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CT Examination Data Analysis as an Effective Method to Stimulate Patient Dose Reduction

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Abstract

Introduction: Radiation exposure from Computed Tomography (CT) examinations remains a concern due to the high doses it is associated with. In this study over 1000 patients' dose information was collected from 11 CT scanners in Greece to evaluate the radiation dose levels in Greece and to examine their compliance with the national Diagnostic Reference Levels (DRLs).

Materials and Methods: The information was collected mainly from CT dose reports and a statistical analysis of the Volumetric Computerized Tomography Dose Index ($CTDI_{vol}$) and Dose Length Product (DLP) values was performed to evaluate their distribution among the studied sites and to identify the factors of overexposure and over usage of CT.

Results and Conclusion: The majority of the examinations satisfied the national DRLs. Cases of overexposure were identified and recorded. A great discrepancy was found in the number of scans performed and the practices followed per type of examination, a fact that had a greater impact on patient exposure than the scanning protocol parameters.

Keywords: Computed tomography; Dose tracking

Introduction

According to information from the Organisation for Economic Co-operation and Development (OECD), in Greece, in 2013, existed 35.2 Computed tomography (CT) scanners per one million population [1] and in 2012, 180.3 CT examinations per one thousand population were performed [2]. CT is used widely in Greece and despite its benefits this radiological modality induces quite high doses to patients, between 1 mSv and 10 mSv [3], for routine examinations, doses that can be easily increased significantly depending on the examination needs and the clinical conditions [4]. A considerable increase in the risk of fatal cancer around these dose values has been detected [5,6] and therefore CT doses should be tracked and kept optimized.

Due to the concerns around the doses delivered during CT examinations, the technological evolution of CT scanners has taken into account patient exposure reduction. Many CT features exist today in order to aid the purpose of keeping the balance between the radiation exposure and the image quality. The dose delivered from CT examinations is now kept in relatively low levels with the use of the automated tube current (mA) modulation (TCM), the automated kV modulation, the iterative reconstruction algorithms and the well-structured scanning protocols [6-10].

In addition, for the purpose of maintaining the CT dose to a rational low level, Diagnostic Reference Levels (DRLs) have been proposed. These specify the Computed Tomography Dose Index volume ($CTDI_{vol}$) and the Dose Length Product (DLP) values for different types of examinations. In Greece, DRLs for the most typical examinations have been legislated by the Greek authority namely the Greek Atomic Energy Commission (GAEC). It has to be pointed out that for CT examinations the actual dose is not calculated and the $CTDI_{vol}$ and DLP are used as dose estimation.

In this study, CT examination data have been collected from various CT systems and analysed with the purpose to track and compare the doses induced to patients. Dose tracking and examination practice evaluation has been reported as an effective method to reduce CT exposure [11,12,13].

Methods

In the course of one year, CT patient data were collected from over one thousand examinations. The data were gathered from 11 different CT systems distributed in nine hospitals and private medical centres in five different regions in Greece (Table 1). The number of the recorded examination data was approximately the same between the investigated CT scanners. The patient sample contained only adult female and male patients. The age range was from 18 years up to 90 years old and the examinations were chosen so as to have a fairly same distribution concerning the age, weight and the sex of the patients.

Up to this date, the established DRLs in Greece exist only for the brain, sinus, inner ear, chest, abdomen, chest-abdomen-pelvis and lumbar spine examinations. Therefore, only data of these types of examinations were included in this study, with the exception of inner ear examinations, due to lack of adequate examination data.

The data from the CT scanners were gathered, mainly by retrieving the information contained in the examinations' generated Dose

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	CT type	Number of slices	Hospital / Medical center	Region of hospital / Medical center	TCM
System 1	Philips Mx 8000 Dual Slice	2	1	Cyclades (Syros Island)	No
System 2	Siemens Somatom Sensation 4	4	2	Athens	Yes
System 3	Toshiba Asteion TSX-021B	4	3	West Attica (Elefsina)	Yes
System 4	Toshiba Asteion TSX-021B	4	4	Corinth	Yes
System 5	Toshiba Aquilion 8	8	5	Athens	Yes
System 6	Siemens Somatom Sensation 16	16	6	Athens	Yes
System 7	Siemens Somatom Emotion 16	16	7	Ionio Islands (Kefalonia Island)	Yes
System 8	Toshiba Aquilion 16	16	5	Athens	Yes
System 9	GE LightSpeed Pro 32 7.X	32	8	Cyclades (Mykonos Island)	Yes
System 10	Siemens Somatom Definition 64	64	6	Athens	Yes
System 11	Toshiba Aquilion CX TSX-101A	64	9	West Attica (Aspropyrgos)	Yes

Table 1: Record of the CT systems used in this study.

Reports. Besides $CTDI_{vol}$ and DLP values, the information about the scan length, the number of scans, the type of scans (scanogram/scout/surview, bolus tracking, protocol name) and the total mAs of each examination was gathered. In some scanners the dose report did not generate the scan length and therefore this was determined by the information contained in the images. Additionally, in some cases, the DLP and/or $CTDI_{vol}$ values per scan was absent from the dose reports. The $CTDI_{vol}$ value was then derived from, the average mAs value of the slices that was calculated from the information contained in the images and manual measurements in CT phantoms. For determination of the DLP values, $CTDI_{vol}$ was multiplied by scan length. In all cases it was confirmed that the reported $CTDI_{vol}$ and DLP values of the studied CT systems were calculated by using the same phantom type (body phantom or head phantom).

The information retrieved and collected from each CT scanner was analysed individually. The data from each scanner was classified according to the examination type and then the mean $CTDI_{vol}$ and DLP values were calculated. The results were then compared between the different CT sites along with the national DRLs.

In order to compare and estimate the patient exposure per entire examination, the DLP value of each scan and the total DLP values were recorded. The total number of scans performed during the examination was also recorded for this reason. Furthermore, the effective dose values were calculated per scan as well as per examination using the corresponding conversion factors of ICRP 103 [5].

In some CT sites certain examinations were performed by using specialised protocols instead of the standard protocols regarding the scanned anatomical region (e.g., high resolution, organ specific protocols). These examinations were identified and excluded from further analysis. However, this data along with records about users' preferences and practices followed in CT examinations were kept in mind as possible causes for the differences in CT patient dose data that were expected to be found.

Data distribution analysis

The examination data collected, contained information for both male and female patients of any body size without any discrimination and together with the fact that the records were of a high number, the distribution was considered as normal. In case of special practices being applied or wrong protocols used, data were omitted. The mean values were considered to best describe the average dose given to an average patient from a CT examination in Greece. Concerning the calculation of the errors, the use of standard deviation alone was supposed to be sufficient.

The statistical software SPSS v.23 was used to further analyse the chest, abdomen and chest-abdomen-pelvis examinations, as these examinations demonstrated the highest variance of the $CTDI_{vol}$ and DLP values.

