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 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?
- Are there 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 Y akoumakis, 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 quality and maintain a standard of results generated. As was done in same study by Reena Sharma and associates[10].

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.

<table>
<thead>
<tr>
<th>Company’s Name</th>
<th>Model and Serial #</th>
<th>Manufactured Date</th>
<th>Maximum Tube Output</th>
</tr>
</thead>
<tbody>
<tr>
<td>SIEMENS</td>
<td>03345209 409161572</td>
<td>05 – 2015</td>
<td>150 kVp</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Examination</th>
<th>Kilovoltage Peak (kVp)</th>
<th>Milliamperes Seconds (mAs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Barium Meal</td>
<td>83</td>
<td>25</td>
</tr>
<tr>
<td>Barium Swallow</td>
<td>87.5</td>
<td>28</td>
</tr>
<tr>
<td>Intravenous Pyelogram 1</td>
<td>80</td>
<td>28</td>
</tr>
<tr>
<td>Intravenous Pyelogram 2</td>
<td>70</td>
<td>25</td>
</tr>
</tbody>
</table>

Table 2: Examinations and Parameters (electro-technical factors).
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 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 2: Diagram showing the setup with the sensitive window of the raysafe meter in the collimated area.

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

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

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

Figure 8: Intravenous pyelogram 1. 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 10: Intravenous pyelogram 2. n.b: Dose readings are accumulated not averaged.

Conversions

1 Gray (Gy) = 1000 millisievert (mSv)
1 milligray (mGy) = 1 millisievert (mSv)
1 microgray (µGy) = 0.001 millisievert (mSv)
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.
the dose delivered in the scout conventional image was recorded, in the other examinations. Increases by as much as 8 times more than the other examinations, however this was so because of the detector shows a significant difference in the barium meal doses compared to the other examinations would be dependent because of the different tissue densities and therefore the 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 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 dose of 118.6 µGy on the scout image while after a series of 5 images the maximum dose increased to 393 µGy, while its lowest was 30.85 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, 0.021 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 does 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).

References

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