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Research article

Dose of CT protocols acquired in clinical routine using a dual-layer detector CT scanner: A preliminary report

F. van Ommen[a,b,*], H.W.A.M. de Jong[a,b], J.W. Dankbaar[a], E. Bennink[a,b], T. Leiner[a], A.M.R. Schilham[a]

[a] Department of Radiology and Nuclear Medicine, UMC Utrecht, P.O. Box 85500, 3508 GA, Utrecht, Netherlands
[b] Image Sciences Institute, UMC Utrecht, P.O. Box 85500, 3508 GA, Utrecht, Netherlands

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ABSTRACT

Purpose: To assess the radiation dose associated with always-on dual-energy acquisitions in clinical practice over a broad range of clinical protocols using a dual-layer detector CT (DLCT; IQon spectral CT, Philips Healthcare) as compared to an otherwise technically equivalent single-layer detector CT (SLCT; Brilliance iCT, Philips healthcare).

Materials and Methods: Dose-length-product data for consecutive examinations over a six-month period acquired with DLCT were retrospectively collected and compared to consecutive examinations from an SLCT. Imaging protocols were optimized for diagnostic image quality for each system prior to data collection. Dose reports of CT protocols that were used at least 50 times on both systems were collected. After exclusion of statistical outliers, protocols were evaluated with regard to reported dose levels.

Results: In total, 4536 dose reports for DLCT and 5783 reports for SLCT were collected. All DLCT examinations were acquired at 120 kVp, enabling dual-energy analysis. With SLCT, 79% of examinations were acquired at 120 kVp, and 21% at 100/80 kVp. Protocols for 15 indications were used more than 50 times on both scanners. For seven protocols there was no significant difference between the two scanners ($p > 0.05$), whereas seven protocols were acquired with higher dose levels on SLCT compared to the DLCT ($p < 0.03$). For one protocol, the DLCT dose was significantly higher ($p < 0.005$) compared to the SLCT.

Conclusion: Dual-layer detector CT enables acquisition of dual-energy information over a broad range of clinical indications without increasing radiation dose when compared to a conventional single-layer detector CT.

1. Introduction

Dual-energy CT (DECT) is a technique in which two attenuation measurements are obtained at two different energies. DECT provides additional information, and allows for the differentiation and quantification of material composition [1] and can be used to improve image quality [2–6]. A number of dedicated DECT techniques have been commercially introduced over the past few years, including rapid kV switching and dual X-ray sources. These approaches acquire two attenuation datasets by separating energies at the tube level. For most patient exams, however, these dual-energy systems are operated as conventional scanners, because dual-energy scanning has an impact on scanner performance [1,7] or increases radiation dose [8,9].

Recently, a dual-layer detector CT (DLCT) system (IQon Spectral CT, Philips Healthcare, Best, the Netherlands) has become clinically available. The DLCT detector allows differentiation of the two datasets at the detector level. With a DLCT the choice for either dual-energy or conventional acquisitions is no longer necessary, since every acquisition is a dual-energy acquisition from which both conventional and dual-energy CT images can be reconstructed. To acquire the two datasets, however, the acquisition needs to be acquired at high tube voltages (i.e. 120 or 140 kVp). In addition, since the separation of the energy spectrum occurs at the detector level, an increase in low-energy photon flux is needed to improve spectral separation, which is achieved by reducing

Abbreviations: DECT, dual-energy CT; DLCT, dual-layer detector CT; SLCT, single-layer detector CT; Q1, first quartile; Q3, third quartile; IQR, interquartile range (Q3–Q1); AEC, automatic exposure control; CTA, CT angiography

* Corresponding author at: Department of Radiology and Nuclear Medicine, UMC Utrecht, P.O. Box 85500, 3508 GA, Utrecht, Netherlands.
E-mail addresses: F.vanOmmen@umcutrecht.nl (F. van Ommen), H.W.A.M.deJong@umcutrecht.nl (H.W.A.M. de Jong), J.W.Dankbaar@umcutrecht.nl (J.W. Dankbaar), H.E.Bennink-2@umcutrecht.nl (E. Bennink), T.Leiner@umcutrecht.nl (T. Leiner), A.Schilham@umcutrecht.nl (A.M.R. Schilham).

