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Importance of Diagnostic Efficacy and Effective Dose Documentation Computed Tomography Procedures

Barrington Brevitt[1]*, Peter Johnson[2] and Mitko Voutchkov[1]

[1]*Department of Physics, Faculty of Science and Technology, University of the West Indies at Mona, Kingston 7, Jamaica, West Indies*
[2]*Department of Radiology, University Hospital of the West Indies, Kingston 7, Jamaica, West Indies*

Abstract

Objectives: To conduct a comparative analysis of ED delivered during CT examinations of the brain, chest and abdomen in three major Jamaican radiology centres.

Methodology: Retrospective review of CT dose reports for patients referred for CT evaluation of the brain, chest and abdomen in 2016. 180 patients age 30 and under were targeted. This review was conducted with the guidance of a Radiologist.

Results: There were variations of ED among facilities conducting CT examinations of similar anatomic areas ranging from 8.03 mSv to 23.2 mSv. In excess of 50% of the cases reviewed reported normal radiological findings.

Conclusion: There is a need to manage and document ED delivered to patients during CT procedures as ED contributes to increased risk of cancers.

Keywords: Effective dose; Dose length product; Sievert; Gray; Computed Tomography

Introduction

The advent of computed tomography (CT) was attributed to Godfrey Hounsfield and Allan Cormack who were accredited the Nobel Prize in Medicine in 1979. CT generates two-dimensional images displayed as thin axial slices which can be reconstructed to create a three-dimensional volume. Reconstruction of a CT image is done through a process called filtered back projection. Images of internal structures are reconstructed from a series of one-dimensional projection taken at different angles. The signal intensity generated to produce the image is dependent on the tissue coefficient attenuation within each slice. The image is then viewed in a pixilated two-dimensional format with each pixel corresponding to the CT number of the anatomy in that spatial location.

The ionizing radiation employed during CT imaging can result in damage to tissue, increasing the risk of cancer and genetic mutation caused by chromosomal damage. The absorbed dose, measured in Gray (Gy) describes the total radiation energy absorbed per unit mass of tissue. However to achieve a more accurate measure of radiation exposure the effective dose (ED) is considered. This is the sum of doses delivered to each organ in relation to its radio-sensitivity and susceptibility to cancer risk and genetic mutation [1]. Jamaica has seen an increase in the number of CT scanners and subsequently CT examinations over the past two decades. Although CT scans are useful in the diagnostic process the high radiation dose imparted to the patients in most cases is not considered. In comparison to conventional radiography, CT is a high-dose imaging modality; with increased risk for radiation-induced cancers or other radiation-induced genetic mutations, which is best quantified by the calculated ED [2].

Studies have proven that the scan length has a direct influence on the ED, depending on the z-axis position of the x-ray beam during scanning [2,3]. For narrow scans on the order of 2 cm, variations in the anatomic location can result in differences in ED of up to a factor of 30. These variations in patient ED are directly related to the locations of radiosensitive organs and tissues, which are predominantly located in areas of the body frequently, investigated using CT scanning [2]. It is therefore important for physicians to keep a record of the dose delivered to patients during diagnostic procedures, and refer to these dose records before requesting additional radiation-based procedures especially for patients requiring multiple scans or repeated scans prior or subsequent to treatment.

The dose report generated by the CT scanner at the end of an examination can be analyzed to ascertain the Computed Tomography Dose Index Volume ($CTDI_{vol}$). The $CTDI_{vol}$ is a volume-averaged measure that is used in situations where the table is incremented in conjunction with the tube rotation. CTDI represents an averaged dose to a homogeneous cylindrical phantom; the measurements are only an approximation of the patient dose [1]. The product of the $CTDI_{vol}$ and the scan length yields a Dose Length Product (DLP). A conversion factor (K) developed by the American Association of Physicist in Medicine (AAPM) can used to calculate the ED. This K factor takes into account the region of the body irradiated and also the patients' age [3].