Results

The data analysis of the collected sample showed that the calculated mean values of the CTDIvol and the DLP of the examinations were, in the majority, within the Greek established DRLs. However, these values presented wide variations in the CT sites for all the examinations, and therefore cases of exposure above the established DRLs were encountered. The mean $CTDI_{vol}$ and DLP values of the recorded data from all CT sites, for all studied examinations are presented in Figure 1 ($CTDI_{vol}$ per scanning region), Figure 2 (DLP per acquisition per scanning region) and Figure 3 (DLP per examination per scanning region). In Table 2 mean (± SD) $CTDI_{vol}$, DLP and effective dose values are compared to the established Greek DRLs and Table 3 shows the mean DLP and effective dose values per acquisition and per examination.

In Figures 1-3, each bar demonstrates a different CT scanner and the different colours differentiate the CT system type (single slice, dual slice, 4 slice etc). The black bar represents the Greek DRLs. Despite the fact that diversity in the $CTDI_{vol}$ and DLP values was expected the magnitude of it is interesting. Figure 1 shows the $CTDI_{vol}$ of analysed examinations. As it can be observed, there are sites where the calculated mean $CTDI_{vol}$ value was more than three times lower than the DRLs (system 8 for chest and system 1 for lumbar spine examinations respectively). The mean effective dose values per scan that were calculated from the data collected per examination type and per scan were found aligned with those reported in the literature and are presented in Tables 2 and 3 [4,14].

The examinations of chest, abdomen and chest-abdomen-pelvis were further analysed by using box plots to observe the distribution of $CTDI_{vol}$ and DLP values as shown in Figures 4-12. In these figures system 1 was not included because it did not utilise the TCM feature in the CT examination protocols. With or without this feature, $CTDI_{vol}$ expected to change between different patients since mAs values change in order to compensate for the different patient's X-ray absorption.

For brain and sinus CT examinations, this change was quite small. It can be attributed to the fact that all examined patients were adults and therefore the X-ray absorption of head region was similar. The differences in the recorded $CTDI_{vol}$ values among the examined CT systems could be attributed to differences in the overall CT technology and differentiations of the scanning protocols. It can be observed from Figure 1 that between the examined CT sites, the differences in $CTDI_{vol}$ values are large for the brain and sinus examinations. In Figure 2, when comparing the DLP values for these two types of examinations it is observed that the variation of the DLP values among the CT scanners

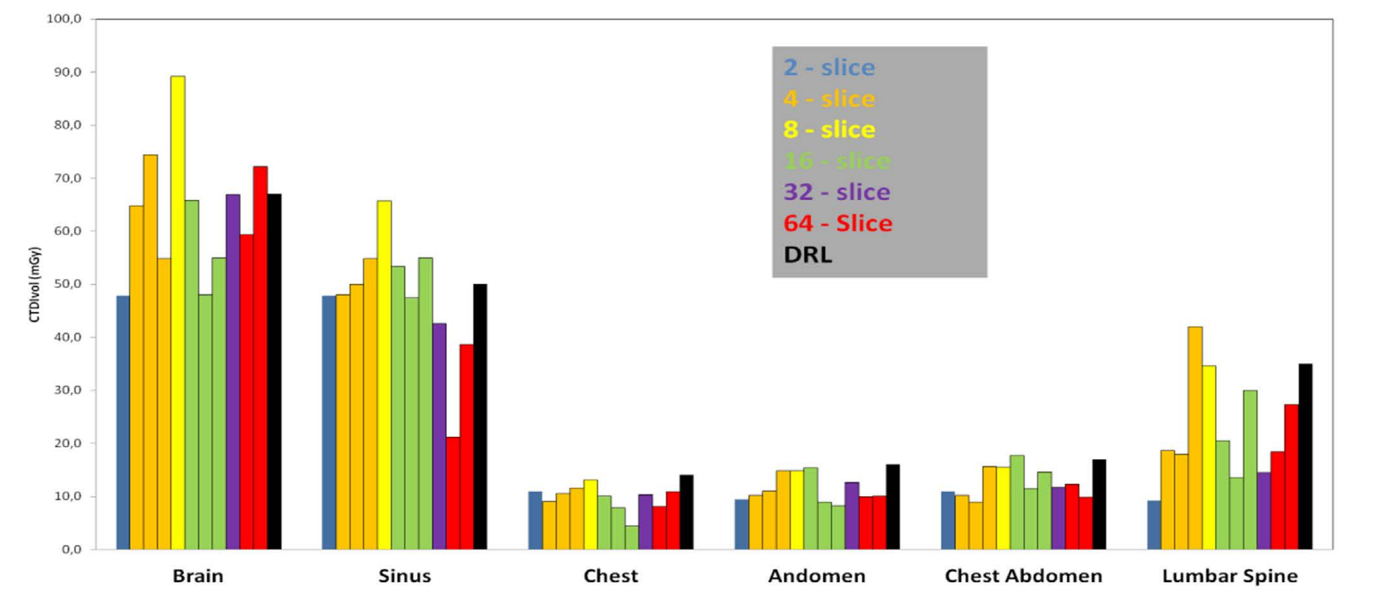

Figure 1: $CTDI_{vol}$ per scanning region per CT scanner.

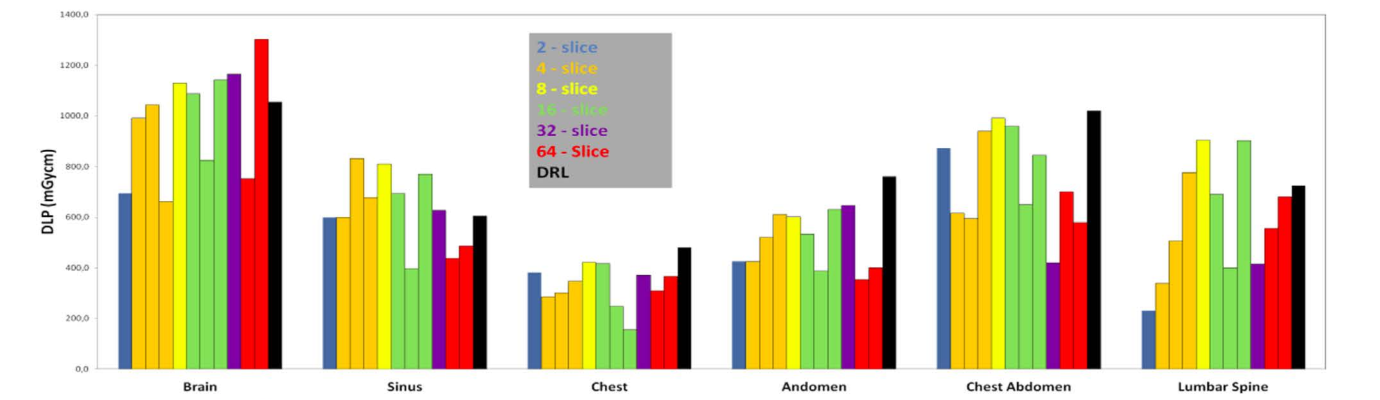

Figure 2: DLP per acquisition per scanning region per CT scanner.