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the titanium filtering on the DLCT compared to a single-layer detector CT (SLCT; Brilliance iCT, Philips Healthcare, Best, the Netherlands). These adaptations both entail changes in the energy spectrum of the DLCT compared to the SLCT and may have implications for the radiation dose patients receive. These changes in the energy spectrum raise the question; does the additional information from the DLCT come at the cost of additional dose to the patient compared to a conventional CT acquisition conducted on a SLCT?

The objective of this study was to assess the radiation dose associated with always-on dual-energy acquisitions in daily clinical practice over a broad range of clinical protocols using dual-layer spectral CT (DLCT; IQon Spectral CT, Philips Healthcare) as compared to an otherwise technically equivalent single-layer detector CT scanner (SLCT; Brilliance iCT, Philips healthcare).

2. Materials and methods

In this retrospective study, dose-length-product (DLP) data for consecutive examinations over a six-month period acquired with a DLCT were collected and compared to consecutive examinations performed on a SLCT. Our retrospective study was approved by the local ethics committee and waived the need for informed consent (ethical number: 18–162/C). To study dose levels of the DLCT in clinical practice, a comparison was made by comparing dose levels of clinically scanned CT protocols on both scanners in retrospect. The SLCT was selected, because the DLCT and SLCT are technically equivalent scanners, with exception of the detector and the difference in X-ray beam filtration.

2.1. Clinical data selection

CT protocols on the DLCT scanner were made by adapting CT protocols of the SLCT. The conversion of clinical protocols from 80 or 100 kVp acquisitions to 120 kVp was based on CTDI matching. Additional modifications to protocol parameters were made to achieve diagnostic image quality, and similar noise levels.

At our institute a dose report of every patient exam is stored in an OpenREM database [10]. In this database patient age, sex, CT protocol description, number of acquired scans and total DLP of the CT exam are stored. Data collected from this database served as input for the present study.

For both CT systems, all dose reports for examinations over a continuous six-month period were collected. CT protocols eligible for inclusion in this study were protocols acquired at least 50 times in the selected time period on both CT scanners. For this comparison examinations acquired from 01-08-2017 until 31-01-2018 were included. With the introduction of the DLCT system, a shift of performing certain examinations from the SLCT to the DLCT was observed. To compensate for this shift, the time period for the SLCT system was set to 01-01-2017 to 30-06-2017.

In clinical practice, a number of examinations were terminated before all acquisitions of the protocol were completed. Furthermore, some examinations required additional acquisitions due to e.g. artifacts or additional request from the treating physician. To exclude these non-standard examinations from the analysis, the interquartile range (IQR) rule was applied to the data [11]; values above $Q3 + 1.5 * IQR$ and values below $Q1 - 1.5 * IQR$ were considered outliers and removed from the analysis. $Q1$ and $Q3$ are the first and third radiation dose quartile and $IQR = Q3 - Q1$.

2.2. Phantom experiments

To verify doses reported by the CT scanners dose measurements in phantoms were conducted. The dose-length-product (DLP) was measured with a 10 cm pencil ionization chamber (Raysafe, Billdal, Sweden) for body and head scans using a body and head phantom (IBA dosimetry, Bartlett, TN, USA). The measured DLP was subsequently compared to the reported DLP on the scanner. Dose was compared at 80, 100, 120 and 140 kVp with an exposure of 200 mAs. All other acquisition parameters (e.g. collimation, rotation time, scan arc etc.) were kept the same on both systems.

2.3. Statistical analysis

Radiation dose of the CT protocols obtained with both systems were visually compared using boxplots. Statistical analysis was performed by two readers (FvO and AS). For statistical analysis of the data MATLAB (Mathworks, Natick, MA, USA) was used. Differences in dose between the two different CT systems were assessed using an unpaired sample t-test. The p-value was set at 0.0033 to account for multiple sampling (Bonferroni correction).

3. Results

3.1. Clinical data selection

In the selected time period a total of 4536 dose reports were collected from the DLCT. A total of 16 protocols were used more than 50 times (range: 52–861). On the SLCT a total of 5783 dose reports were collected, and 24 protocols were scanned more than 50 (range: 55–1340) times. After exclusion of outliers, 15 protocols were scanned more than 50 times (range: 53–1099) on both systems. In Table 1 these protocols are broken down into five anatomical categories.

