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ESTABLISHMENT OF DIAGNOSTIC REFERENCE LEVELS FOR CT TRUNK EXAMINATIONS IN THE WESTERN REGION OF SAUDI ARABIA

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Diagnostic reference levels (DRLs) are an important optimisation tool, which aid in identifying abnormally high dose levels. These are currently not available in Saudi Arabia, and this research aims to remedy this. CT dose data (DLP and CTDIvol) were collected for a minimum number of 10 adult patients of average size (60–80 kg) presenting for a range of CT examinations from public hospitals in the western region of Saudi Arabia. These include routine chest, high-resolution chest (HRCT), pulmonary angiography (CTPA), abdomen and pelvis (AP) and the combined chest, abdomen and pelvis (CAP) CT examinations. Mean values for each site were calculated, and the 75th percentile of DLP and CTDIvol was used as a basis for DRLs. Data for 550 patients were collected from 14 hospitals over a 7-month period. The rounded third-quartile CTDIvol and DLP were 18 mGy and 630 mGy cm^{-1} for chest CT, 20 mGy and 600mGy cm^{-1} for HRCT, 18 mGy and 480 mGy cm^{-1} for CTPA, 15 mGy and 800 mGy cm^{-1} for AP, and 16 mGy and 1040 mGy cm^{-1} for CAP, respectively. Regional DRLs have been proposed from this study. Dose variations across CT departments have identified an urgent need for optimisation to improve distribution of observed doses for CT examinations.

INTRODUCTION

Computed tomography (CT) has been reported as being one of the largest sources of medical radiation when compared with other modalities such as plain radiography[1]. Recent research has shown that CT contributes >60 % of the total collective dose from medical exposures in the UK and Ireland[2, 3]. Ongoing technological advances in multislice CT (MSCT) makes it an exceptionally valuable diagnostic imaging modality that is increasingly used[4]. However, such widespread use also increases the potential for inappropriate clinical application, which could result in unnecessary exposure of patients to radiation[4, 5]. Therefore, radiation protection is especially important in CT, because of the association between the relatively high doses employed and the potential for both stochastic and deterministic effects[6].

Therefore, optimisation processes that comply with the 'As Low As Reasonably Achievable' (ALARA) principle should be encouraged[7]. To facilitate optimisation, investigation is required of current practice to review compliance with such principles and dosimetry surveys measuring dose distribution over wide geographic regions form an important aspect of such studies[8]. The establishment of diagnostic reference levels (DRLs) can be considered as a first step of optimisation aimed at correcting dose delivery variations[9]. DRLs were defined by the ICRP in 1996 as being a form of investigation level to identify unusually high radiation doses[10]. Owing to the wide variations of CT dose delivery identified by such dose surveys[11, 12], the establishment of DRLs is well referenced as a useful optimisation method that can increase awareness of dose levels being used, encourage optimisation among CT centres and reduce the dose distribution[10, 13].

In 2000, as per national regulations, the implementation of DRLs became a requirement at the European level[6]. Subsequent surveys were carried out in different European countries, to include the UK[14], Ireland[12], Switzerland[15] and Italy[16]. In the UK, for example, a 50 % reduction in the average dose between 1985 and 2000 has been achieved and is attributed in part due to the use of DRLs[8, 17]. Currently, there are no available data on radiation exposure delivered to patients from CT in Saudi Arabia and neither is there a legal obligation to establish DRLs in the country. Therefore, the purpose of this study was to identify the current practice employed in Saudi Arabia in terms of CT radiation dose distribution and then to establish DRLs for CT trunk examinations, as a first stage of a larger study aimed at optimisation for CT examinations.

METHODS AND MATERIALS

Ethical approval was sought and received from the Institutional Review Board in the educational institute as well as hospitals that volunteered to participate in the survey. Currently, there are 45 hospitals in the

western region of Saudi Arabia, all of whom were contacted and 24 agreed to participate in this study. Five types of examinations, namely, routine chest, HRCT, pulmonary angiography (CTPA), abdomen and pelvis (AP) and the combined chest, abdomen and pelvis (CAP) CT examinations were chosen for the study. All centres were asked to provide data just for single-phase examinations. These examinations were specifically selected as this is the first stage of a larger study aimed at optimisation for CT trunk examinations in Saudi Arabia. Furthermore, a recent study demonstrated that CT scans in the trunk region can result in higher effective doses, reaching up to a maximal value of 15 mSv[18].

