Radiation Doses in Computed Tomography: Need for Optimization and Application of Dose Reference Levels in Nigeria

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ABSTRACT

Background: Establishment and use of "diagnostic reference levels" (DRLs) is essential for proper use and audit of ionizing radiation in medicine and other radiation applications. Nigeria does not yet have a guideline for DRL. The European Commission reference dose levels were applied to routine computed tomography (CT) examinations in Nigeria's major hospitals. **Aim:** To determine the dose of CT examinations at the University College Hospital, Ibadan, Nigeria and provide a template for dose optimization. **Materials and Methods:** Data were obtained from a GE Brightspeed multidetector CT scanner. The dose characteristics and estimates were derived from computed tomography dose index ($CTDI_{vol}$), and dose length product (DLP) with the effective dose (E) calculated using software developed by ImPACTscan group with the National Radiological Protection Board–S250 conversion coefficients data for a random sampling of 1 per 10 typical CT patients. **Results:** The mean values of $CTDI_{vol}$ in mGy were 73.5 ± 4.2 (head), 22.7 ± 6.7 (chest), 37.9 ± 5.6 (abdomen), 28.2 ± 8.3 (abdomen-pelvis), 41.4 ± 13.2 (cervical spine), and 40.1 ± 4.2 (lumbar spine) examinations. The corresponding mean values of DLP in mGy.cm were 1898, 1189, 1902, 2548, 1372, and 1563, respectively. The calculated E values in mSv for the above examinations were 2.8, 11.8, 22.5, 39.6, 4.6, and 29.0, respectively. All values consistently exceeded recommended ECRDLs except the $CTDI_{vol}$ for chest, cervical, and abdomen-pelvis examinations. **Conclusion:** CT doses were higher than EC recommended guidelines necessitating a need for optimization of CT practice and the requirement for a CT dose survey in Nigeria.

Key words: Computed tomography; computed tomography dose index; dose length product; effective dose

Introduction

Computed tomography (CT) examinations typically deliver relatively higher radiation doses than any other diagnostic procedure; in spite of this, it has become more readily available in Nigeria owing to the better diagnostic information obtained. In Europe, diagnostic radiology represents the largest man-made contribution to population doses.[1,2] This observation may not be different in developing countries like Nigeria with growing demands in CT applications. Radiation dose in CT procedures can be estimated using several methods.[3-7] The European Commission (EC) specifies criteria for patient dose for CT examinations and gives examples of good imaging techniques. The dose that the patient receives in a CT examination is determined by two aspects of the particular scanner – the radiation output characteristics of the scanner and the clinical protocol of how the scanner is used in performing the examination.[8] The European Guidelines (EG) on quality criteria for CT[8] were published by the EC, in which two dose descriptors, computed tomography dose index ($CTDI_{vol}$) and dose-length product (DLP), were proposed as reference dose levels (RDLs) for optimizing patient exposure. The DLP is directly related to the stochastic risk of the patient and may be used to set reference values for a given type of CT examination to help ensure that patient doses follow the as low as reasonably achievable principles.[9] Comparison of both $CTDI_{vol}$ and DLP values for a specific examination using different protocols or scanners will provide information on their relative performance and compliance with set guidelines. A summary of the proposed RDLs is presented in Table 1.

Effective dose (E) is a descriptor that can be used to characterize radiation exposure of patients in CT.[10,11]

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It correlates reasonably well with radiation risk. The computation of effective dose necessitates the knowledge of the absorbed dose to all irradiated organs and tissues, which may be obtained by means of Monte Carlo computational techniques. The organ dose can also be experimentally determined by using anthropomorphic phantoms such as Rando phantom and thermoluminescent dosimeters. Shrimpton *et al*.,[11,12] calculated E from CTDI measurements using Monte Carlo conversion coefficients.

In developed countries, the information on the frequency of CT procedures, patient dose levels in CT practices, and optimization strategies are well-known. However, similar information is not readily available in majority of developing countries. In African countries, CT dose reports are infrequent and where available, comparatively higher CT doses are reported for various examinations. These findings demonstrate a need to establish regular CT dose surveys to ensure good and safe radiation practice.[13-15]

To our knowledge, there is a dearth of reports in the West African subregion on the survey of patient dosimetry in CT. To the best of our knowledge, there is also no evidence in literature of a CT dose survey in Nigeria. Medical radiation practitioners have no local or national guideline for reference to ensure safe practice. This is in spite of the fact that the use of CT in medical practice in Nigeria dates back to more than 3 decades. Also, CT applications have been constantly increasing locally and worldwide.[16,17] The aim of this study was to investigate and determine the radiation doses for some routine CT examinations in the University College Hospital (UCH), Ibadan and compare the values with the EC reference dose levels which have been in use for over a decade and are internationally recognized.