All DLCT examinations were acquired at 120 kVp. For the SLCT 79% of examinations were acquired at 120 kVp and 21% at 100 or 80 kVp. Six protocols on the DLCT included acquisitions in which the tube voltage was increased to be able to acquire dual-energy datasets (i.e. CT brain perfusion, CTA of the carotid and cerebral vasculature, CTA of pulmonary arteries, high-resolution CT of the chest, CT intravenous pyelography and CT of kidney stones). In the remaining 9 protocols, the tube voltages were already at 120 kVp on the SLCT system.

3.2. Phantom experiments

The difference between the measured and reported DLP on the DLCT was within maximally 4.0% for both body and head scans (Table 2). The reported DLP was underestimated at all kVp, except for the 140 kVp body scans. Generally, the difference on the SLCT was slightly higher (Table 2) compared to the DLCT. The SLCT underestimated the reported dose compared to the measured dose. In all cases, however, the measured DLP was still within 7.5% of the reported DLP.

Table 1
CT protocols scanned at least 50 times on both scanners.

Head and Brain	Neck	Cardiac	Chest	Abdomen
CT Brain	CT Neck	CT Heart	CT Chest	CT Abdomen
CT Brain perfusion	CT Cervical spine	CTA Pulmonary arteries	CT non-contrast chest	CT Intravenous pyelography
CTA Circle Willis			CT High-resolution chest	CT Kidney stones
CTA Carotids				CTA Abdomen

Table 2
Reported and measured DLP (mGy/cm) at different tube voltages for body and head scans for the DLCT and SLCT. The difference is given in %. Dose was measured at 200 mAs, with 64 × 0.625 mm collimation.

	DLCT						SLCT					
	Body			Head			Body			Head		
	Meas.	Rep.	Diff.	Meas.	Rep.	Diff.	Meas.	Rep.	Diff.	Meas.	Rep.	Diff.
80 kVp	24.52	24.0	2.12	47.4	47.6	−0.42	18.16	16.8	7.49	36.00	34.8	3.33
100 kVp	47.48	45.6	3.96	89.24	88.8	0.54	37.80	35.2	6.88	70.72	70.0	1.02
120 kVp	75.28	72.4	3.77	136.64	137.2	−0.41	60.72	58.8	3.16	116.72	114.8	1.64
140 kVp	103.64	104.0	−0.35	193.40	194.4	−0.52	88.00	86.4	1.82	172.60	167.6	2.90

Note: Meas. = Measured DLP, Rep. = Reported DLP and Diff. = Difference between the measured and reported DLP.

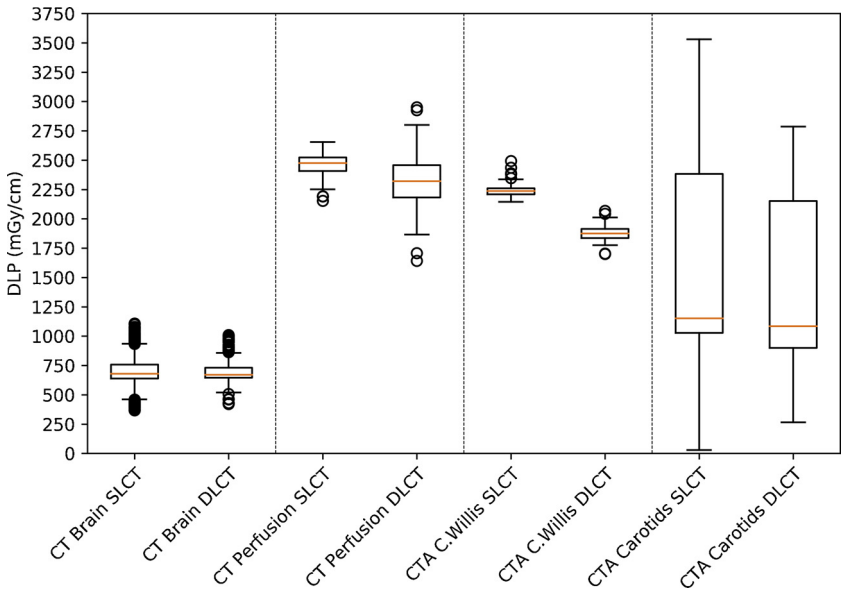

Fig. 1. Boxplots showing the dose levels (DLP) of head and brain CT protocols on the SLCT and DLCT. CT Brain perfusion is abbreviated with CT perfusion, CTA Circle Willis with CTA C.Willis and CTA of the carotids and cerebral arteries with CTA carotids. Outliers are marked by circles.