Examination type	$CTDI_{vol}$ (mGy)	DLP (mGy*cm)	Effective dose (mSv)	DRL $CTDI_{vol}$ (mGy)	DRL DLP (mGy*cm)
Brain	64 ± 12	980 ± 215	2,1 ± 0,5	67	1055
Sinus	48 ± 11	630± 146	1,3 ± 0,3	50	605
Chest	10 ± 2	330 ± 79	4,6 ± 1,1	14	480
Abdomen	11 ± 3	503 ± 109	7,5 ± 1,6	16	760
Chest - Abdomen - Pelvis	13 ± 3	742 ± 188	11 ± 3	17	1020
Lumbar Spine	22 ±10	581 ± 226	9 ± 3	35	725

Table 2: Mean (± SD) $CTDI_{vol,}$ DLP and effective dose values from the collected data compared to the established Greek DRLs.

compared to the $CTDI_{vol}$ variation is either similar, enhanced or reversed. The DLP is calculated by multiplying the $CTDI_{vol}$ with the scan length and the length of the head does not vary in a degree to produce such results. However, the scan length is affected by the use of axial or helical slices, the pitch and the orientation and angle of the slices. These factors affect the scan length and consequently the DLP, which explains the variation of the values recorded. The values that surpassed the DRLs (Figures 1 and 2) can be attributed to protocols with high CTDIvol and/or scans with high scan length not constrained in the region of interest. One significant finding was that the brain protocol was commonly used for all the head scans regardless of the type of examination (brain, sinus or whole head), a wrong practice which increased greatly the patient exposure.

For CT examinations in the body, the $CTDI_{vol}$ and DLP values between different sites (even for the same CT system) demonstrated significant variances. The TCM feature affects greatly the mAs used for examinations in the body region and has a great impact in the $CTDI_{vol}$ value. Except the TCM feature, the different scanning protocols, the scanning capabilities of each system, the differences in patient size and the practices followed were also responsible for these variances.

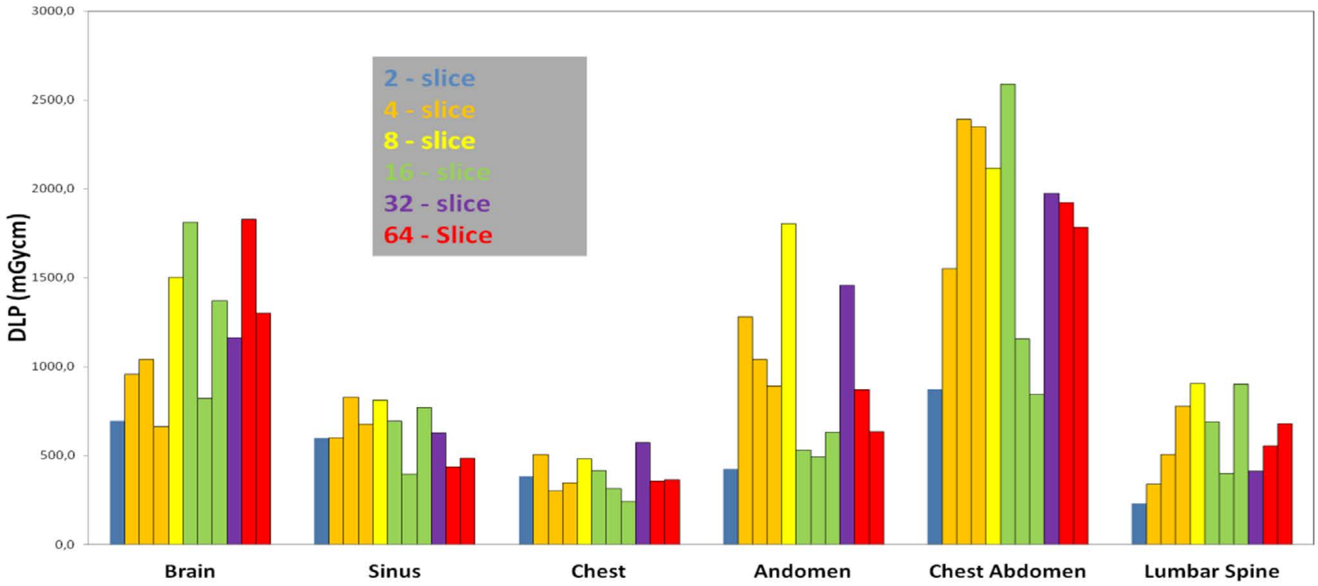

Figure 3: DLP per examination per scanning region per CT scanner.

