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Establishment of Computed Tomography Diagnostic Reference Levels in Tobruk

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Abstract

Introduction: CT examinations are the cause of 40% of the collective dose resulting from medical exposure in the UK. The use of CT in the UK and worldwide is still increasing, so it is likely that the contribution to collective dose will rise even further in the next few years. It became clear that the responsible use of CT requires the optimisation of exposure factors. In response, the radiology community has worked to implement as low as reasonably practicable principles in CT imaging.

Objective: The aim of this study was to determine the diagnostic reference levels (DRLs) of the six most frequent CT-scans examinations of adults in Tobruk.

Material and Method: CT dose data of 171 patients was collected from November 2017 to February 2018 in adult patients in Tobruk Medical Center' scanner. The mean Dose Length Product (DLP), standard deviation, range, median, standard error of the mean, and the 75th ercentile of dose spread were calculated and analysed using SPSS software version 23.0. The common CT examinations such Routine Head, Chest CT without contrast, Chest, Abdomen, pelvis (CAP), Kidneys, Ureters, Bladder (KUB), Abdomen and pelvis with contrast, Abdomen with contrast were reviewed. The DRL for each type of examination was defined as the 75th percentile of its DLP.

Results: Out of the 171 examinations, 33.3% were head, 15.2% chest, 23.4% CAP, 11.1% KUB, 10% Abdomen/pelvis and 7% abdomen. Examinations were nearly comparable with male and female patients, and 38% were in patients between 19 and 40 years of age. The 75th percentile of DLP or DRLs was: (1999.2 mGycm), (2284.9 mGycm), (3116.8 mGycm), (3527.3 mGycm), (2840.1 mGycm), and (2754.3 mGycm), respectively for Routine Head, Chest CT without contrast, Chest, Abdomen, pelvis (CAP), Kidneys, Ureters, Bladder (KUB), Abdomen and pelvis with contrast, Abdomen with contrast.

Conclusion: Our DRLs values were extremely high in almost all CT examinations comparing with Diagnostic Reference Levels (DRLs) derived from UK, Canada, Ireland, and Japan. There is remarkable variation in dose for the commonest CT-scans examinations in Tobruk, requiring then an optimization process from these determined DRLs and establishment of national DRLs.

Keywords: CT dose index; Diagnostic reference level; Dose-length product; Effective dose

Introduction

Since the introduction of the multi-slices CT, the speed and the quality of the resulting images of CT scanning have dramatically increased [1]. Consequently, the clinical utility has significantly increased in our practice not only in diagnosis, but also in therapy, and management of patient care [2,3]. However, with this increases in CT utilization, the concern about radiation hazards from CT also increases [4].

In fact, the global average annual percentage effective dose from medical procedures has nearly doubled in the past 10-15 years [5]. In United States, the total radiation doses from CT were more than seven times as much ionizing radiation from medical procedures in 2006 than in the early 1980s [6]. Although CT scans represented only 12% of imaging procedures, they contributed almost 50% of the total radiation dose to the U.S [1]. In United Kingdom, CT scans represented only 5% of all radiology examinations, but contributed to 40% of annual collective dose in the population in 1999 compared to 20% in 1990 [7]. In the end of 2000s, CT scans accounted for 10%-25% of X-ray based medical procedures, but contributed to 50% of the annual collective dose [8].

This increase in population radiation dose is of concern because of the potential for radiation-induced malignancies [9]. Consequently, sensible use of the CT modality requires strict adherence to the principles of radiation protection-justification and optimisation. Justification is the fundamental principle of radiation protection, under which no practice should be undertaken unless it produces a sufficient benefit to exposed individuals in order to offset the radiation harm that may cause [10,11]. Optimisation, once the CT examination has been justified, the other responsibility is ensuring that the examination is performed effectively, conscientiously, and with good technique. The protection and safety will be optimised to ensure that

the magnitude of individual doses and the number of people exposed are kept as low as reasonably practicable (ALARP) [12,13].