3.3. Radiation dose per anatomical region

3.3.1. Head and brain

In Fig. 1, DLP of the head and brain protocols are shown, corrected for outliers. For the CT brain perfusion and CTA of the carotid and cerebral vasculature acquisition in the CT perfusion and CTA Circle Willis protocol the peak kilovoltage was changed from 80 or 100 kVp to 120 kVp on the DLCT to facilitate acquisition of dual-energy datasets. For both these protocols the radiation dose on the SLCT was slightly higher compared to the DLCT ($p < 0.001$, Table 3). The brain CT and CTA of the carotids protocols showed near identical dose levels for both scanners. The difference between the two was not significant ($p > 0.27$, Table 3). For CTA of the carotid and cerebral arteries a large spread in observed dose levels was found. To illustrate the CT images typically observed with a brain CT scan, we have provided a CT brain scan from the DLCT and the SLCT in Fig. 2.

3.3.2. Neck

For neck and cervical spine examination the DLP was slightly higher on the DLCT compared to the SLCT (Fig. 3). The difference, however, was not significant ($P > 0.07$, Table 3). For both scanners a large spread in dose levels was observed.

3.3.3. Cardiac

Mean radiation dose levels in the cardiac examinations are shown in Fig. 4. The pulmonary artery CTA protocol was changed from 80 kVp to 120 kVp to enable routine acquisition of dual-energy datasets. Mean dose levels on the SLCT were slightly lower compared to the DLCT for the Heart CT protocol. This difference was significant ($P < 0.005$, Table 3). The CTA Pulmonary exams illustrated the opposite of this, in which the DLCT was slightly lower compared to the SLCT ($P < 0.001$, Table 3).

3.3.4. Chest

In Fig. 5, radiation dose levels of the chest CT protocols are shown. The high-resolution (HR) chest CT protocol was changed from 100 kVp to 120 kVp to be able to acquire the dual-energy datasets. For both the non-contrast chest CT and the HR chest CT a small, but significant difference was observed between the SLCT and DLCT ($P < 0.001$, Table 3), with slightly lower mean radiation dose levels observed on DLCT versus SLCT. The contrast enhanced chest CT protocol displayed comparable dose levels, which did not show a significant difference ($P > 0.61$, Table 3). The protocol varied widely with regard to dose levels.

3.3.5. Abdomen

Radiation dose levels of abdominal CT protocols after outlier correction are shown in Fig. 6. For both the CT intravenous pyelography and kidney stones protocol the peak kilovoltage of the non-contrast CT was changed from 100 kVp to 120 kVp. In general, the radiation dose of the SLCT protocols was slightly higher compared to the DLCT. For the intravenous pyelogram this difference was significant ($p < 0.001$, Table 3), whereas for the kidney stones protocol the difference was not significant ($p > 0.33$, Table 3). Mean dose levels of the abdomen CT

Table 3
Mean dose levels (DLP) of indications scanned more than 50 times, with the mean dose difference (%) and the p value.The highest mean dose was highlighted bold.

CT Protocol	DLCT (IQon)		SLCT (iCT)			
	Total	Dose (DLP)	Total	Dose (DLP)	Diff. (%)	P value
CT Brain	715	696.58	1099	**702.12**	0.79	0.279
CT Brain perfusion	168	2317.35	168	**2463.59**	5.94	< 0.001
CTA Circle Willis	100	1878.66	91	**2241.68**	16.19	< 0.001
CTA Carotid and cerebral arteries	66	1376.67	88	**1480.10**	6.99	0.418
CT Neck	92	**641.30**	82	573.56	−11.81	0.121
CT Cervical spine	147	**365.47**	135	292.84	−24.80	0.072
CT Heart	110	**226.72**	53	204.78	−10.71	0.003
CTA Pulmonary arteries	262	167.46	219	**226.35**	26.01	< 0.001
CT Chest	702	563.03	496	**571.65**	1.51	0.612
CT non-contrast Chest	184	81.06	123	**135.07**	39.98	< 0.001
CT High-resolution Chest	147	97.11	92	**163.16**	40.48	< 0.001
CT Abdomen	341	575.97	607	**641.34**	10.19	< 0.001
CT Intravenous pyelography	75	520.73	106	**668.55**	22.11	< 0.001
CT Kidney stones	80	280.83	56	**301.00**	6.70	0.330
CTA Abdomen	72	1234.22	77	**1387.01**	11.02	0.141

Note: Diff. = Mean dose difference.

protocol were significantly higher on the SLCT compared to the DLCT ($p < 0.001$, Table 3). Lastly, mean radiation dose levels for CTA of the abdomen exams did not show significant differences between both systems ($p > 0.14$, Table 3). However, a large variation in dose levels was observed. Similarly, to the brain scan, in Fig. 7, an example of a typical CT-scan of the abdomen is shown.