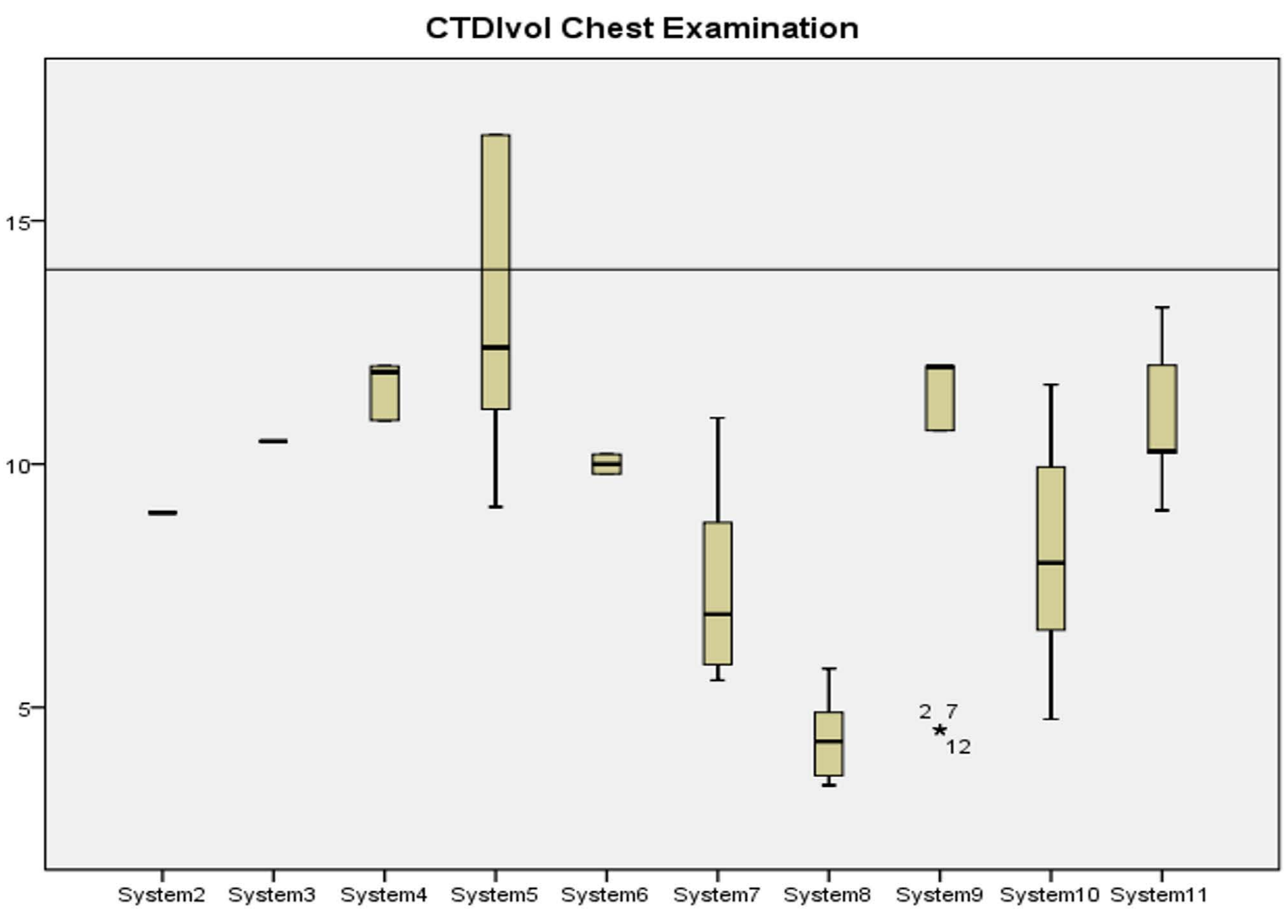

Figure 4: Boxplot analysis of the $CTDI_{vol}$ values per CT scanner for chest examinations. The horizontal line corresponds to the Greek DRL value.

Examination type	DLP (per acquisition) (mGy*cm)	Effective dose (per acquisition) (mSv)	DLP (per examination) (mGy*cm)	Effective dose (per examination) (mSv)
Brain	980 ± 215	2.1 ± 0.5	1200 ± 410	2.5 ± 0.9
Sinus	630± 146	1.3 ± 0.3	630± 146	1.3 ± 0.3
Chest	330 ± 79	4.6 ± 1.1	390 ± 98	5.5 ± 1.4
Abdomen	503 ± 109	7.5 ± 1.6	914 ± 442	13.6 ± 6.5
Chest - Abdomen - Pelvis	742 ± 188	11 ± 3	1780 ± 605	26.7 ± 9.1
Lumbar Spine	581 ± 226	9 ± 3	581 ± 226	9 ± 3

Table 3: Mean (± SD) DLP and effective dose values per acquisition and per examination from the collected data.

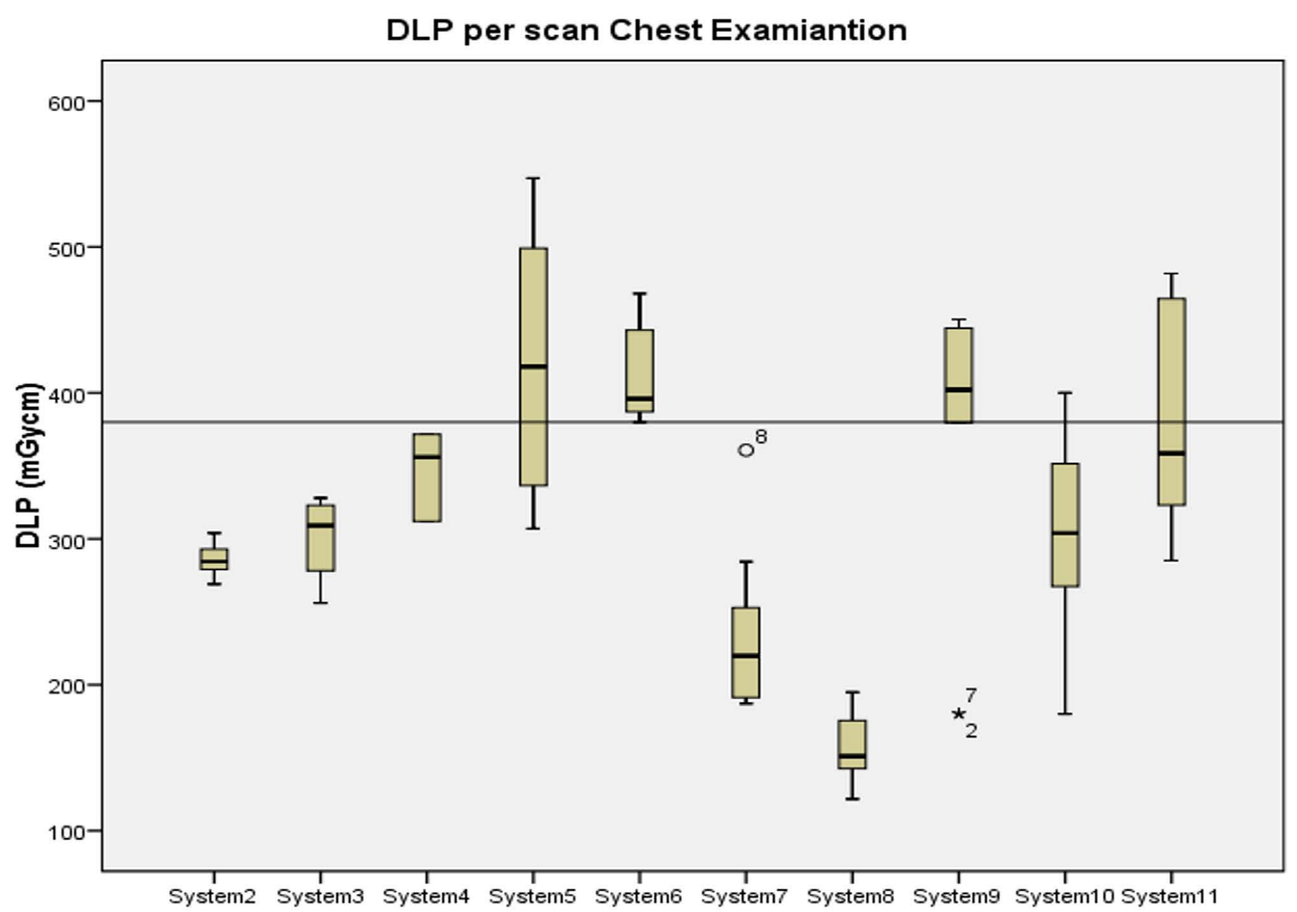

Figure 5: Boxplot analysis of the DLP values per scan values per CT scanner for chest examinations. The horizontal line corresponds to the Greek DRL value.

