. However, when calculating the effective doses of the organs in these individual examinations they were well below the dose limit, but tracking the patient's doses over time can lead to that exposure level getting closer therefore the method developed in this study to track patient dose can be used as a means to protect patients and as future reference for similar studies and comparison and further establishing and strengthening of the institutionally based Diagnostic Reference Levels (DRLs) [27].

The resultant dose profiles of the four (4) examinations revealed the dose delivery and its spread across the collimated area. This in turn, directly mapped individual organ effective doses, adding up these doses to give the whole body effective dose for the respective examination (barium meal 3.53 mSv; barium swallow – 0.06 mSv; 1st IVP – 0.19 mSv; 2nd IVP – 1.89 mSv).

Recommendations

Include physicians after minimum images are taken and enough information is recorded before proceeding to take additional images.

Gradually decrease electro-technical parameters with the sole aim of reducing patient's doses without interfering with diagnostic image quality.

To be up to date with dose deliverance and optimization techniques, CMEs for the MITs should be planned and conducted at least annually.

Use new protocols established by this baseline study to create own departmental DRLs and for future referencing for similar studies conducted for this particular geographical location thereby aiding in further enhancement of skill and knowledge in this field as it modernizes with the rest of the world.

A dose audit programme should be established in all imaging department delivering standard radiographic exposures at the Georgetown Public Hospital Corporation since this institution see majority of patients on a daily basis

Within the Ray Safe kit are the R/F unit, the portable unit and a survey meter along with detectors for Computed Tomography readings. These will be used for future work.

Future work

Project was conducted using a fluoroscopic unit taking series of static images and can be extended to include Computed Tomography (CTs – HIGH energy and doses) and Mammography (low energy and doses).

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