An important optimization tool is Diagnostic Reference Levels (DRLs) [14], the International Commission on Radiological Protection (ICRP) introduced the DRLs in 1990 and clarified with further detail in 1996 in publication 73 [15,16]. The use of DRLs is endorsed by many professional and regulatory organizations such as American College of Radiology (ACR), United Kingdom (U.K.) Health Protection Agency, and European Commission (EC) [17].

DRLs are defined as dose levels for typical medical radio diagnostic examinations for groups of standard sized patients for broadly defined types of equipment in a country or in a region" [18]. Such levels allow the identification of abnormally high dose levels by setting an upper threshold -75th percentile of the dose distribution from an audit conducted across a broad user base, which standard dose levels should not exceed when good practice is applied [19]. Due to the fact that, equipment and protocols can vary between different hospitals in countries or regions, it is a good practice to establish region diagnostic reference levels in Tobruk to ensure restriction of the doses to individuals [20].

The purpose of this study was to investigate the current radiation doses for most common adult CT examinations within Tobruk Medical Centre and, based on this data, propose national diagnostic reference levels for the most common CT examinations using two primary dosimetry metrics Volume Computed Tomography Dose Index (CTDIvol) and Dose Length Product (DLP).

Materials and Methods

Study design and period

The study was performed on 16-slices CT scanners (TOSHIBA-CXXG-010A Activion) in Tobruk Medical Center in Tobruk city. This is including collecting CT parameters for various time periods between November 2017 and February 2018 in adult patients (age>16 years).

CT dose quantities

The dosimetric quantities recorded were DLP and CTDIvol. Currently, most of CT scanners have built in dose information software, which allows both these parameters to be displayed on the control console. Due to their ease of collection, they were the main parameters selected for this audit. Scanner site was asked to record the following parameters from the CT console for each patient: Peak tube potential, tube current, number of scan phases, CTDIvol and DLP. Further details of the standard CT protocol for each examination were recorded once for each examination; these included the beam collimation, scan field of view, tube rotation time, scan length, pitch and imaged slice thickness and reconstruction algorithms used.

CTDIvol represents the average absorbed radiation dose over x,y and z directions. It accounts for overlaps or gaps between the beams from consecutive rotation of the X-ray tube [21]. It is a useful indicator of radiation dose for a specific exam protocol because it accounts for protocol specific information, such as pitch [22]. It is the preferred expression of radiation dose in CT dosimetry and most CT scanners display the value of CTDIvol on the operator's console [23]. However, it does not represent the dose for objects of different sizes, shape, and attenuation and it does not indicate the total energy deposited into the scan volume because it is independent of the total scan length [24].

DLP is second metric that is easily accessible on operator's console. It is an indicator of the integrated radiation dose for the entire CT examination [25]. DLP accounts for both the intensity of irradiation (represented by the CTDIvol) and the extension (represented by length of the scanned patient L). The SI unit of DLP is mGycm, and it is calculated by multiplying the CTDIvol by the scan length (L) [26,27].

DLP increases with length of the scan, while CTDIvol remain unchanged with scan length. DLP affected by the variation in patient anatomy i.e the value of DLP is higher for taller patient. Therefore, DLP is the parameter of choice used in this study because it accounts for both scan length and intensity of radiation, while CTDIvol accounts for only intensity of radiation [28,29].

Data collection

Doses were recorded in terms of DLP, measured in mGycm, as displayed by the scanner for the 6 most common examinations in Tobruk. These are Routine Head (Brain); Chest CT without contrast; Chest, Abdomen, pelvis (CAP); Kidneys, Ureters, Bladder (KUB); Abdomen and pelvis with contrast; and Abdomen with contrast.

The data is collected for a sample of a least 10 patients for each selected procedures and there is no maximum limit for the data collected, because increase the amount of collected data will reduce the standard deviation. Only examinations with complete patient information such as age, study date, dose indexes and study descriptions were included. Examinations in which more than one body part was were excluded in this audit to prevent over estimation of the radiation dose. One-way frequency table is produced for demographic distributions of the study population (Table 1).