Survey booklets were designed and piloted randomly in four hospitals to check for appropriateness; these centres were not included in the main survey. Necessary amendments which were mostly of a formatting nature were made prior to distribution to each CT centre for completion by CT personnel. The information collected included baseline details related to departmental CT protocols routinely applied to average-sized patients, to include scanning parameters, such as detector collimation, slice thickness, tube current, tube potential, tube rotation time, pitch and scan range. Average-sized patients were defined as weighing between 60 and 80 kg.

Radiation dose recordings, namely the displayed CT dose index volume (CTDIvol) and dose length product (DLP), were also recorded by the examining radiographers for a minimum number of 10 adult patients presenting for these 5 CT examinations over a period of 7 months from June 2013 to January 2014. The dose metrics recorded were CTDIvol in milligray (mGy), used to express the absorbed radiation dose in a cylindrical-shaped phantom for a specific volume slice computed tomography dose index (CTDI), and DLP in milligray per centimetre (mGy cm^{-1}), which is the CTDI volume multiplied by the length of the scan[14]. Weight (kg) for those patients was recorded by CT radiographers using their recording files.

Descriptive statistics of the dose distribution found across CT scanners surveyed were used to determine mean, minimum and maximum values. Mean values for each site were calculated, and the rounded 75th percentiles of DLP and CTDIvol were used as a basis for DRLs (Table 1). Local DRLs were also calculated and communicated back to each site to encourage comparison and optimisation with regional DRLs and with other anonymised participating centres with similar scanners, where appropriate. To compare doses between scanners of different numbers of detectors, Student's *t*-test and one-way ANOVA test were used to compare two and more than two groups, respectively, following normality testing, with *p*-value ≤ 0.05 being considered statistically significant. All calculations were performed using SPSS system v.17 (PASW, Chicago, IL).

RESULTS

From the 24 participating hospitals with an installed base of 24 scanners, 14 hospitals representing 30 % of all hospitals available in this province and with the data from a total of 550 patients were used in the study. Six hospitals submitted either incomplete or invalid data such as submitting data for <10 patients, for paediatric patients or without providing DLP details, whereas four hospitals were used in the pilot survey; thus, they were omitted from the study. All scanners were MSCT in design with just 3 varieties represented, namely 16 ($n = 2$), 64 ($n = 8$) and 128 ($n = 4$) slice. Scanners were from three manufacturers: Siemens (58 %), GE (35 %) and Philips (7 %). The dose distributions for the five surveyed examinations are displayed in Figure 1, with the 75th percentile DRL being identified by the broken horizontal line. These proposed regional DRLs are compared with published EU studies in Table 2. Comparison of the dose resulting from each examination type between scanners of 16, 64 and 128 detectors, using Student's *t*-test and one-way ANOVA test, demonstrated no

Table 1. Descriptive statistics of the dose distribution across the 14 surveyed CT scanners.

Exam	Mean DLP mGy cm^{-1} (range)	Mean CTDIvol mGy (range)	75th percentile DLP mGy cm^{-1}	75th percentile CTDIvol mGy
Chest ($n = 120$)	520 (101–1635)	14.3 (3.2–31.2)	630	18
HRCT ($n = 90$)	430 (59–1068)	14.5 (3.1–33.5)	600	20
CTPA ($n = 90$)	410 (61–1080)	16.7 (2.1–62.6)	480	18
AP ($n = 140$)	685 (180–1772)	14.1 (6.3–41.9)	800	15
CAP ($n = 110$)	1000 (299–2584)	15 (8.8–39.7) 10.3/12.5 L (6–22), A (7–24)	1040	16 L: 13/A: 16

Ranges of values are displayed in parentheses.
CTDIvol, CT dose index volume; DLP, dose–length product; HRCT, high-resolution CT; CTPA, CT pulmonary angiography; AP, abdomen and pelvis; CAP, chest, abdomen and pelvis; L, lung sequence; A, abdomen sequence.