Materials and Methods

Data acquisition

A total of 100 adult patients were selected using a simple random sampling technique of body regional cases from a list of 899 eligible patients who had been referred for clinically indicated routine head, cervical, chest, abdomen, abdomen/pelvis, and lumbar CT examinations at the department of Radiology of UCH, Ibadan, Oyo State, over a 3-month period. During the period of this study, available records showed that only this hospital had a functional CT scanner in this state with a population of over 5 million people. Brain (head) CT constituted over 50%of the studies selected; therefore, 50 CT brain patients were selected for this study. The remaining examination types had 10 each, bringing the total to a hundred. The mean patient age was 46.1 ± 17.2 years (range: 17-101 years). All studies were performed by radiographers using the hospital routine CT protocols. The examinations were categorized as follows: (1) Brain (head); (2) chest; (3) abdomen; (4) abdomen/pelvis; (5) cervical spine; and (6) lumbar spine. The following parameters were collected for each examination type: Use of contrast; patient age; scan length; slice width; X-ray tube voltage (kVp); tube current-exposure time product (mAs); and pitch.

Table 1: Proposed European commission reference dose levels for routine computed tomography examinations on the basis of absorbed dose in air[11]

Examination	$CTDI_{vol}$ (mGy)	DLP (mGy_{air} cm)
Head	60	1050
Chest	30	650
Abdomen	35	780
Pelvis	35	570

CTDIvol – Computed tomography dose index; DLP – Dose length product

CT dose determination

The dose characteristics of the GE Brightspeed S multidetector scanner (General Electric Medical systems Milwaukee, USA) were determined using the *ImPACTscan* CT dosimetry software (version 1.0.2).[18] The E-value of previously examined patients was estimated using the software developed by the *ImPACTscan* group, a free downloadable software from http://www.impactscan.org/ctdosimetry.htm which makes use of the National Radiological Protection Board (NRPB–S250) Monte Carlo dose data sets to determine results.[11,18,19] The software was used to estimate E for all the examinations reported in this study.

The software also provides automatic calculation of CTDI and DLP values when a specific scanner model, scanner manufacturer, and scanning technique are logged in as input. For each examination, $CTDI_{vol}$ for the patient and DLP for a complete examination were displayed by the scanner. The software is able to give E by using the conversion coefficients established by NRPB based on the recommendations of the International Commission on Radiological Protection. Typical uncertainty in calculating CTDI is <10% while that of calculating E varies between 10% and 20%. From each $CTDI_{vol}$ value obtained, the corresponding E was automatically calculated by the NRPB-S250 software.

Details of exposure, parameters used, such as kVp, mAs, and scan length are presented in Table 2. The conventional sequential scan mode was used for routine brain (head) examinations, while helical scan mode was used for abdomen, cervical, chest, and lumbar studies. All routine brain (head) scans were achieved with a slice thickness of 2.5 mm/3 mm at the base of skull and 7 mm/8 mm through the rest of the brain. The scan length for all examinations depended on patient's size. The helical pitch ranged from 0.75 to 1.35 for chest, abdomen, abdomen/pelvis, cervical, and lumbar spine.

Results

The estimated mean $CTDI_{vol}$, DLP, and effective dose (E) of various examination type and body region obtained are given in Table 3. The ranges of dose equivalents were 22.7 ± 6.7 to 73.5 ± 4.2 mGy for $CTDI_{vol}$, 1189 to 2548 mGy cm for DLP and 2.8 ± 0.5 to 39.6 ± 15.4 mSv for E.

$CTDI_{vol}$ values of each examination protocol investigated exceeded the EC RDLs except for chest, cervical, and abdomen/pelvis examinations. Figure 1 depicts the comparison of mean $CTDI_{vol}$ values for UCH, Ibadan with EC RDL. DLP and E values were also found to exceed those proposed by the EC guidelines for all the examinations reported in this study. The DLP values exceeded the EC RDL values which ranged from 30% for cervical to 226% for abdominal/pelvis CT. Figure 2 shows the mean values for DLP compared with the EC RDLs. The values of E obtained in this study were also compared with EC and data reported in other studies to give a proper perspective of the comparative doses. This is depicted in Figure 3.