As with the head examinations (brain, sinus or whole head), it was found that in some sites the scan length was not restricted to the region of interest and more slices at each side were included either from the technologist's personal practice or the doctor's suggestion. Due to this fact, it was observed that there were cases where the $CTDI_{vol}$ satisfied the DRLs but the DLP did not because of an increased scan length. Also in cases where the $CTDI_{vol}$ was over the DRLs the DLP could be within the limits, again because of the scan length. This can be observed by cross comparing the graph bars in Figures 1 and 2. For the sites where the calculated mean values were aligned with the established DRLs, there were also recorded cases of overexposure.

In Figure 3 the total DLP per examination is depicted. It is shown that chest-abdomen-pelvis and abdomen examinations can reach high total DLP values meaning high doses that in some cases can reach an effective dose around 40 mSv. However, it should be mentioned that DRLs do not specify total DLP values per examination. Not all CT sites follow the same practices for these types of examination. It is observed that the scanning practices differ among them and in some it is common to perform these examinations with more series.

In Figures 4-12 the distribution of the $CTDI_{vol}$ and DLP values is presented. As expected values that surpass the DRLs exist, even in CT sites where the mean was found to be under the DRLs. This is due to patient size and the TCM feature. It is also observed that although the patient size sample was chosen to be evenly distributed the mean of the boxes in some cases is near the edge of the box and not in the middle showing that the low or high values were more commonly encountered. This can be an indicator showing how patient exposure can be affected by the quality of the TCM feature and also the scanning

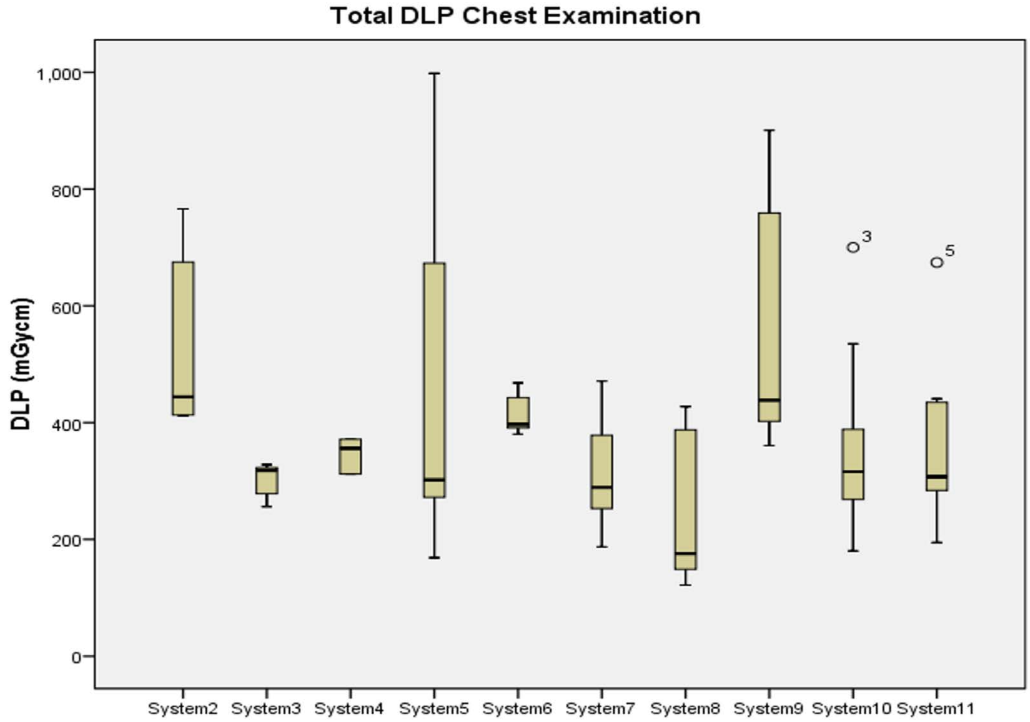

Figure 6: Boxplot analysis of the Total DLP values per examination per CT scanner for chest examinations.

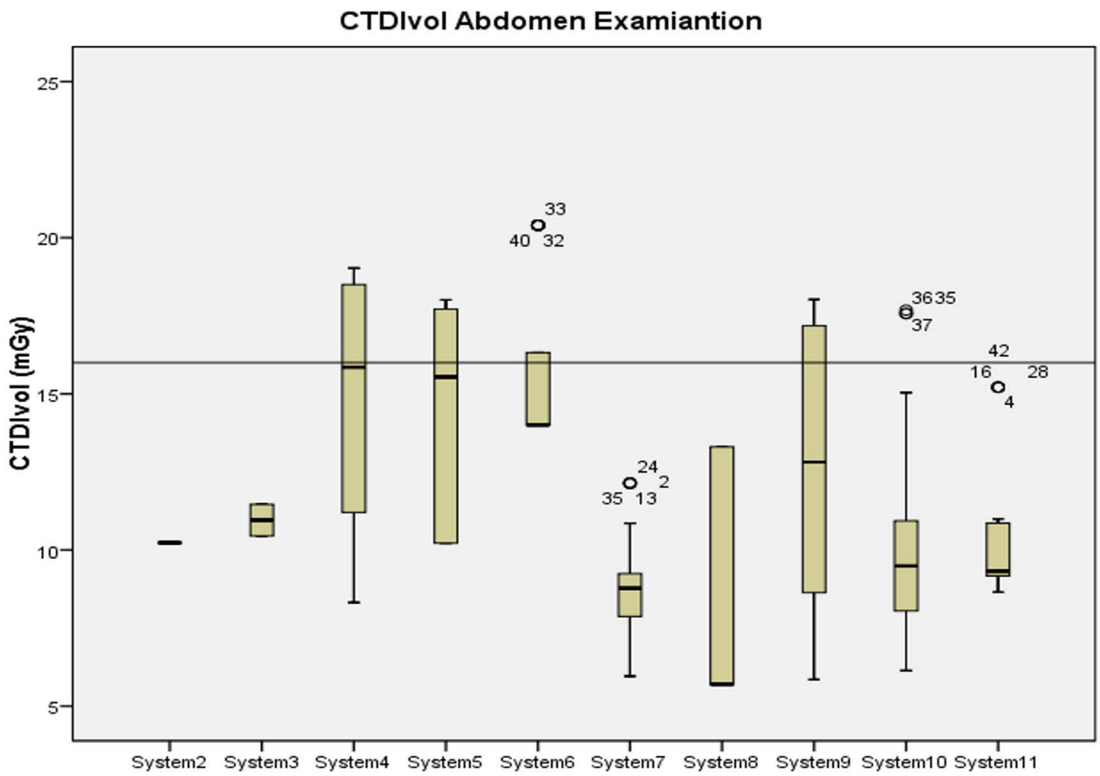

Figure 7: Boxplot analysis of the $CTDI_{vol}$ values per CT scanner for abdomen examinations. The horizontal line corresponds to the Greek DRL value.