Characteristic	No. of Examinations in the Study	Percentage (%)
Sex		
Female	84	49.12
Male	87	50.87
Total	171	100
Age group (y)		
19-40	58	38.59
41-59	47	27.48
≥ 60	66	33.91
Total	171	100

Table 1: Demographic distributions of the study population.

Ideally data for patients weighing between 50 kg to 90 kg-known as medium-sized patient- should only be included in this audit. However, this is not true since the Software system does not mention the patient's sizes, thus we try to ensure that the extremes of patient's sizes were excluded from a dose audit [30]. This was not done for head examination as this is less affected by patient size; therefore, the selection was only based on the clinical indication. Moreover, in some examination such as CAP, KUB, and abdomen and pelvis, we ensured only the examinations that present with the mentioned indications were included in the audit. Information about CT examinations and their specific clinical indications are described in Table 2.

Examination	Clinical Indication
Routine Head (Brain)	Headache, weakness, infarct, bleed (Acute stroke)
Chest CT without contrast	Diffuse lung disease
Chest, Abdomen, pelvis (CAP)	Lymphoma staging and follow up
Kidneys, Ureters, Bladder (KUB)	Renal stones scan
Abdomen and pelvis with contrast	Abscess
Abdomen with contrast	Liver diseases

Table 2: Common CT examinations and their specific clinical indications.

Because this is the first time Tobruk Medical Center -specific data have been collected for CT DRLs, results are compared to the Diagnostic Reference Levels (DRLs) derived from UK, Canada, Ireland, and Japan. No national or local diagnostic reference levels exist for CT examination within Libya or Tobruk. The date from this audit has been used to establish these and will be used for comparison in future audit. Values of DRLs of other countries are shown in Table 3.

Clinical Examination	DRLs (UK) 2014 (30)	DRLs (Canada) 2017 (31)	DRLs (Ireland) 2012 (32)	DRLs (Japan) 2015 (33)
Routine Head (Brain)	970	1302	940	1350
Chest CT without contrast	610	521	390	550
Chest, Abdomen, pelvis (CAP)	1000	1269	850	1300
Kidneys, Ureters, Bladder (KUB)	1150	-	-	1410
Abdomen and pelvis with contrast	745	874	600	1000
Abdomen with contrast	910	-	1120	-

Table 3: International DRLs comparison for common CT examinations.

Statistical analysis

The date was collected and analysed using SPSS software version 23.0. The CT data were analysed using descriptive statistics. Quantities variables for each above examination are expressed as number of examination, mean DLP, standard deviation, range, median, and standard error of the mean [31,32]. (SEM) is calculated to give an idea of the accuracy of the mean. The 75th percentiles of distribution of DLPs in this study were calculated for Routine Head, Chest CT without contrast, Chest, Abdomen, pelvis (CAP), Kidneys, Ureters, Bladder (KUB), Abdomen and pelvis with contrast, Abdomen with contrast in Tobruk. Comparison of the DLP dose resulting from each CT examination with DRLs of other internationals surveys, using student's t-test, noticed statistically significantly different between the dose values with a p-value<0.05.

Ethical considerations

Ethical approval was sought and received from the Institutional Review Board in the educational institute as well as Tobruk Medical centre.

Results

Number of data presented in this audit is 171 adult CT examinations after going through elimination process and excluding data of large patient's size. The date was extracted from an automated dose tracking software database of one 16-slice CT scanner in Tobruk Medical Centre. Not all CT exams performed in the Tobruk's scanner included in the survey, some scans could not reach the adequate numbers of minimum of 10 patients which within the 4 months period. Consequently, these were excluded from the final data.

Six examinations were selected for the main survey from November 2017 to February 2018. Examinations were nearly comparable with male and female patients, and 38% were in patients between 19 and 40 years of age (Table 1). The examinations were distributed as CT head (n=57,33.3%), chest (n=26,15.2%), CAP (n=40,23.4%), KUB (n=19,11.1%), Abdomen/pelvis (n=17,10%), abdomen (n=12,7%).