Discussion

Virtually, all the CT dose values obtained in this study were higher than the typical values recorded in the UK, British Columbia, and those published by EC. The highest $CTDI_{vol}$ values obtained in this series were from head and cervical spine examinations, which suggest that the protocol parameters such as KVp and mAs were essentially higher than the reported studies, especially the tube current which showed significant variation and which is likely to be adjusted by the operator to improve image quality. The use of a higher 140 kVp tube voltage for lumbar spine studies may also result in up to 25% increase in dose.[20] The DLP values which result from CTDIs appear to be higher than the values reported by EC up by a factor of 3.3 considering the maximum DLP for abdomen/pelvis in this study. The lowest mean value of E (2.8 mSv) for head CT is understandable in view of the lower radiosensitivity of organs in the head when compared with the highest mean E value (39.6 mSv) for abdomen/pelvis CT examination.

A comparison of the mean effective doses of this study with that published from other countries including countries like Tanzania with near or similar patient parameters as Nigeria shows relative higher values for Nigeria, especially in the abdominal/pelvis and lumbar spine regions. The values for cervical spine were not available from these studies for a direct comparison but the head and neck (cervical spine) are sometimes considered to be one region and the values may, therefore, be extrapolated to be similar to that of the head. If this assumption is made, then the cervical spine values may be regarded as normal. Also, in the context of the presence of the highly radiosensitive thyroid gland in the neck these E values may be within acceptable range of normal for the cervical region.[21]

The large irradiation volume or length of scan area may be an important contributory factor to the higher dose values recorded, as few of the $CTDI_{vol}$ values which are used to determine the DLP and ultimately patient dose appear to be within range of EC RDLs recommendations. Reducing the scan length as much as possible, without missing any vital anatomical regions essential for diagnosis, could be a first step to lowering DLP and subsequently the E values. Furthermore, there is a need to optimize all protocols bearing in mind patient's weight and size. Reducing mAs used for the examination protocol is important, especially for patients who are smaller than the standard sized patient. However, dose reduction techniques that are employed must not sacrifice image quality which is essential for diagnosis. Weight measurements are not routinely obtained before a scan at our center, which is critical for dose optimization and modulation. On the contrary, a previous study showed that changes in the patient weight did not significantly affect the dose calculations.[1]

The most commonly cited RDLs for CT are from surveys in the UK adopted by the European Union and by the American College of Radiology CT accreditation program.[22-24] When the radiation doses estimated in this study were compared with those published in UK surveys and other African countries it was observed that our values were consistently higher in all

Table 2: Mean computed tomography scanning parameters at University College Hospital, Ibadan

Study	Tube voltage (kVp)	Current-time product* (mAs)	Scan length (cm)*
Brain	120	188.2±27.1	12.7±1.4
Chest	120	205.0±57.4	18.6±3.7
Abdomen	120	109.0±16.2	37.9±1.9
Abdomen-pelvis	120	218.7±72.5	35.1±8.1
Cervical spine	140	153.8±48.0	20.3±3.7
Lumbar spine	140	251.7±22.5	27.0±1.3

*± standard deviation

Table 3: Mean computed tomography doses obtained at University College Hospital compared with european commission values for the studied procedures

Examination	$CTDI_{vol}$	% above EC value	DLP	% above EC value	E
Head	73.5±4.2	22.5	1898±375	80.7	2.8±0.5
Chest	22.7±6.7	Below EC value	1189±266	82.9	11.8±3.8
Cervical*	41.4±13.2	Below EC value	1372±584	30.6	4.6±1.3
Abdomen	37.9±5.6	8.3	1902±979	143.8	22.5±3.1
Abdomen/pelvis	28.2±8.3	Below EC value	2548±827	226	39.6±15.4
Lumbar*	40.1±4.2	14.6	1563±356	174.2	29±4.6

*The european commission reference table did not provide values for cervical and lumbar spine. Therefore, we used the values for head and abdomen for the cervical and lumbar regions respectively to account for this gap considering this are in similar regions of exposure. $CTDI_{vol}$ – Computed tomography dose index; DLP – Dose length product; EC – European commission examinations. The relatively low values in UK institutions may be the result of strict adherence to the guidelines by the EC.