Methods and Measurements

Ethical approval was sought and granted from the Ethic Review Committee of The University of the West Indies, Mona campus to conduct a retrospective clinical review. An analysis of patients' radiological report was conducted in consultation with a consultant radiologist who possess over 10 years of experience in said field. Patients up to age 30, who were sent to the radiology department for CT imaging, were targeted. This age range was selected due to longer life expectancy; therefore, the possibility for the delayed manifestation of radiation-induced illness is more likely. Parameters such as; the patients' age, sex, type of examination done,

***Corresponding author:** Mr. Barrington Brevitt, Department of Physics, Faculty of Science and Technology, University of the West Indies at Mona, Kingston 7, Jamaica, West Indies, E-mail: physics@uwimona.edu.jm

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$CTDI_{vol}$ and DLP were recorded. These parameters were extrapolated from the dose report which was automatically generated and stored as part of each CT examination. The actual radiological findings were not documented or any other pertinent patient information. This review was done in 3 facilities; a type "A" public hospital and 2 large private facilities. The main cohort (180 individuals) was randomly selected (60 at each facility), of a population indiscriminately chosen from patients who were sent to the radiology department in 2016 for CT scans of the brain, chest or abdomen. A sample size of 60 was chosen at each facility using the formula $\{n= (z\alpha/2)^2 \sigma^2/ E^2\}$ where n is sample size, $z\alpha/2$ is the significance level, σ is the standard deviation with E the margin of error.

Inclusion criteria

- All patients under age 30 sent for CT scans of head, chest and abdomen.
- All patients under age 30 who did CT scans of the head, chest and abdomen with dose report affixed to scan data.

Exclusion criteria

- Patients sent to the department over age 30.
- Patient doing CT scans of the head, chest and abdomen with no dose report affixed to scan data.
- Patients doing CT scans outside selected facilities.

The following equations were used to determine the ED:

- DLP (mGy/cm) = SCAN LENGHT (cm) *CTDI (mGy)
- ED (mSv) = DLP (mGy/cm) *K ($mSv\ mGy^{-1}\ cm^{-1}$)

The data obtained was used to determine the mean ED of the anatomy under investigation along with the mean dose at each facility. The radiologist also indicated if the radiological findings were normal or anomalous. This information was used to determine the diagnostic efficacy weighing the risks posed to these patients versus the benefits of the examination. Statistical analysis was done using a two-part ANOVA statistical test without replication. This test compared the mean ED and age at each facility in relation to the three anatomical regions of interest. The degree of variance in ED and age within and between facilities was assessed at a 95% level of accuracy.

Results

Of the 180 examinations reviewed 67 were males and 113 were females. These accounted for 37% and 63% of the cohort respectively as depicted in Figure 1. The mean age across all three facilities was also tabulated with facility one having a mean age of 20.1 that at facility two was 21.3; while facility three had a mean age 22 as shown in Figure 2. Comparison was also done between the mean ages of persons undergoing each procedure. The mean age for persons who had examinations of the chest was 20.03, abdominal scans accounted for a mean age of 21.03 with brain studies accounting for a mean age of 18.4 as illustrated in Figure 3. The average ED per procedure was also compared across all facilities. The mean ED for CT brain was the lowest, facility one had a mean ED of 16.3, the mean ED of facility two was 19.5 and facility three had an average of 19.3. The mean ED for chest examinations was 24.3 for facility one, 23.6 for facility two and 24.2 for facility three. Chest examinations accounted for the highest ED among the cohort. The mean ED for abdominal CT ranged from 19.7 for facility one to 22.5 for facility three. Facility two had a mean ED of 20.9 this is represented by Figure 4. Facility one had an average ED

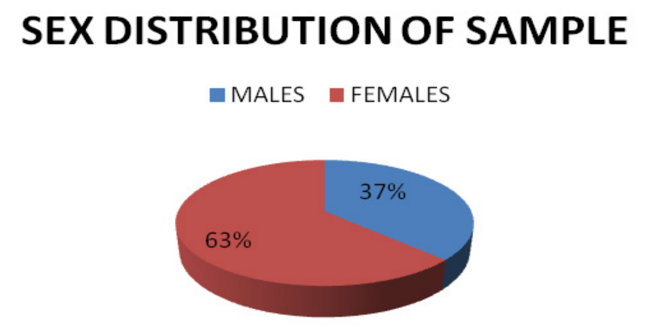

Figure 1: Depicting the sex distribution among the cohort.