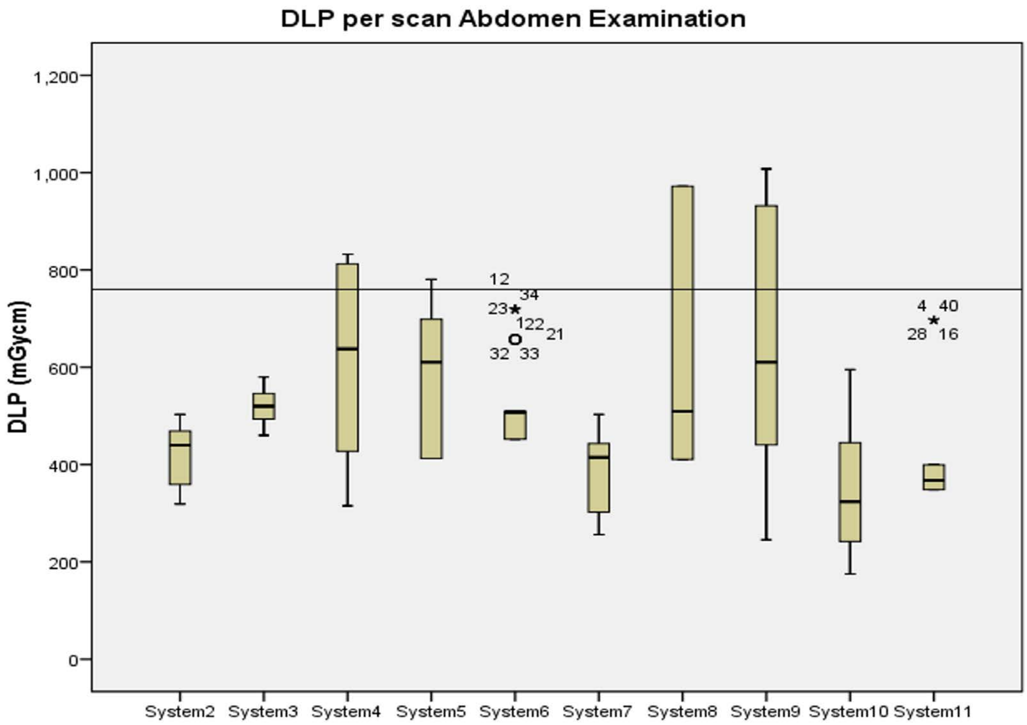

Figure 8: Boxplot analysis of the DLP values per scan values per CT scanner for abdomen examinations. The horizontal line corresponds to the Greek DRL value.

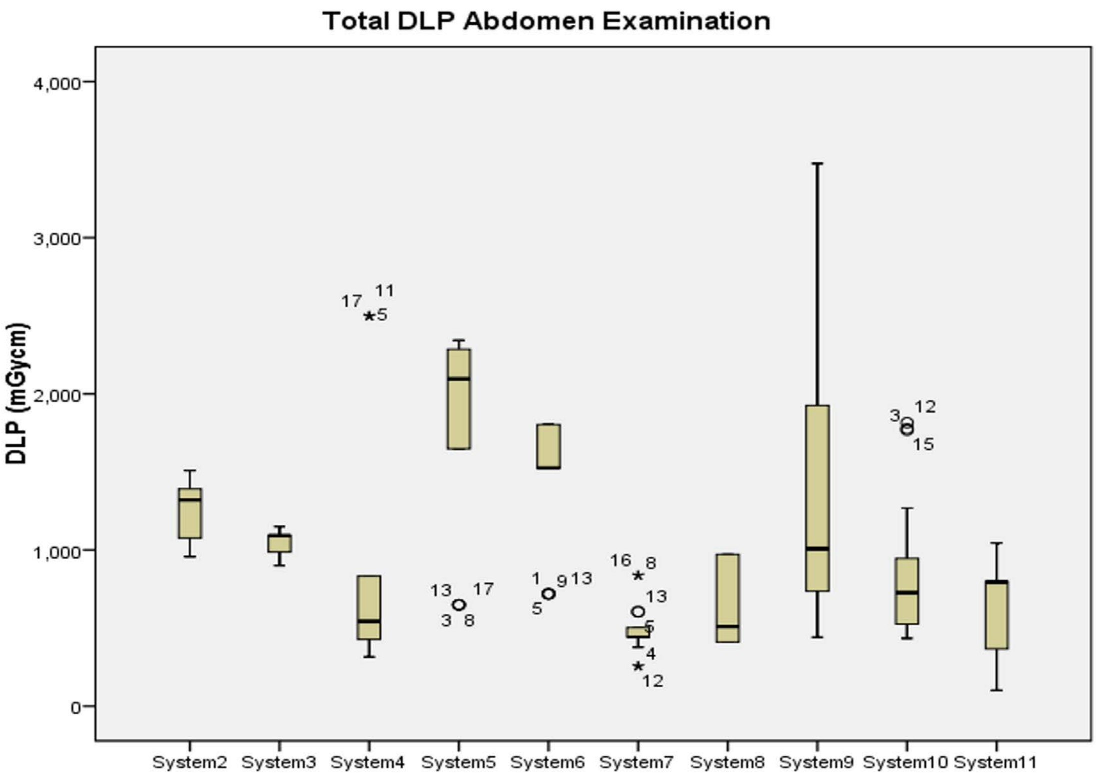

Figure 9: Boxplot analysis of the Total DLP values per examination per CT scanner for abdomen examinations.

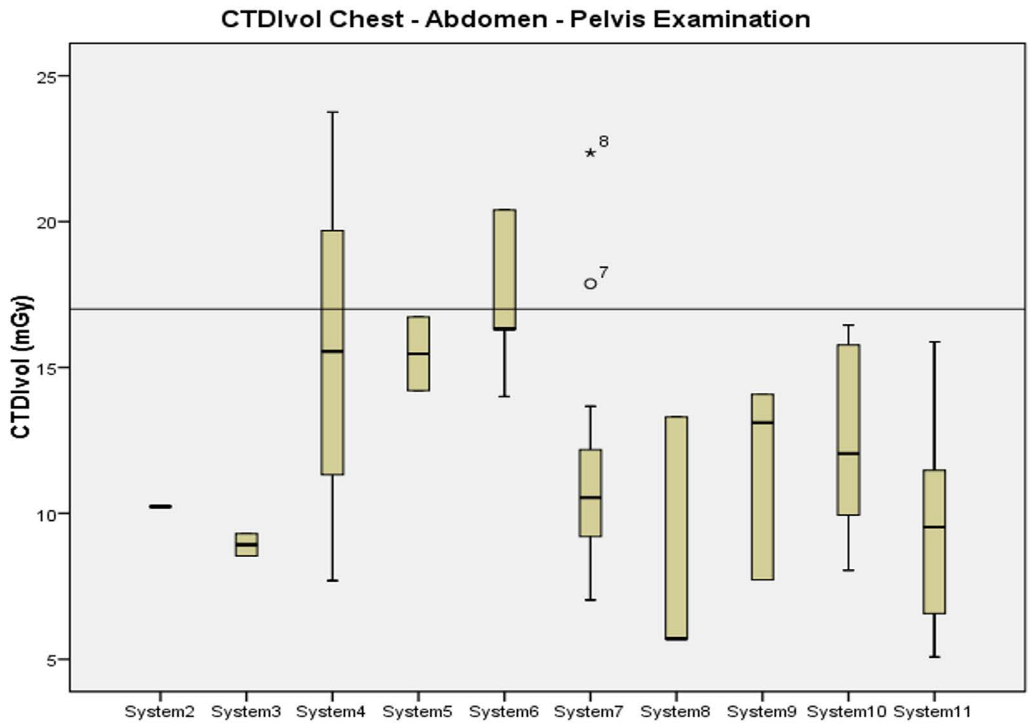

Figure 10: Boxplot analysis of the $CTDI_{vol}$ values per CT scanner for chest - abdomen - pelvis examinations. The horizontal line corresponds to the Greek DRL value.