This hospital evaluation study which demonstrate unacceptably higher CT dose values above the EG dose criteria, creates an opportunity for an audit of the system and for other similar hospitals in this region to review their protocols to ensure safer radiological services; in order to operate within the limits of international best practice. There is the need to define acceptable DRLs for our institution which should be communicated to all users. CT practices should be monitored at regular intervals to constantly ensure optimization of procedures for better patient safety and compliance to international standards. Furthermore, all examination protocols performed at CT centers in Nigeria should be investigated in terms of technique and radiation dose with a view to compare them with the EC RDLs, since this has been established as a standard and may act as a useful tool in assessing CT performance. This practice is essential to minimize

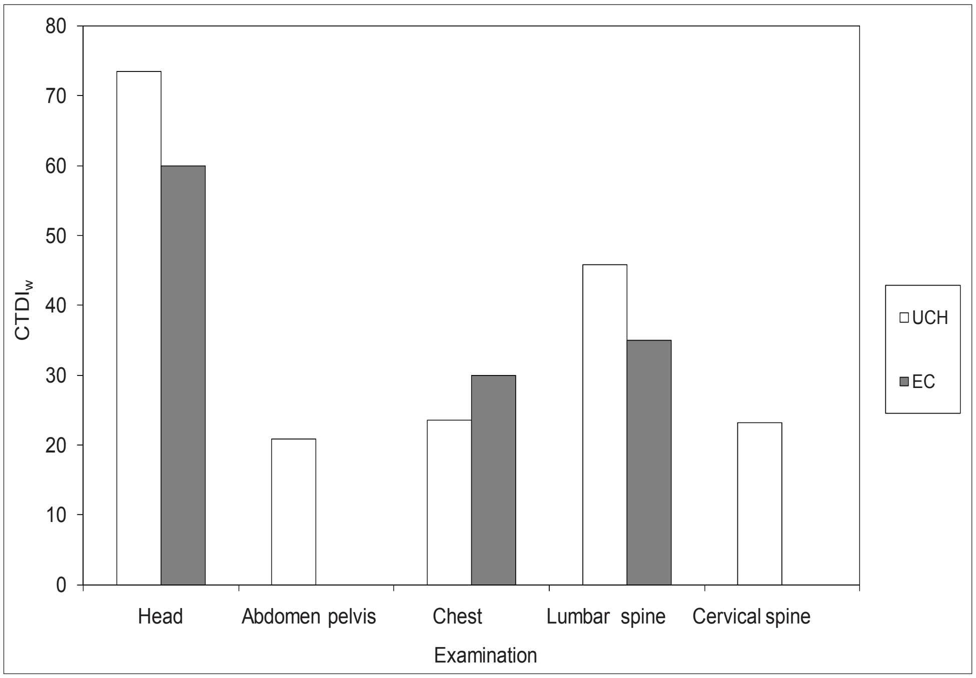

Figure 1: Comparison of mean computed tomography dose index (mGy) in University College Hospital with European commission reference dose levels. UCH-University college hospital, EC-European commission

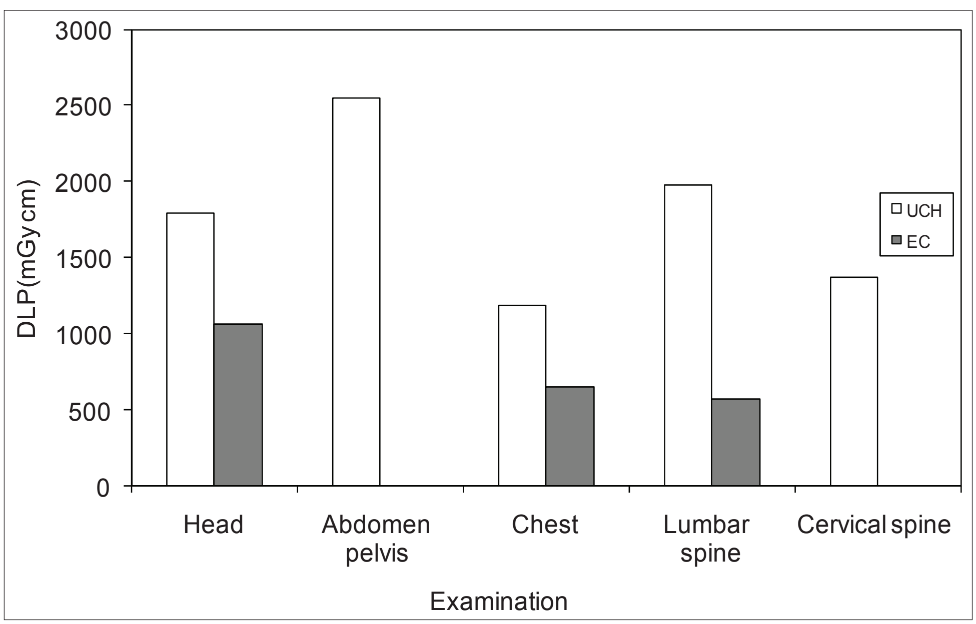

Figure 2: Comparison of mean dose length product (mGy cm) in University College Hospital with European Commission reference dose levels, UCH-University college hospital, EC-European commission

