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Local Diagnostic Reference Levels for Common Computed Tomography Procedures at a Tertiary Hospital in South Africa

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ABSTRACT

Introduction: An operational computed tomography (CT) scanner is a major source of human exposure to ionizing radiation. Exposure increases the risk of cancer and aplastic anaemia. All radiation exposures should be justified and optimized to meet the clinical objective. In order to avoid the administration of excessive radiation dose to patients, diagnostic reference levels (DRLs) were proposed. The DRLs identify unusually high radiation doses during CT procedures, which are not commensurate with the clinical objective. They have been successfully implemented in Europe, United States, some developed countries, and a few developing countries. In this regard, the present study aimed at establishing DRLs for the head, chest, and abdomen/pelvis CT procedures at a tertiary hospital in South Africa.
Material and Methods: A retrospective analysis of volume CT dose index ($CTDI_{vol}$) and dose length product (DLP) was performed on 100 randomly selected adult patients for each of the head, chest, and abdomen/pelvis CT procedures. The mean values of the DLP and $CTDI_{vol}$ dose parameters were calculated using SPSS, version 24.
Results: The established DRLs for $CTDI_{vol}$ were 32; 7, and 32 mGy for the head, abdomen/pelvis, and chest, respectively, while the DLPs for the respective protocols were 767, 386, and 593 mGy.cm.
Conclusion: The implementation of DRLs facilitates identifying CT doses that are not commensurate with the clinical objective, thereby lowering patients' doses significantly.

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Introduction

The introduction of computed tomography in the early 1970s [1-3] and subsequent development in technology have revolutionized medical imaging [3-5]. Currently, the computed tomography (CT) scanners constitute a very important imaging modality for any health care facility [6]. Almost every emergency medical facility is equipped with a CT scanner, which is used to acquire quick images needed to make informed decisions on patient admission [7]. The CT imaging modality is very flexible; as a result, it has replaced several radiologic techniques [2]. The CT scanners provide three dimensional images of the body organs of interests [4]. Currently, the CT images play a significant role in patient management [1, 6].

Despite the increased benefits of the CT imaging modality to patients, there are concerns about patient exposure. A CT scanner, when operating under normal conditions, is a major source of diagnostic X-ray [8]. The diagnostic X-rays are a form of ionizing radiation capable of extracting the outer electron on the absorbing material and creating ions [6, 9, 10]. In the presence of a biological matter, hydroxyl radicals are formed. In extreme cases, the hydroxyl radicals may result in DNA double-strand break (DSB) upon interacting with DNA, leading to cell apoptosis and eventual death. However, in the case of the biological matter or human tissues, the cell may repair and recover [6, 10, 11]. All CT procedures are therefore associated with a high likelihood of increased risk of carcinogen [1]. In order to guarantee that the dose is commensurate with the clinical objective, the International Commission on Radiological Protection (ICRP) proposed the implementation of diagnostic reference levels (DRLs). The DRLs are meant to optimize and justify radiation dose delivered [12, 13] in medical imaging. The DRLs were further clarified in 1996 [14].

According to the International Atomic Energy Agency Technical Document 1423, the DRLs can be viewed as guidelines that stipulate suitable doses, which meet the clinical objectives; hence, they can be used for optimizing patient doses [15]. The use of DRLs has been recommended by several professional bodies and regulatory institutions [15-19]. In order to emphasize patient safety against ionizing radiation, the ICRP introduced the terms of optimization and justification in radiological examinations. Justification stipulates that the benefits of using ionizing radiation

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for any prescribed examinations should outweigh its detrimental effects to the patient. Optimization on the other hand limits radiation exposure, ensuring that radiation is commensurate with the clinical objective [12, 20].

The national DRLs are normally set on the 75th percentile or quartile doses sampled from the data selected from actual measurements obtained from clinical practice in various national CT centres [1, 12, 20, 21]. However, at a local or institutional level, local DRLs are established based on the mean dose. The local DRLs should not exceed the national DRLs. Establishment of the DRLs for specific CT procedures facilitates monitoring and auditing of CT doses with the view of improving radiation safety [1]. The need for the establishment of DRLs arose due to the wide variations of patients' doses for the same CT examinations [13, 14]. These variations necessitated dose assessment in order to optimize CT imaging techniques.

The DRLs can be established locally, regionally, and even across nations. Use of the DRLs has been accredited for assisting the reduction of overall dose and range of doses used in clinical practices. For instance, in the United Kingdom, doses were reduced by as much as 50% between 1984 and 2000 without affecting the overall quality of the acquired images [20]. Consistent monitoring of the patient doses and image quality is crucial in dose reduction. The weighed CT dose index ($CTDI_w$), volumetric CT dose index ($CTDI_{vol}$), and dose length product (DLP) provide essential dose parameters for successful dose optimization [20, 22]. This study aimed at establishing DRLs for the head, chest, and abdomen-pelvis CT procedures at a tertiary hospital in South Africa.