4. Discussion

In this retrospective study, we assessed the radiation dose of always-on DLCT dual-energy acquisitions in daily clinical practice over a broad range of clinical indications by comparing dose levels with a technically equivalent SLCT system. In general, dose levels of CT protocols scanned on the DLCT were equivalent to or lower than the dose levels on the SLCT.

Our results extend the current literature on dose levels when using a DLCT system. A number of studies have been published on applications of DLCT dual-energy analysis [2,12–19]. These studies, however, disregard dose levels or omitted a comparison to conventional SLCT system. In only two instances the dose levels of chest [12] and abdominal [13] CTs were mentioned, in which the dose levels were found to be equivalent or significantly lower compared to the SLCT. To establish the radiation dose associated with use of 120 kVp DLCT in clinical routine a direct comparison of dose levels was merited.

The differences between measured and reported dose on the DLCT and SLCT were 7.5% at most. The difference was slightly higher on the SLCT compared to the DLCT. These differences, however, are not substantial. Therefore, we used the reported DLPs without correction in our analysis.

For a number of CT protocols (i.e. CTA carotid and cerebral arteries, CT neck, CT cervical spine, CT chest and CTA Abdomen), we observed a

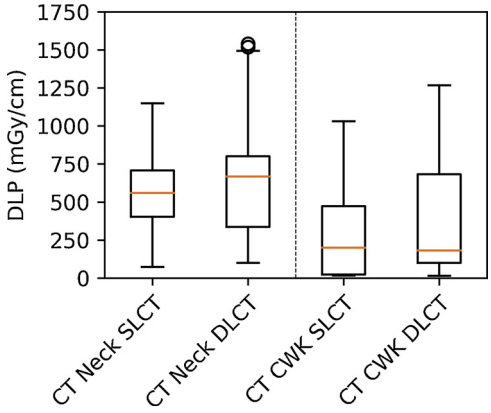

Fig. 3. Boxplots showing the dose levels (DLP) of neck CT protocols on the SLCT and DLCT. CWK stands for cervical spine CT protocols. Outliers are marked by circles.

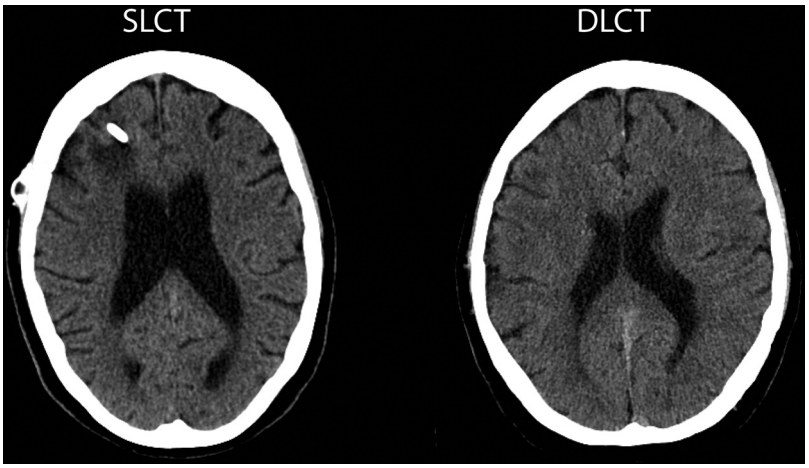

Fig. 2. Characteristic images of the CT brain protocol from the SLCT and DLCT. The contrast between the grey and white matter is clear in both images. In the SLCT image, a drain is visible. The window level and width for both images is 40/80.