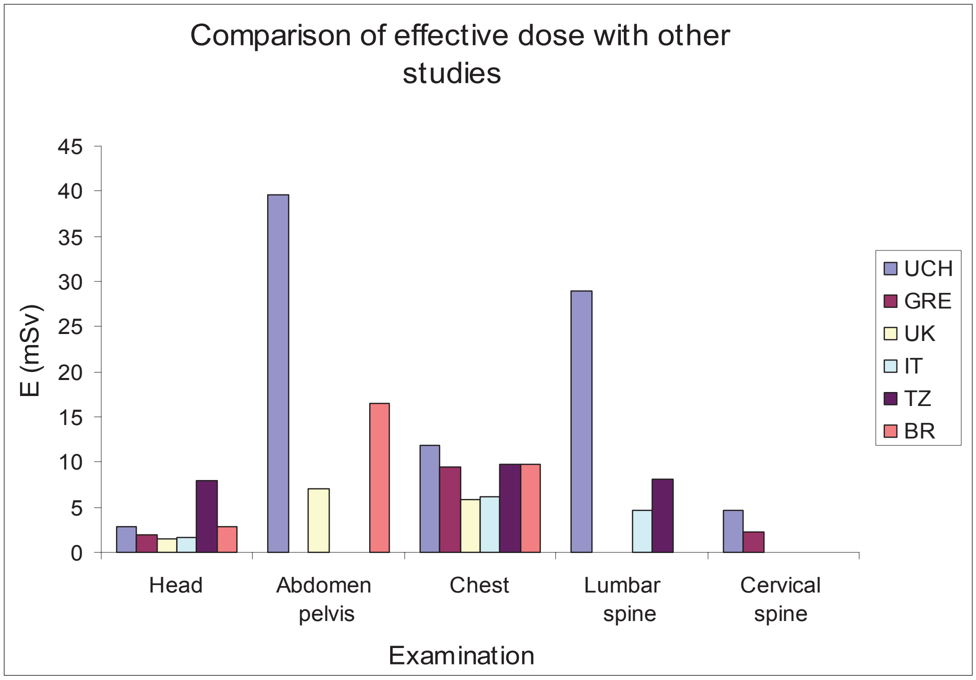

Figure 3: Comparison of the mean effective dose E (mSv) in University College Hospital with literature reports from other countries. UCH-University College Hospital, EC-European commission, BC-British Colombia, UK-United Kingdom, TZ-Tanzania

radiation risks from medical exposure in a developing country like Nigeria.

One of the limitations of our study is the lack of weight measurements in the examinations evaluated. Understandably, the possible differences in the body mass index (BMI) of our patients as compared with Europeans on whom the EC figures were based may be a compounding variable in our comparative analysis. However, available data suggest that the BMI of Nigerians is not significantly different from that of the British.[25] It is our intention, however, to carry out a prospective study, to evaluate more accurately the real doses our patients receive using more complete patient data and employing appropriate dosimeters.

Our future work would also involve comparisons of the calculated values with experimental values using standard head (16 cm diameter) and body (32 cm diameter) phantoms (Lucite) with a pencil chamber/electrometer system determining the CTDI values for all scan techniques. We also propose the utilization of tissue equivalent thermoluminescent dosimeters embedded in an anthropomorphic (e.g. Rando phantom) to determine the actual organ doses. These proposed studies hopefully will pave the way for making our hospital a local or even national reference center.

Conclusion

The estimated doses obtained for our CT examinations were higher than the reference values of the EC and those reported in the literature. The optimization of CT practice in Nigerian hospitals is essential. A CT dose survey for hospitals in Nigeria is, therefore, proposed. It is anticipated that such exercise would promote CT surveys in other developing countries as well and encourage the development and review of national DRLs and local CT protocol guidelines based on international standards.

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