Table 4 details the descriptive statistics for the surveyed examinations in DLP. The result revealed significant discrepancies in DLPs values among the six commonest CT exams compared to some countries' values, which can be mainly attributed to variations in the protocols used. The means of DLPs (mGycm) were reported for all six CT examinations. The highest DLP was observed on KUB CT scans (mean 3102.7 mGycm), whereas the lowest one found in chest CT scans (mean 1640.9 mGycm). Furthermore, the 75th percentiles of DLPs doses were calculated to allow us to determine DRLs for head, chest, CAP, KUB, abdomen/pelvis, and abdomen CT scans in adults in Tobruk. It is clear that a smaller patients number of chest, abdomen and abdomen/pelvic and KUB examinations lead to larger values of the standard error of the mean. In addition, the smallest variation between the maximum and minimum dose, with a difference of 53%, reported in DLP of abdomen CT examination, whereas KUB scans had the largest variation, with a difference of 62% in DLP values.

The mean DLPs per CT examination for Tobruk Medical Center' scanner were calculated and used to compared doses with current DRLs in different countries as shown in Figure 1. The DRLs from our study for all CT examinations are globally higher than those in UK, Ireland, Canada and Japan. Our DLPs for head CT scans were comparable to those in Japan and Canada while they were higher than those in UK and Ireland. The highest DRLs are observed on chest CT scans which is extremely exceeding DRLs values of UK, Ireland, Canada, and Japan; this due to the use of higher scan parameters such as mAs and KVp and the need for dose optimization of chest CT scans protocol. Moreover, our mean DLPs are extremely higher on CAP, KUB, abdomen and pelvis, and abdomen CT examinations than internationals DRLs values. This suggested the use of longer scan length. Closer attention and dose optimisation are required for all CT examination performed in Tobruk Medical Center scanner.

Exam	No. of Exam	Mean DLP mGy/cm	Std. Error of Mean	Std. Deviation	Range	Median	75th Percentiles
Routine Head	57	1715.4	85.9	648.5	634.7-3652.2	1385.1	1999.2
Chest	26	1640.9	144.5	736.7	654.3-2924.8	1543.9	2284.9
(CAP)	40	2832.1	86.3	546.1	1082.3-3793.3	2904.6	3116.8
(KUB)	19	3102.7	160.5	699.5	1841.5-4799.6	3057.6	3527.3
Abdomen/pelvis	17	2507.3	125	515.4	1485.5-3466.2	2581.9	2840.1
Abdomen	12	2465.3	120.3	416.9	1396.6-2958.1	2519.6	2754.3

Table 4: Descriptive statistics of the dose distribution for the scanner in Tobruk Medical Centre surveyed in DLP (mGycm) for six CT examinations.

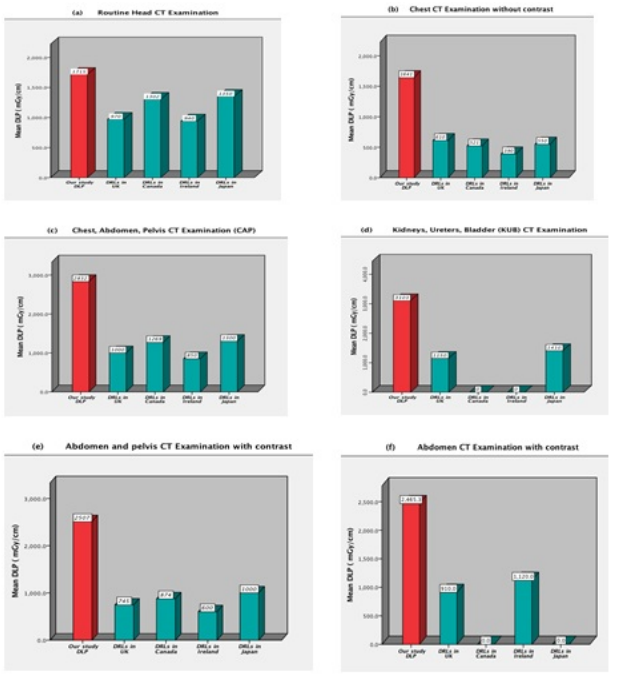

Figure 1: Dose length product (DLP) distribution for CT examinations surveyed with comparison with Diagnostic Reference Levels (DRLs). (a) Head CT examination; (b) CT chest examination; (c) Chest, Abdomen/pelvis CT examination (d) Kidney, Ureters/Bladder CT examination; (e) Abdomen/pelvis CT examination with contrast; (f) Abdomen CT examination with contrast.