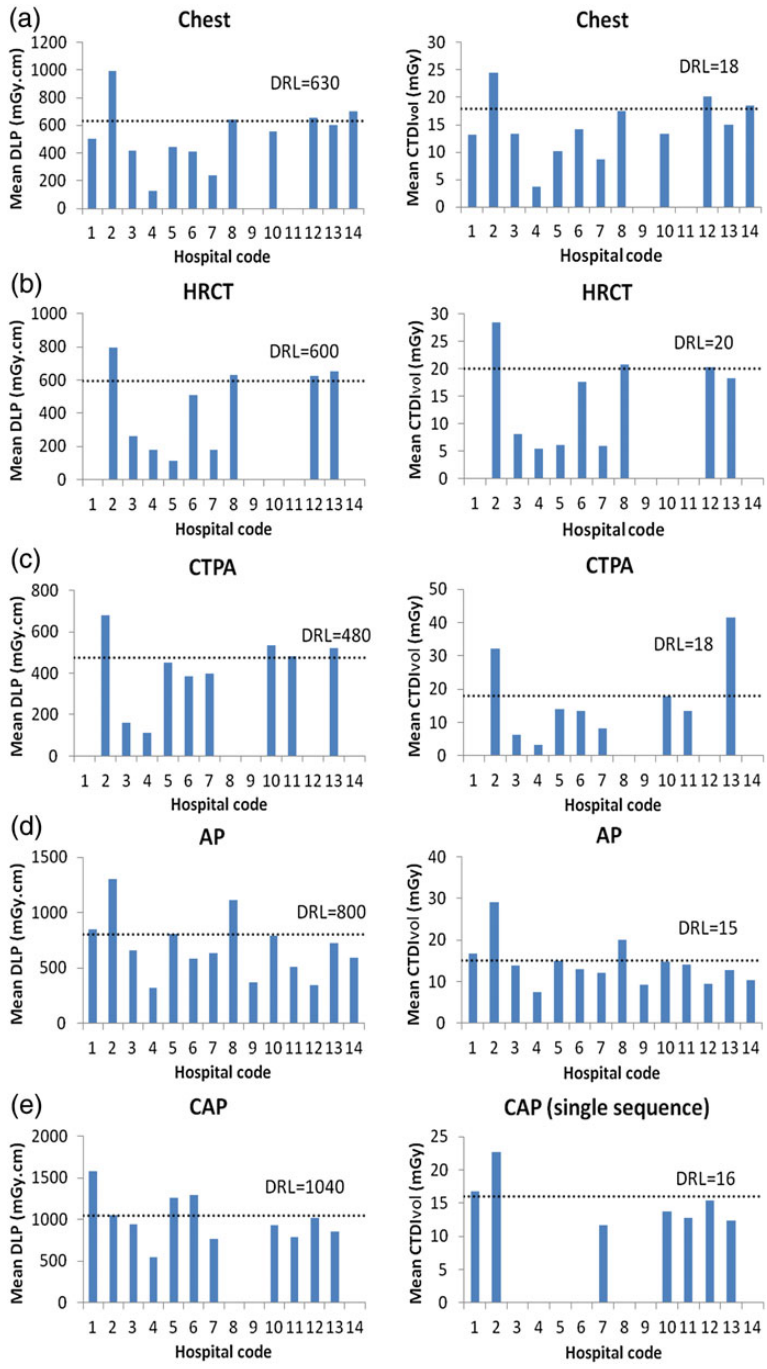

Figure 1. (**a**) DLP and CTDIvol distributions for chest CT examination. (**b**) DLP and CTDIvol dose distributions for HRCT examination. (**c**) DLP and CTDIvol dose distributions for CT pulmonary angiography (CTPA) examination. (**d**) DLP and CTDIvol dose distributions for abdomen/pelvis CT (AP) examination. (**e**) DLP and CTDIvol dose distributions for chest, abdomen/pelvis CT (CAP) examination.

Table 2. Comparison of DRLs [CTDIvol (mGy) and DLP (mGy cm)] with other European surveys.

Exam	Saudi Arabia 2013		Ireland 2010[12]		Italy 2013[16]		Switzerland 2010[15]	
	DLP	CTDIvol	DLP	CTDIvol	DLP	CTDIvol	DLP	CTDIvol
Chest	630	18	390	9	569	15	400	10
HRCT	600	20	280	7	—	—	—	—
CTPA	480	18	430	13	—	—	450	15
AP	800	15	600	12	920	18	650	15
CAP	1040	16	850	10/12	1200	17	1000	15

significant difference between the dose values with a p-value of >0.05 (Table 3). These parametric tests were chosen based on normality distribution results with a p-value of 0.20 for the Kolmogorov–Smirnov test.