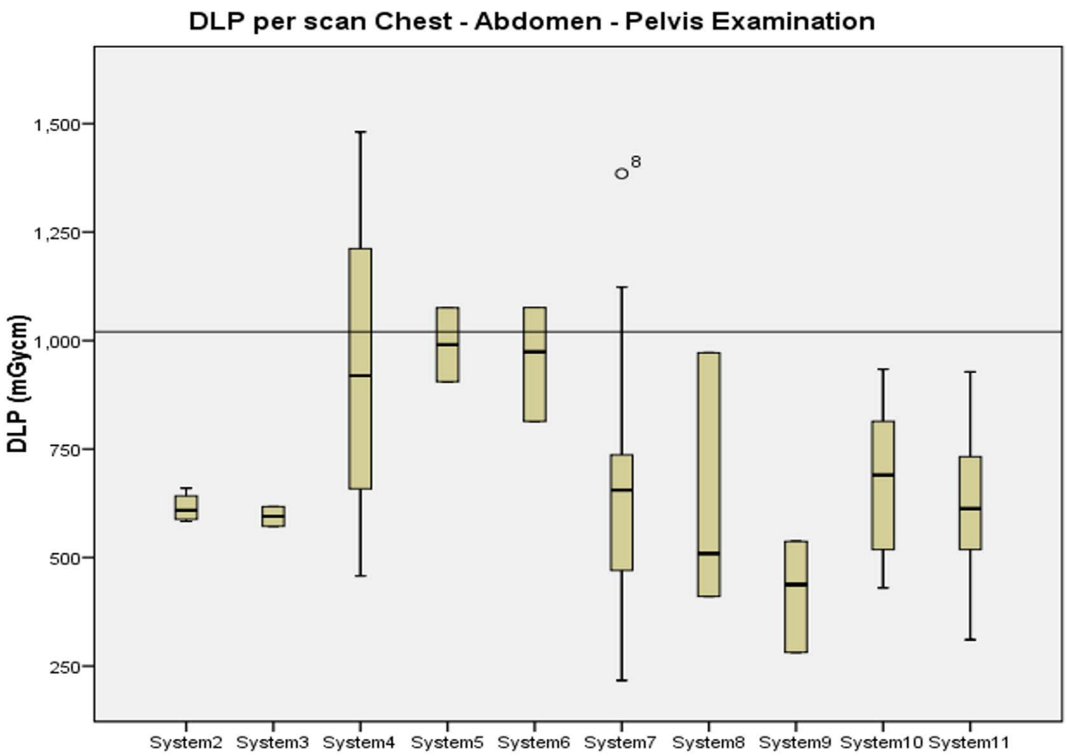

Figure 11: Boxplot analysis of the DLP values per scan values per CT scanner for chest – abdomen - pelvis examinations. The horizontal line corresponds to the Greek DRL value.

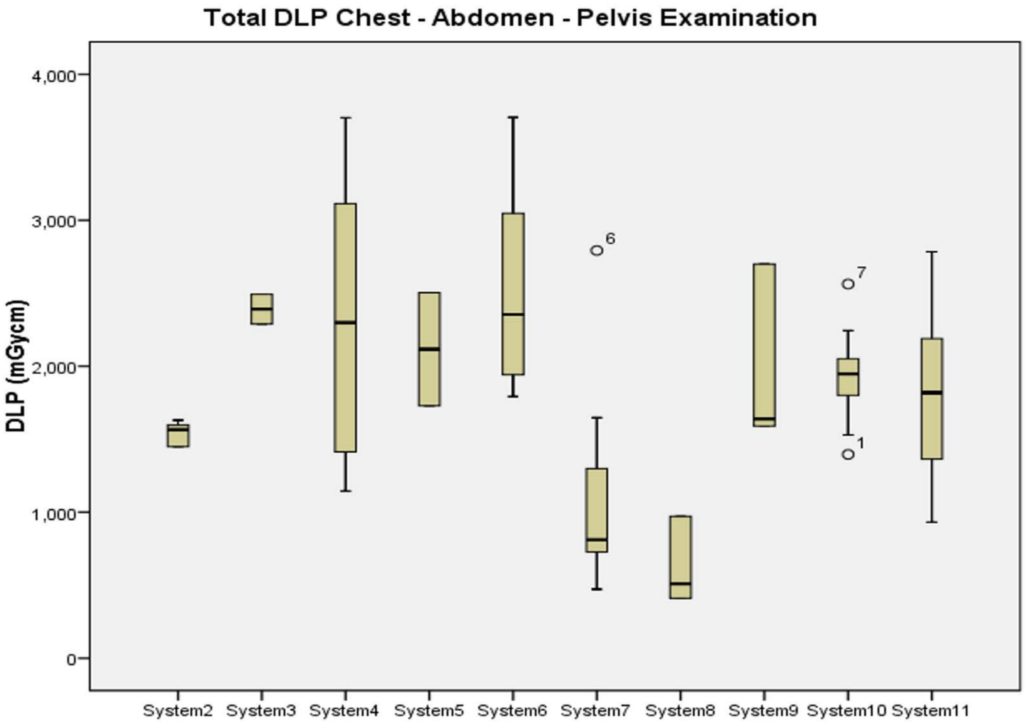

Figure 12: Boxplot analysis of the Total DLP values per examination per CT scanner for abdomen examinations.

practice followed per site. The systems 3 and 4 are the same CT models and it is observed that the exposure to patients is different between the two sites. Figures 4, 7 and 10 show that $CTDI_{vol}$ values for system 4 have a wider distribution compared to system 3. Since the model is the same this can be attributed to different protocols applied.

Discussion

The data collected during this study demonstrated that a large diversity exists between CT examination protocols and practices. Differences in the scanning protocols among the CT systems are expected due to the hardware and software technology of each CT system. The scanning protocols are set to keep the dose to patients as low as reasonably possible without affecting the diagnostic image. However, the way they were found to be planned was in order for the system to produce $CTDI_{vol}$ and DLP values within the accepted levels as specified by the national DRLs. Apart from this, dose to patients is also heavily affected by the correct usage of the CT scanners' features. For example, TCM is greatly affected by the patient positioning. When this feature is used with the patient wrongly positioned the mAs value of the examination can significantly increase and consequently increase the patient dose. These factors affect the $CTDI_{vol}$ and DLP values and therefore to the dose to patients.