Discussion

The DRLs are significant part of the optimization of radiation doses, without which it is very difficult for technicians to simply identify when unnecessarily high radiation dose being delivered. The straightforward approach is to set numerical values that can allow operators to perform this significant review quickly and take the right action if necessary. However, these values should take an account for variation in doses occurred depending on the model of CT scanner, such as, filtration, number of detector rows, beam geometry, and the scattering radiation [6,10]. Other variation may occur due to the type of scanner and protocol used [13]. Despite the increasing number of CT scanners used in Libya, the DRLs have not yet been established. This is the first time the data have been collected for CT DRLs in Tobruk; therefore, the comparison data of this study was based on a UK survey conducted in 2014, Canada date from 2017, Ireland date from 2012, and Japan date published in 2015.

The six examinations selected for this study account for over 90% of all CT examination performed in Tobruk Medical Center in Tobruk. The ICRP advised that Diagnostic Reference levels are set for common radiological examinations; as a result, the examinations that are less commonly performed omitted form this audit [10]. The collection of these data may lead to delay in the time needed to complete such survey because of the infrequent scanning. The CT sinuses examination was excluded following discussion with some referring clinicians and radiographers because the nature of this examination may differ considerably depending on the clinical indication given (e.g. sinuses with orbit/ sinuses with mastoid process)

The pilot survey for routine CT head examination revealed that our DLP level is comparable to DLPs of Canada and Japan while it is slightly higher than UK and Ireland (Figure 1). This is due to the significant discrepancy observed globally in some parameters among the radiology departments. In such examination most of departments use similar slice thicknesses (5 mm-10 mm) and tube voltages (120-140 kvp) while the scanned volume length and mAs may differ by factor of 3.0. The variation in mAs could be because of the variances in scanner geometry whereas the significant difference in scanned length might be due to the routine head could be interpreted differently through the CT clinics worldwide.

Significant differences have been observed in DLP values calculated for the rest of CT examinations of our study compared with the other DRLs (p-value<0.05). Such results demonstrated that we are not broadly in line with UK, Canada, Ireland, and Japan data, and emphasize that the optimization process to be effected each region has to set and use own DRLs in their area.

Unexpected, the greatest variability in patient doses is meanly observed in chest examination (Figure 1). In addition, there is a great variation in DLP values within the scanner that is shown by the large value of the standard deviation (144.5) (Table 4). This reflects the variations in protocols used in different services, scanned region

selection techniques, and the absence of local DRLs on which operators can refer to self evaluate their practice. During my visit to Tobruk CT scanner, it has noticed that some examinations were not recorded in the Radiology Information System exactly as performed. For instance, a patient with additional slices sequence of abdominal area is only registered as one complete chest examination, and therefore, the high dose that is recorded for this examination includes the high doses of the additional slice sequence of abdominal region. For chest CT examination, a corrective action is required and there is a possibility that mean DLPs value could be lower if the examination recorded in the RIS exactly as being performed and any additional slice should be registered in the system.

Significant discrepancies have also been observed in the DLP values calculated for CT CAP examination (Figure 1). As highlighted in Table 4, the radiation dose for CT CAP in quit high in Tobruk' s scanner with variations of up to 71.5% between the highest and lowest means. Such DLPs are extremely higher than those in UK, Ireland, Canada, and Japan. They exceeded the internationals DRLs by a statistically significant amount and therefore further investigation is required. Variations between the CT scanner demonstrate that dose differences are not just attributed to the CT scanner design, but can be due to differences in protocols used and scanning parameters. Moreover, the higher DLP mean can be probably attributed to variation in data collected, because the nature of this examination may vary significantly depending on the clinical indication. A process of continuous audit is recommended to ensure that all data collected are for the same clinical indication (Lymphoma staging and follow up).