Table 3. Comparison of doses between scanners of different number of detectors for trunk examinations.

Exam	Scanner	Mean (DLP) (mGy cm^{-1})	SD	p-value*
Chest	16	352	497	0.42[a]
	64	493	292	
	128	407	217	
HRCT	16	N/A	N/A	0.73[b]
	64	314	330	
	128	356	247	
CTPA	16	N/A	N/A	0.27[b]
	64	347	260	
	128	237	216	
AP	16	480	154	0.09[a]
	64	821	264	
	128	511	230	
CAP	16	N/A	N/A	0.83[b]
	64	863	433	
	128	1029	346	

[a]One-way ANOVA test.
[b]Student's t-test.
*$p \leq 0.05$ is considered statistically significant.

DISCUSSION

DRLs have been shown to be useful in identifying suboptimal practice and in increasing staff awareness with respect to the radiation dose administered in CT departments[10]. When high radiation doses are being delivered, DRLs can alert CT personnel to take corrective action to remedy this[12]. Departments delivering high doses can also be identified by review of DRL values. Since the DRL will always be exceeded by a quarter of the population, they should be used as an indicator, rather than a proof of excessive dose and many centres may justifiably be using higher values, but this should always be investigated[8]. This study describes the first study of adult CT radiation dose collection in multiple public hospitals conducted in Saudi Arabia for five CT examinations.

Wide dose variations were noted across the departments surveyed for all examinations (Table 1), with the highest being an 18-fold difference in DLP for the HRCT examination (59–1068 mGy cm^{-1}) reported. The potential reasons for these variations could be attributed to the variation in techniques, protocols and use of dose reduction software identified in the hospital information collated, despite the Automatic Tube Current Modulation software being employed on all scanners, which can keep noise constant and reduce the radiation dose during scanning[19]. The use of iterative reconstruction has also contributed to the large differences in CT dose.

Inter-hospital comparison (Figure 1) identified exceeding of the proposed DRLs in specific sites, where hospital 2 exceeded the DRLs for all examinations. For chest and abdomen examinations, for example, DRLs were exceeded by 60 %. Hospital 8 also exceeded DRLs for almost all examinations, such as chest (10 %) and abdomen (30 %). This may suggest that there are scanning technique-related issues here. These findings are similar to one study, which identified a variation of 10–40 % in mean doses observed between individual scanners, largely due to imaging technique[20]. The consequence of such variation is that patients attending different centres are being exposed to varying degrees of radiation for the same examination and these risks require attention. On the other hand, hospitals such as hospital 3 and 4 have shown overall lower average doses when compared with others. Centres with doses above DRLs are encouraged to carry out urgent investigations with a view to take corrective action or to provide justification for the use of exceptionally high doses[21]. These centres are also advised to routinely update and review their protocols to ensure that they comply with the ALARA principle.

The results also show a variation of mean doses within hospitals. Hospital 6 achieved a low comparative mean dose for chest and abdomen examinations yet provided the second highest recorded dose for the combined chest, abdomen/pelvis examination. The

situation was similar for hospital 13, whose HRCT and CTPA mean doses were one of the highest, yet they had comparatively low doses for their chest and abdomen/pelvis CT examinations. This inconsistency in dose delivery within hospitals may suggest that there could be protocol-related issues here, such as prescribing a higher requirement for image quality for those exams in those two centres. This further highlights the need for vigilance in examining CT doses across the entire range of examinations. Actions should also be made to investigate solutions for this inconsistency by reviewing scanning protocols at least annually[11, 22, 23].

The incidental high figures for the ratio between the minimum and maximum dose range may also be attributed to heterogeneity in examination techniques employed in some centres such as when spiral versus sequential HRCT of the lungs or when the combined chest, abdomen and pelvis examinations are performed in one run, while in others are scanned in two separate scan sequences, which inevitably leads to overlapping radiation exposures[11]. In this study, the latter axial technique for HRCT was only performed in hospital 5, which had the lowest DRL and mean values compared with other centres. For CAP examinations, only four hospitals[2–5] perform two separate acquisitions for the chest and the abdomen; thus, these centres with the exception of hospital 4, which additionally had an iterative reconstruction algorithm, showed a relatively higher DRL (1124, 976 and 1412 mGy cm^{-1}, respectively) when compared with other centres which scan a single range, such as hospitals 7, 11 and 13 with mean DLPs of 766, 784 and 858 mGy cm^{-1}, respectively. Although scan length can significantly cause changes in radiation dose delivery, there was no obvious variation between DLP and CTDIvol recorded in the study, and this parameter is unlikely to contribute to the observed dose variation.