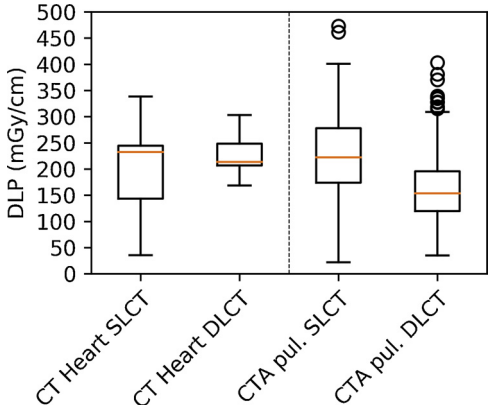

Fig. 4. Boxplots showing the dose levels (DLP) of cardiac CT protocols on the SLCT and DLCT. CTA of pulmonary arteries is abbreviated with CTA Pul. Outliers are marked by circles.

large variation in dose levels. There are two reasons for this variation. First, we compared CT protocols based on protocol name, and not on clinical question. We have a number of standard protocols, and depending on the clinical question such a protocol is extended or scans are simply omitted to save dose, which results in a large variation in observed dose levels. We consider this a limitation of this study; however, we do believe that this comparison gives a reliable insight in dose levels in a clinical setting of the DLCT, since a protocol was included when it was completed at least 50 times and statistical outliers were removed before the analysis. Secondly, the use of automatic exposure control (AEC) also results in a larger IQR. Philips utilizes a reference-image based AEC, in which a topogram is used to assess the patient's attenuation to set the tube current [20]. AEC aims to reduce radiation exposure to the patient, due to large inter-patient variability; large differences are observed in tube current settings between patients resulting in substantial dose differences.

Seven out of 15 protocols we compared did not show any significant differences. For seven protocols, radiation dose on the SLCT was significantly higher compared to 120 kVp DLCT. The difference for the CT brain perfusion and the CTA of the circle of Willis protocol can be attributed to the fact that on the SLCT the CT perfusion acquisition consists of 30 images, whereas on the DLCT only 22 images. This exam required a technique called Jog Mode to extend the spatial coverage from 40 to 80 mm to match the spatial coverage of the SLCT, subsequently increasing the temporal sampling interval from two s to 3.4 s per image. For the non-contrast chest CT and CT Abdomen, a small, but significant difference was found. This difference is most likely due to the use of AEC in the acquisition. Since, these protocols were already imaged at high-tube voltage on the SLCT. In the pulmonary artery CTA, the HR chest CT and the CT Intravenous pyelography protocol a significant difference in favor of the DLCT was observed. These protocols were for exams in which some of the acquisitions were changed from a low-tube voltage to a high-tube voltage, which demonstrates that dose does not necessarily increases with the acquisition of high kVp dual-energy CT datasets instead of low kVp conventional CT.

The dose on the DLCT was significantly higher for the CT heart protocol compared to the SLCT. This small difference can be attributed to a slightly higher exposure in the locator and tracker for the CTA acquisition for the DLCT protocol compared to the SLCT.

This study has another limitation. We did not objectively measure the image quality of the acquired CT images. However, a number of studies found that conventional CT images from the DLCT and SLCT are of comparable image quality [13,21,22]. In addition, these scans were used clinically; we therefore concluded that the acquired images are of sufficient image quality for routine diagnostic evaluation. For further research, an extensive evaluation of image quality in the routine clinical images should be considered. Lastly, we did not perform patient based radiation monitoring, but rather used the dose report of the CT scanner itself, which we consider another limitation of our study.

In conclusion, DLCT, using a 120 kVp tube potential, can be routinely used in daily clinical practice to provide additional information without increasing radiation dose when compared to conventional SLCT.