The great variability observed in patient dose, mainly for KUB CT examination as seen in Figure 1d. The reordered mean DLP was 3102.7 mGycm. This mean is exceedingly higher than those in UK, Ireland, Canada, and Japan. Regarding the range of doses collected, large variations were marked across the scanner surveyed, with around 62% differences in mean DLPs in such examination. This is in line with previous work that shown variations, which may occur due to the scanner, model and the protocol used. One might expect range of doses, because departments are correctly changing parameters for each patient. The main CT parameters that affect dose kVp, mAs, ATCM software use, scan length, and collimation.

As noticed in Figure 1e/1f, the DLP values calculated for CT abdomen, and CT abdomen /Pelvis examination are high across the scanner. Certain steps should be taken to lower such doses, including reducing the scan length and focusing on the anatomical region to be assessed. Close collaboration of physicists is important to modifying the exposure factors such as KVp and mAs. In addition, it is recommended to enter the patient sizes in the Radiology Information System (RIS), or at least entered the patients who are obese. Further audits might be conducted to understand the effect of all these measures.

Limitation

The data were limited to one scanner due to a lack of resources to cover other scanner over the country. Including of more scanners would have strengthened the study. In addition, the absence of equipment for quality control on the scanner before the collection of data. Furthermore, this study relied on the accuracy of recorded CTDIvol and DLP from the scanner. Despite the regular check for accuracy by manufacturers and staff, deviation could occur between displayed metrics leading to inaccuracies with final result. Finally, no controlled variation of patient height influences the scan length, which affects the DLP.

Conclusion

The aim of this study was a comparison of the radiation doses of patients who underwent six CT examinations in one scanner within Tobruk medical centre. The process of comparison started with the choice of examination type and calculating the mean patient dose values for each scanner. Each examination mean value was compared with those DLPs in UK, Ireland, Canada, and Japan for that examination type. From these comparisons, extremely high dose means were identified in all five examinations except CT head examination. Optimisation of the scan protocols was suggested toward dose saving while maintaining acceptable image quality for the clinical task. Possible dose reduction strategies suggested in this study are reduction in mA, adjusting KV, and increasing the slice thickness.

Recommendation

Scanner in this audit is multi-slice scanner with a wide range of applications available. A pronounced increase in the patient dose is possible if care is not taken to optimise the scan protocols. The most straightforward way of dose optimisation is adjusting the mA and mAs. However, the limitation of such optimisation is the image noise, because the aim is reducing the patient dose while ensuring a sufficient image quality for clinical diagnostic and ensures acceptable noise level. In addition, most of these exam protocols use automatic mA modulation (SmartmA) that altered the mA with present noise index level as guideline.

The methods suggested in this project for dose reduction is reducing the tube current (mAs), adjusting tube potential, and increasing the slice thickness to acceptable level and possibly the same thickness as employed by other scanners. For example, in CT sinuses the current protocol is 100 mA with slice thickness of 0.625 mm. However, a combination of 80 mA with slice thickness of 2.5 mm or combination of 55 mA with 3.7 mm slice thickness could reduce the CTDIvol to more than half and sill maintained the image noise level.

Further dose reduction strategy is adjusting tube potential based on patient sizes. There have been many physics and clinical research on the use of lower KV in CT imaging to reduce radiation dose or improve image quality. The principle behind the benefit of lower KV in some clinical application is this: because the attenuation coefficient of iodine increases as energy of photon decrease toward the k-edge energy of 33 KeV. In CT exams involving the use of iodinated contrast media, such as, abdomen and pelvis examination with contrast, the higher enhancement of iodine at lower KV improves the observation hypovascular and hypervascular pathologies [13]. However, the image obtained using lower KV might be much noisier, mostly because of the higher absorption of lower energy photon in the patient body. Consequently, a trade-off between contrast enhancement and image noise must be made.

In order to implement these suggested methods derived from this project, the level noise that determines the diagnostic value of the image quality should be addressed. Implementation of these techniques would like close collaboration with manufacturers, radiologist, and radiographer to achieve dose saving with acceptable image quality.

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