Materials and Methods

A retrospective analysis of computed tomography dose index volume ($CTDI_{vol}$) and dose length product (DLP) values was performed on 100 randomly selected adult patients for each of the head, chest and abdomen/pelvis CT procedures at a tertiary hospital in South Africa. For the purpose of the study, individuals aged 18 years and above were considered as adults. Only data of the adult patients weighing 65-75 kg and undergoing non-contrast CT procedures were included in the study. All CT examinations were conducted using Philips Brilliance scanner from January 1, 2018 to April 30, 2018. The scan protocols for the three CT procedures are presented in Table 1. The Phillips CT scanner was installed in the tertiary hospital in September 2017. Records showed that the scanner had passed all the quality control tests at the time of installation.

Descriptive statistics were used for data analysis. Furthermore, the mean values of the DLP and the $CTDI_{vol}$ were calculated using SPSS software (version 24). The $CTDI_{vol}$ (considered as the average dose per slice measured in mGy) and DLP (i.e., the product of $CTDI_{vol}$ and the scan length measured in mGy.cm) were extracted from the CT monitor. The established local DRLs were compared with international DRLs, including those established in Ireland [23], Egypt [24], and Italy [25] for the similar CT protocols.

Results

Data for 300 male and female patients were extracted from the Philips Brilliance CT scanner console. The mean weight of the patients was 70±3 kg. The patient data consisted of information corresponding to 100 head CT procedures, 100 chest CT examinations, and 100 abdomen/pelvis CT procedures. A helical scan mode was employed during the acquisition of all data. The scan parameters used during the CT procedures are presented Table 1. The DLP and $CTDI_{vol}$ values established for this study are shown in Table 2.

Table 1. Summary of scan protocols and parameters for the Philips Brilliance computed tomography scanner applied in the present study

	Scan parameters			
Scan protocol	Tube voltage (kVp)	mAS	Scan time (sec)	Pitch
Head	120	30-300	0.5-10	0.7-1.4
Chest	120	30-300	0.5-10	0.88-1.5
Abdomen	120	30-300	0.5-10	1.2-1.5

Table 2. Mean values for the dose length product (mGy.cm) and volume computed tomography dose index (mGy) for common computed tomography procedures established in this study

Computed tomography procedures	No. of patients	Dose parameters	Mean value
Head	100	DLP	767
		$CTDI_{vol}$	32
Chest	100	DLP	593
		$CTDI_{vol}$	32
Abdomen/pelvis	100	DLP	386
		$CTDI_{vol}$	7

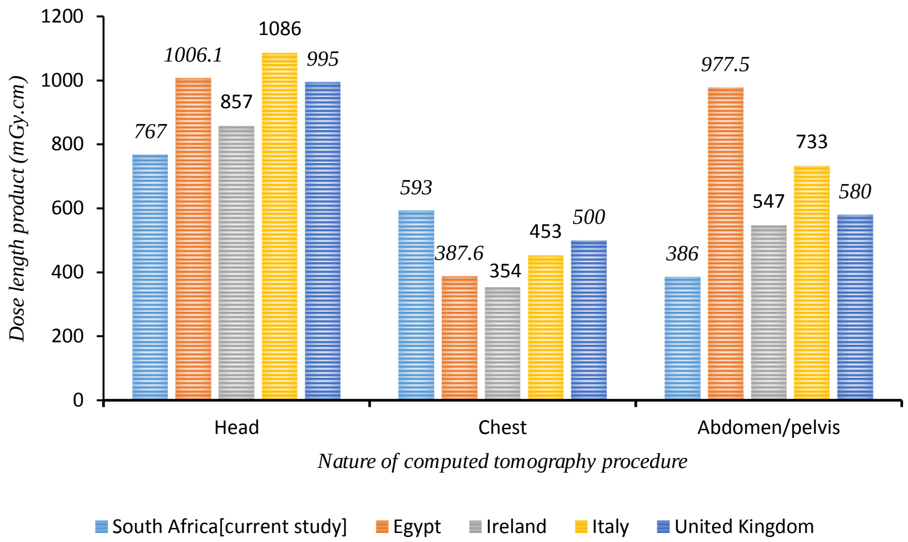

Figure 1. Comparison of dose length product values established in this study with international values