In cases, where DRLs were exceeded, the analysis revealed that the cause was mainly the applied practices and secondarily the structure of the scanning protocols. For example, as mentioned before, the brain protocol was often used for all the head region scans even for sinus examinations (the cases were this had happened were omitted from the calculations). Brain examinations compared to sinus examinations require better resolution and lower noise and thus the brain scan protocols use more mAs and smaller slice thickness than the sinus scanning protocols. Performing all head examinations (brain, sinus or whole head) using solely the brain protocol results in exposing the patient to more radiation that actually required for a specific clinical indication. Furthermore, when performing thorax-abdomen-pelvis scans the abdomen protocol was often used for all the examination phases (Non-contrast phase, arterial phases, and delayed phases) which had a negative impact on the exposure to patients. Another interesting finding was that there exists a wide variety in the number of scans and practices followed for similar examinations. When analyzing the data it was observed that many scanning protocols required by default one or two further scans, compared to other sites. This happened especially for examinations in the abdominal region. Although the recommended DRLs per scan were maintained in acceptable level, the dose per examination was doubled or tripled (Table 3).

From the data collected in this study it was also revealed that many differences in protocols and practices were due to doctor's or/and technologist's personal preference, opinion or experience and this can affect the dose to patients. It was found during this study that the determination of the scan length changed not only due to the examination needs and scanning system capabilities but mostly from personal practice. It was observed that sometimes the limits of the scan length were not entirely restricted to the minimum necessary; therefore more slices were taken, leading to an increased DLP and consequently patient exposure.

Another observation was that protocols with more scans or with contrast phases, were often asked to be performed in certain CT sites so as to omit or to be certain for some pathologies, whereas these additional scans where rarely asked in others. Many times these factors have a more severe impact on patient dose than CT capabilities and not optimized protocols.

In Table 4 the recorded $CTDI_{vol}$ and DLP values of this study, along with the ones provided by a previous study performed in Greece

	This Study		Greece [15]		European Commison [16]		Switzerland [17]	
Examination type	**$CTDI_{vol}$ (mGy)**	**DLP (mGy*cm)**	**$CTDI_{vol}$ (mGy)**	**DLP (mGy*cm)**	**$CTDI_{vol}$ (mGy)**	**DLP (mGy*cm)**	**$CTDI_{vol}$ (mGy)**	**DLP (mGy*cm)**
Brain	64	980	60.7	909	72	945	65	1000
Sinus	48	630	38.9	473	30	297	25	350
Chest	10	330	12.1	395	12	421	10	400
Abdomen	11	503	13.9	628	15	724	15	650
Chest - Abdomen - Pelvis	13	742	13.8	834	/	/	15	1000
Lumbar Spine	22	581	28.2	646	/	/	30	850

Table 4: Comparison of the recorded mean $CTDI_{vol}$ and DLP values of this study with corresponding results provided from literature.

[15] (which was the base that established the national DRLs) and with the values provided by other studies performed in Europe [16,17] are depicted. With the exception of sinuses' $CTDI_{vol}$ and DLP values, the corresponding values are close. However, this comparison cannot reveal any of the findings discussed before. Therefore using the mean $CTDI_{vol}$ and DLP values or taking into account the DLP per scan when reviewing CT doses can be quite misleading, since the problem occurs when a lot of scans and examinations per individual pile up.

One important parameter to be considered is the justification of examinations. Doses near 40 mSv were observed. Doses of this level have been received in workers in nuclear industry [14,18] and their health effects have been analysed. There have been reports, which show that doctors (radiologists and non-radiologists) and patients are not well informed about ionizing radiation and the radiation risks are not taken into serious account or are not yet clear to many of them [19,20,21]. Knowledge over the radiation effects could have lead to many situations be alternatively resolved. It has been also observed that many doctors believe MRI to be an ionizing radiation imaging modality, and therefore ignore one of its benefits.

The above can answer a commonly asked question regarding the assumption that the new generation CTs induce higher doses to patients compared to older ones. The newer CT models have the technology and the hardware to produce higher doses but the way they are used determines the exposure to patients.

The dose received from CT examinations compared to other imaging modalities has been reported to be higher [22,23], for example, CT chest examination dose compared to chest radiography dose is 100-1000 times more. Also there exist situations where patients are undergoing a lot of CT examinations, many of them unnecessary, due to missing or not well communicated information. In one extreme situation it is reported that a patient underwent 112 brain computed tomography scans in three years [24]. It is also suggested that computed tomography may have been overused and many examinations are not well justified [4,25,26].

In literature there are reports discussing that many CT scans are being ordered for profit, for doctor's convenience and also many times a CT examination is prescribed because the clinicians or the radiologists do not know or consider the alternatives [21,26,27]. The risks from the excessive doses of CT examinations can be reduced if other imaging modalities without ionizing radiation are employed like MRI and ultrasound, or by using traditional radiography that although it is ionizing radiation the dose is significantly lower if using instead.

The collection of the data and the analysis of the results presented in this study seem to confirm most of the above assumptions as well. Therefore in order to reduce and constrain the dose to patients the people involved must be further informed about CT imaging risks and benefits and also about alternative methods. In Greece from statistics available in OECD it is seen that in 2008 CT exams were 321.8 per 1000 population and in 2012 180.3 per 1000, around 45% less [1]. This can be attributed to the effort to inform the radiologists on the CT dose effects and their encouragement to try other diagnostic methods. Also the financial situation in this period with the significant health spending reduction may also have affected it. Analysis of the data in this study showed that, a further reduction in dose and financial cost can be achieved. By avoiding the unnecessary examinations and scans the dose to patients is reduced and the lifetime of the CTs' X-ray tubes is increased.

Conclusion

Over 1000 CT patient exams performed in 11 CT scanners were studied in order to review and estimate CT radiation dose levels in Greece. The results showed a great variety in the $CTDI_{vol}$ and DLP values recorded, a fact attributed not only to CT systems' specifications but more importantly to scanning protocol set-ups and differences in the examination practices followed. As shown in Figures 1-12 the variance of the $CTDI_{vol}$ and DLP values can be as 3 times high. Therefore, despite the fact that the mean of these values satisfied the national DRLs, and were found to be similar to those reported in literature, the dose levels in most of the CT scanners studied can be lowered. In order to reduce the radiation risk of CT examinations, interventions are required to improve protocols and technologists' practices where appropriate, to encourage continuous training and education of the people involved (medical physicist, technologists and doctors), but more importantly to assure justification of the examinations. Information about radiation risks and radiation effects must be channeled to all relevant health providers and patients to help in this respect.

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