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Conflict of interest

The authors declare no conflict of interest. H.W.A.M. de Jong and

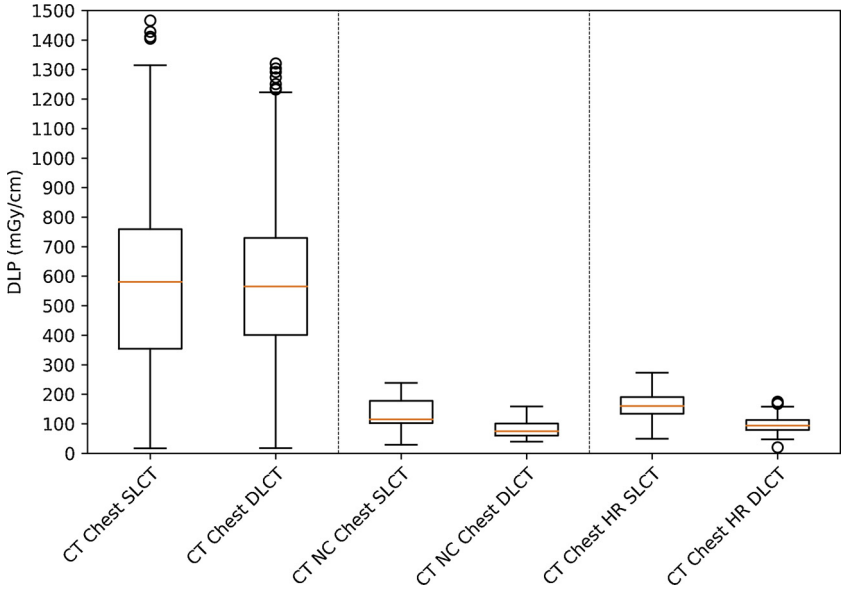

Fig. 5. Boxplots showing the dose levels (DLP) of chest CT protocols on the SLCT and DLCT. CT NC chest represents the non-contrast chest CT protocol. Outliers are marked by circles.

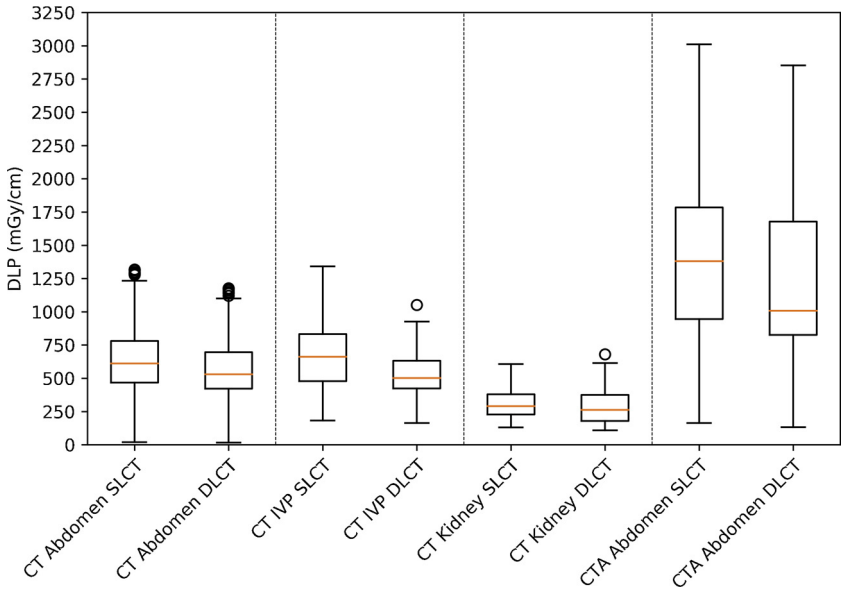

Fig. 6. Boxplots showing the dose levels (DLP) of abdomen CT protocols on the SLCT and DLCT. In which IVP stands for intravenous pyelography, and Kidney for kidney stones CT protocols. Outliers are marked by circles.

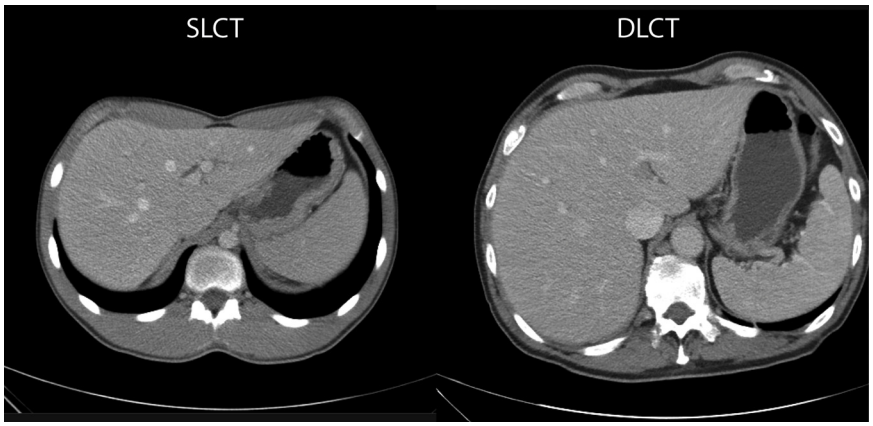

Fig. 7. Characteristic images of the CT abdomen protocol from the SLCT and DLCT. In both images the liver, intestines, spleen and ribs are clearly visible. The window level and width for the SLCT image is 40/400, whereas for the DLCT image it is 25/400. This is to correct for a difference in intensity between the two images.

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