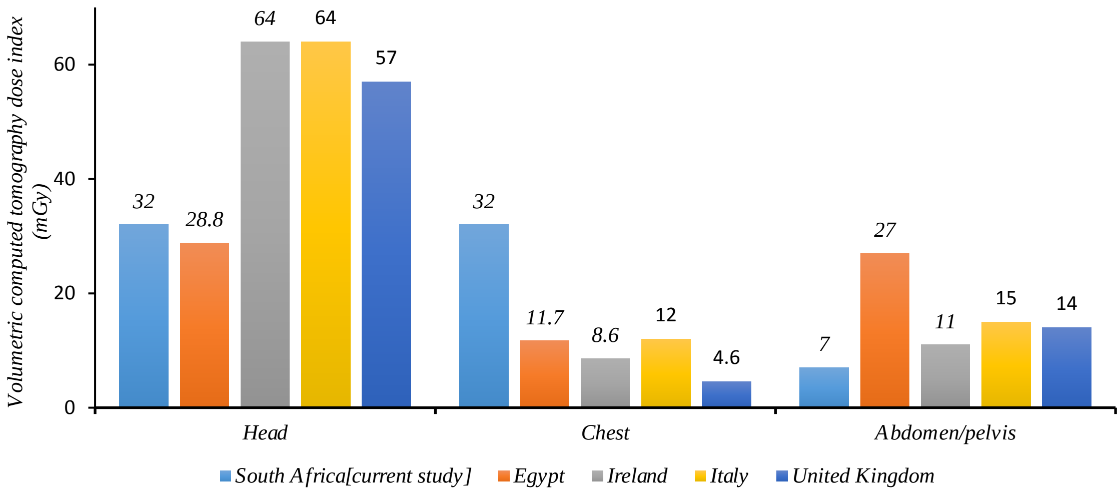

Figure 2. Comparison of volume computed tomography dose index values established in this study with international values

As demonstrated in Figure 1, the DLP values established for the head and abdomen/pelvis CT procedures were lower than the international values. The low DLP values for the head and abdomen/pelvis scans suggest that the protocols were relatively optimized. However, the high DLP value for the chest protocol in comparison to the international values draws the attention to the need for the optimization of the chest protocol. The DRLs for the $CTDI_{vol}$ in the head and abdomen/pelvis scans established in this study were found to be lower than the international values (Figure 2), indicating that the protocols were optimized to some extent. However, the DRL for the $CTDI_{vol}$ chest scan was found to be higher than international values, demonstrating the need for the optimization of the chest protocol.

Discussion

The ICRP discussed the establishment of measures commonly known as DRLs aimed at the reduction of CT exposures in 1996. The DRLs were further elucidated in a corrected version the following year [26]. One of the main objectives of DRLs is to identify unusually high CT doses with the view of optimization and justification of CT doses [12]. The DRLs have been established and successfully implemented in Ireland [23], Egypt [24], Italy [25], and UK [27], as well as among other countries. However, due to the difference in the population, the use of the DRLs established in other countries is not encouraged.

Furthermore, the training and experience of radiographers differ from one country to the next. International DRLs are therefore helpful for benchmarking purposes only. Foley et al. [23] emphasized that the DRLs should reflect the actual current practice of the particular country. In this regard, the DRLs established in one country should not be used in the next country since these DRLs will not reflect the current practice of the second country. It is therefore significant that the DRLs are established at local, regional, and national levels for each particular region or country.

In this study, the DRLs for the head, chest, and abdomen/pelvis CT procedures undertaken at a tertiary hospital in South Africa were established based on a set of the mean values for the $CTDI_{vol}$ and DLP dose parameters as per recommendations by ICRP [28]. This procedure was also in line with the approaches adopted by other researchers [23, 26, 27], as well as those from developing countries in Africa [24, 29].

According to the results, the established DRL value for $CTDI_{vol}$ in the head scan was 32 mGy (Table 2). This value was close to 28.8 mGy reported by Salama et al. in Egypt [24] (Figure 2). In the current research and the Egyptian study, the tube current ranged 30-300 mAs, and the scan times ranged 0.5-1.0s. The DRLs for $CTDI_{vol}$ for the head scan established in this study were almost half the $CTDI_{vol}$ values established in Ireland [23] and Italy (64 mGy) [25] and just slightly above half the value (57 mGy) estimated by Shrimpton et al. in the United Kingdom [27] (Figure 2). These variations may have been due to variations in scan protocols. However, the scan protocols for the studies performed in Ireland [23], Italy [25], and UK [27] were unknown to the researchers. Furthermore, differences in the training and experience of radiographers, which vary from country to country may contribute to variations in reference doses [23]. The use or non-use of the automatic tube current modulation also has a bearing on the DRL values. In this study, automatic tube current modulation was used. Salam et al. [24] benchmarked their results (DRL of 28.8 mGy for $CTDI_{vol}$) with the UK value (57 mGy) [27] and concluded that the huge difference was attributed to the differences in the pitch factor used. They noted that a smaller pitch factor (0.3-1.2) was used in the UK [27], whereas in their Egyptian study, a higher pitch factor (0.765-1.5) was used [24]. Similarly, for this study, a high-pitch factor (0.7-1.4) was employed. This explains why the result obtained in this study (32 mGy) was close to (28.8 mGy) the value obtained by Salam et al. [24].