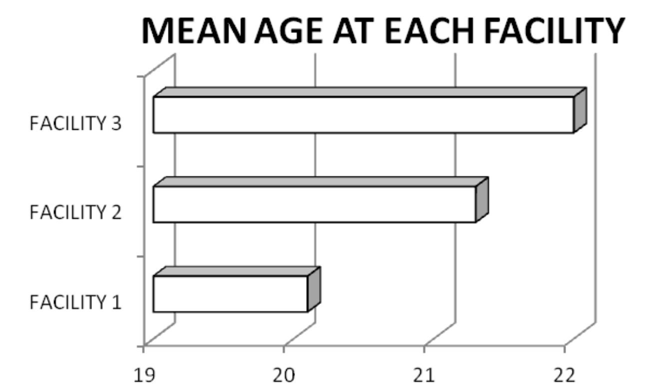

Figure 2: Illustrating mean age distribution at each facility.

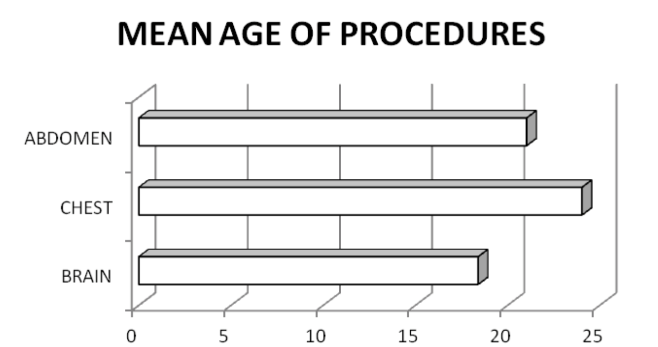

Figure 3: Three illustrating the mean age of persons per procedure.

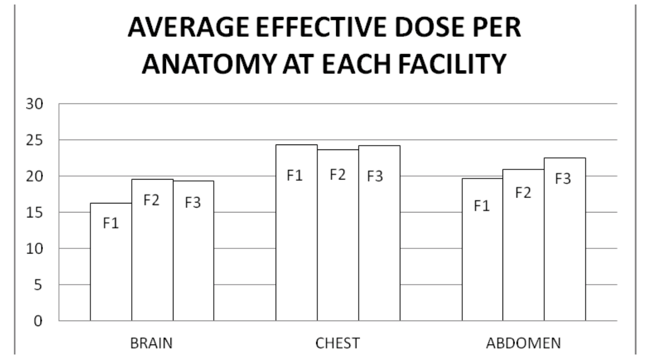

Figure 4: Illustrating the average effective dose per anatomy at each facility.

of 23.2 mSv, facility two averaged 8.03 mSv and facility three had an average of 25.5 mSv, as shown in Figure 5. The average ED delivered during the examination of the brain across all facilities was 5.2 mSv, chest exams had an ED of 16.3 mSv and abdomen an average of 35.3 mSv as illustrated in Figure 6. Sixty two percent of the reports under review at facility one reported normal radiological findings, with 38% yielding some abnormal results. This trend was also evident in facility two and three yielding findings of 58% and 60% respectively being normal and 42% and 40% respectively being not normal. Overall 59% of the procedures reviewed returned normal radiological findings with only 41% reporting incidence of abnormality as depicted in Figure 7.

The ANOVA test was conducted at the 0.05 significance level. The degree of freedom was 2 for the analysis of dose across facilities and the average standard deviation was 15.24. A critical value of 0.019 was obtained for ED in relation to each body part and a critical value of 0.086 was obtained for variations in ED across facilities. This trend was also evident when ages were compared. A degree of freedom of 2 was also obtained with an average standard deviation of 2.86. Critical values of 0.009 and 0.227 were obtained for ages across and within the facilities respectively.

Synopsis

The ionizing radiation employed during computed tomography (CT) imaging can result in damage to tissue, increasing the risk of cancer and genetic mutation caused by chromosomal damage. The absorbed dose, measured in Gray (Gy) describes the total radiation energy absorbed per unit mass of tissue. However to achieve a more accurate measure of radiation exposure the effective dose (ED) is considered. This paper seeks to evaluate effective dose in Jamaican radiology centres in accordance with international standards and offer recommendations where necessary.