The implementation of the iterative reconstruction algorithm can also play an important role in causing this variation of findings across sites. This was demonstrated for hospital 4, which was the only hospital using this algorithm, where dose reductions of up to 45 % from the mean DLP were noted for the abdomen/pelvis examination when compared with all other hospitals and for almost all examinations surveyed with the exception of the HRCT examination where the sequential technique is only being performed in hospital 5. This algorithm can reduce image noise and provide images with diagnostic quality, similar to or better than those of routine dose CT with filtered back-projection, but with dose reduction of up to 50 %[24]. This software by itself does not reduce the radiation dose but rather improves the image quality of low-dose protocols by optimising image noise and contrast.

A comparison of these data with other CT dose surveys is given in Table 2. Doses are 50–70 % higher than those established in the Irish survey from 2010[12] and of comparable value to those from Switzerland[15] and Italy[16]. The reasons for the Saudi doses to be on the higher end of the scale could be due to differences in radiographers' education, protocol design and guidelines with regard to CT radiation dose. Lack of radiographers' awareness of radiation dose and protocols has been shown in a study aimed at evaluating the knowledge of paediatric CT radiation among Saudi Arabia radiographers to be the cause of differences between doses delivered among Australian and Saudi hospitals[9]. It has been found that understanding the factors affecting patient radiation doses in CT has a great impact on dose delivery and is usually considered as the first step in optimisation strategies[25].

International guidelines promoted by the International Commission of Radiation Protection (ICRP)[10], The National Council of Radiation Protection and Measurements in the USA[13] and the European Atomic Energy Community (Euratom) at the European level[21] focus on the importance of protecting patients from high radiation doses from CT. Although basic radiation protection legislation does exist in Saudi Arabia, this is predominantly focused on staff protection with an obvious deficit existing in relation to patient protection, especially with regard to DRLs for patients undergoing imaging modalities that use ionising radiation[21, 22]. Therefore, applying changes to radiation protection recommendations to emphasise the importance of dose optimisation in CT and establishing DRLs should be considered as these international guidelines and recommendations are not fully applied in Saudi Arabia currently. Implementing an obligation for at least annual local surveys in all CT centres can help those departments to encourage dose optimisation. Compliance with the international guidelines and the development of national examination protocols based on these guidelines would assist in reducing the observed discrepancies in radiation doses. The DRL values established from this work form an evidence base that can be used to test future trends in CT doses across CT clinics in Saudi Arabia.

LIMITATIONS

The response rate of this survey at 40 % was greater than that of the Portuguese DRL survey at 21 %[26], but lower than the Swiss[15] and Irish[12] DRL surveys at 80 and 54 %, respectively. While 24 hospitals submitted data, some entries were partly invalid or incomplete and not all hospitals contributed in the same way to the protocol submission. The number of radiographers and the workload, which differ from one hospital to another, could be a possible reason for

this limited contribution. The hospitals that participated represent public hospitals including military, educational and public centres. However, inclusion of private centres could have been more useful due to the significant numbers of those centres in the region. A further limitation is the frequency of some of the examinations in departments. As seen from Figure 1b and c, only nine hospitals completed the surveys related to HRCT and CTPA. The reason behind this is that, in some centres, the former examination is obtained by applying additional thin slice reconstruction to routine chest examinations, whereas for CTPA, due to the nature of such exams of not being performed regularly, as evidenced by responses, the completion of this part of the survey may not have been possible in some centres due to infrequent examination. Finally, no quality assurance testing of the equipment was performed by the authors to check whether the displayed dose metrics (CTDI and DLP) on each scanner were accurate, although this is typically done as part of routine annual QA within individual departments.

CONCLUSION

DRL values for trunk CT examinations have been established for the western region of Saudi and are an important step in radiation protection as they can increase awareness of doses being used and also encourage optimisation across centres. The results showed significant variations in dose values among the CT scanners, which can be mainly attributed to variations in examination protocols and techniques used. These variations in dose delivery between hospitals even with similar scanners suggest that patients' dose reductions are achievable. All departments are advised to review and update their protocols to ensure that doses are optimised.

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