The DRL for DLP in the head scan established in this study (767 mGy.cm) was much lower than the values established in Egypt (1001 mGy.cm) [24] and Italy (1086 mGy.cm) [25] (Figure 1). These differences may be attributed to the shorter scanning time (0.5-10 sec) used in this study. However, the DLP value obtained in this study was comparable to the value established in the UK (995 mGy.cm) [27] (Figure 1). In establishing the DRL for the head in Egypt, Salam et al. [24] used one phase, this may explain why their value was higher than those obtained in the current study and the UK [27]. Another possible explanation could be that in the study conducted by Salam et al. [24], a longer scanning range was used. The same explanation may be also used to justify the high DLP value (1086 mGy.cm) established in Italy [25] (Figure 1). Nei et al. [30] attributed dose variations to several factors, among which differences in technology and scanning protocols were included.

In this study, it was further established that the use of optimized protocols significantly contributed to dose reduction. Han et al. [31] also attributed dose reduction in some centres to the development of CT technology and image reconstruction algorithms. They reported that CT systems fitted with sonogram-affirmed iterative reconstruction and adaptive iterative dose reduction 3D software have the ability to drastically reduce CT dose, compared to those that use filtered back projection algorithm. Foley et al. [23] also attributed the reduction of DLP values to the improvement of the scanner technology, in particular the detector efficiencies and the incorporated dose-serving software.

The DLP value obtained in this study for the head scan (767 mGy.cm) well accords with the DLP value (760 mGy.cm) obtained at the Kingdom of Bahrain [32]. It is worth noting that in the Kingdom of Bahrain, the optimization of protocols played a crucial role in reducing the DRL for DLP in the head scan from 1218 to 760 mGy.cm. Use of optimized protocols also played a significant role in the reduction of the DRL for the chest from 794 mGy.cm to 401 mGy.cm [32].

Analysis of Figure 2 showed that the DRLs for $CTDI_{vol}$ for the chest scan was 32 mGy. This value was much higher, compared to the international values 17.7 for Egypt [24], 8.6 for Ireland [23], 12 for Italy [25] and, 4.6 mGy for UK [27] . Ngaile et al. [33] observed that the type and model of a CT scanner significantly contributed to dose variations due to the differences attributed to filtration, geometry of the beam, number of detector rows, and scattered X-rays.

The DRL for the abdomen/pelvis scan (386 mGy.cm) established in this study was lower than the values reported for Egypt (977.5 mGy.cm) [24], Ireland (547 mGy.cm) [23], Italy (733 mGy.cm) [25], and the UK (580 mGy.cm) [27] (Figure 2). These differences may be attributed to scanner types and the protocols used. The low values for the DLP established in this study may also be attributed to the short scan time used and limitation of scan length to the anatomical region under investigation. Furthermore, the DRL for $CTDI_{vol}$ (7 mGy) for the abdomen/pelvis scan established in this study was lower, compared to the values established in Egypt (27 mGy) [24] (Figure 2). This may be attributed to the use of a lower tube current (30-300 mAs) in this study, compared to the tube current (100-430mAs) used in Egypt [24].

The reduction of tube current in combination with the reduction of tube potential significantly reduces patient doses without any adverse effects on image quality [34]. However, the $CTDI_{vol}$ (7 mGy) was comparable to those of Ireland (11 mGy) [23], the UK (14 mGy) [27], and Isfahan in Iran (10.29 mGy) [35]. This indicates that the protocols used in the tertiary hospital under study were to some extent optimized.

Conclusion

The data of this study were collected at a tertiary hospital in South Africa for the commonly performed CT procedures, namely the head, chest, and abdomen/pelvis examinations, to establish local DRLs. The established local DRLs showed good practice for radiation safety at this tertiary hospital. Furthermore, the established local DRLs were well compared with the international values; hence, other CT centers in South Africa can rely on the DRLs established in this study to estimate the efficiency of their CT dose distribution. A comparison with these established DRLs will facilitate the identification of doses that are not commensurate with the clinical objective. South Africa does not currently have national DRLs; regarding this, the investigation of doses in all CT centres following the present article may gather sufficient data to establish national DRLs.

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