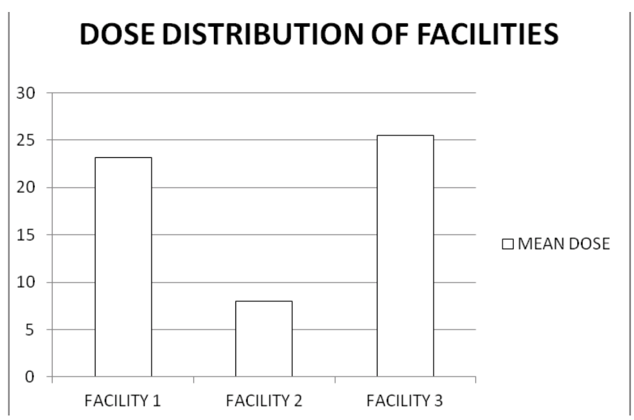

Figure 5: Showing the mean dose distribution at each facility.

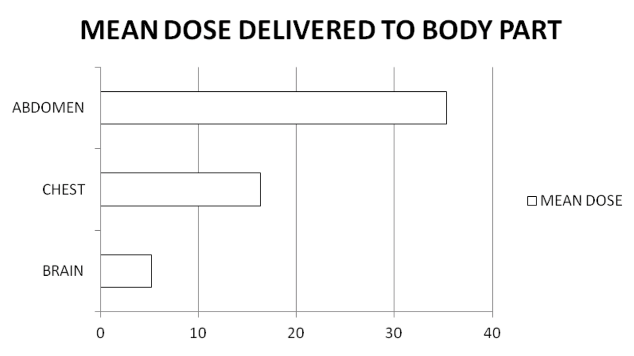

Figure 6: Showing the mean ED delivered to each body part.

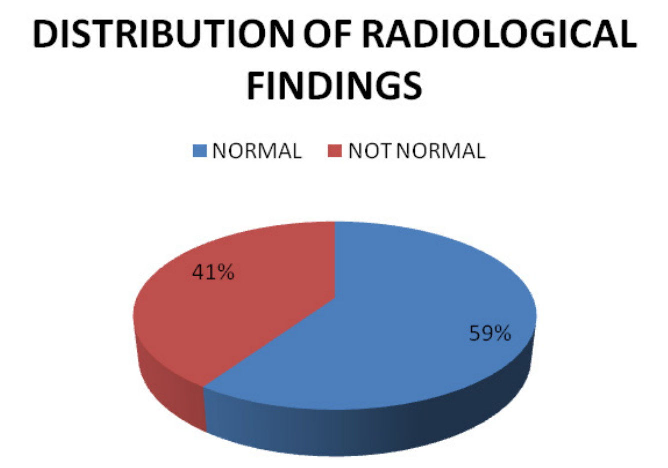

Figure 7: Depicting the incidence of normal vs. not normal radiological findings.

Discussion

The sample size selected for retrospective review consisted of 180 CT procedures 37% of which was accounted for by males and 63% accounted for by females. The target group ranged from ages 0-30 years. The mean age at facility one was 20.1 years that at facility two was 21.5 years while facility three had a mean age of 22 years. The age distribution among procedures varied within each facility. The average age of persons doing CT brain at facility one was 16.3 years, CT abdomen 19.7 years and CT chest 24.3 years. Facility two had averages of 19.5, 23.6, and 20.9 years for examinations of the brain, chest and abdomen respectively. Facility three also showed variations with age. The average age of persons doing CT brain here was 19.3 years, with chest and abdomen accounting for 24.2 and 22.5 years respectively. The mean age for CT brain among all facilities was 18.4 years; chest had an average of 24 years with abdomen averaging 21 years.

The ED delivered to a patient during a CT examination is dependent on a number of factors. These include; the anatomy under investigation, body habitus of the patient, the examination protocol being employed, the scan method used, scan speed, type of scanner and scan length etc. These parameters are considered when technical factors of kVp, mAs, pitch and scan time are selected. Technical factors subsequently determine the $CTDI_{vol}$ and DLP which are used to calculate the ED of the procedure. ED/DLP values vary with x-ray tube voltage for body CT examinations. Increasing kVp generally increases the ED/DLP values; an increase in the x-ray tube voltage from 80 to 140 kV increases the average ED/DLP coefficient for body scans by approximately 25% [2].

There was marked ED variation among procedures across all 3 facilities. Facility two had the lowest ED average of 8.03 mSv, facility three accounted for the highest with 25.5 mSv. Facility one had an average ED of 23.2 mSv. Similar dose distribution trends were identified in all facilities. CT brain accounted for the lowest ED with an average of 5.2 mSv. Abdominal scans accounted for the highest ED average in all facilities, averaging 35.3 mSv, while CT procedures of the chest averaged 16.3 mSv. The scan protocol employed by a reporting radiologist has a high influence on the effective dose delivered during a CT examination.

At facility one the average effective dose for CT brain was 6 mSv, facility two had an average of 1.7 mSv, with facility three averaging 7.9 mSv. This trend was also evident with chest and abdominal procedures with mean doses of 18.9 mSv, 7.5 mSv, and 22.4 mSv for CT chest and doses of 44.7 mSv, 14.9 mSv and 46.3 mSv for abdominal CT at facility one, facility two and facility three respectively. Further checks revealed that on average fewer scans were done per protocol at facility two. This was in dissimilarity to facility three which conducted more scans within specific examination protocols. All facilities had multi-detector (MD) CT scanners, however, the pitch and scan time of these machines varied. Facility two and three had 16 slice MD scanners. Typical ED from a single full-body CT examination is about 16 mSv to the lung, 14 mSv to the digestive organs, and 10 mSv to the bone marrow. For example, if an ED of about 12 mSv is obtained from a CT procedure and 10 such examinations were undertaken in a lifetime, the effective dose would be about 120 mSv, which is 10 times higher than that for a single procedure [4].

As outlined by Ogden [3] the information yielded in this study allow radiologic technologists to convert the $CTDI_{vol}$ and DLP generated by the CT scanner into an ED which can be affixed to the patients' radiological report. The data also permit radiology staff to compare patient's ED received from CT procedures to other x-ray based modalities or with base line values such as; radiation dose limits and background radiation. Whenever patients are referred for medical procedures the referring and attending physicians must evaluate all possible outcomes of the procedure weighing the benefits and the risks. Diagnostic efficacy is an important parameter to be considered before patients are referred for radiation-based diagnostic or therapeutic procedures. Questions to be asked include but not limited to:

- How will this procedure aid in the diagnosis of the patient?
- Will it affect the prognosis of the patient?
- What are possible risks?
- Is there another way to achieve the desired outcome?

During the review, it was discovered that a larger percentage of scans yielded normal radiological findings. Fifty-nine percent (59%) of the 180 procedures reviewed reported normal findings. This tendency was identified in all three facilities where in excess of 50% of procedures reviewed reported normal findings. Only 41% of such procedures indicated any form of abnormality. It is therefore important to manage and document the ED delivered to the patients during CT examinations. Atomic bombs, with radiation dose ranging from 5 to 100 mSv show a statistically significant increase in solid cancer risk, survivors who were exposed to a dose of 5-50 mSv also displayed an associated increased cancer mortality risk [4-7].

Conclusion and Recommendations

It can be concluded that the incidence of CT brain among persons less than 18 years is highest when compared to other procedures. It can also be confirmed that facility one had the youngest age distribution of approximately 20.1 years with facility two accounting for the highest with approximately 22 years. There was statistical evidence of a significant difference of ED for the body parts under investigation. However, a critical value of 0.086 provides evidence that there was no statistically significant difference of ED across facilities. [8-11]

It is recommended that ED delivered to patients during CT examinations be managed and documented as accumulated radiation exposure increases the risks of cancers and other genetic anomalies.

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Author's Contributions

Barrington Brevitt envisaged paper, conducted data collection and analysis, prepared manuscript and approved the final version for submission. Dr Peter Johnson and Professor Mitko Voutchkov participated in data analysis and interpretation, study design and revision of manuscript and approval of final version. The authors declare that there is no conflict of interest.

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