

Experience with the use of a dose management system in the everyday routine of a CT department. A touchstone or a millstone?

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ABSTRACT

Purpose: A dose tracking software was recently installed in our CT department. The study aimed at evaluating the software capabilities and staff performance in every day routine.

Material and Methods: A dose tracking software was connected to a 64-slice CT scanner. All technical and dosimetric data of 6,010 CT examinations were analysed. Organ doses estimated by the software were also evaluated.

Results: The software provided easy and quick statistical overview of clinical and technical data. Typical local doses were comparable to national and internation-

al data. Organ doses proved to be an instrumental and supportive tool in individualised patient dosimetry.

Conclusions: The software offered easy and quick statistical overview of all CT clinical and technical data and a valuable overview of workload statistics, which occasionally required discussion with the staff and, in some cases, corrective actions. It easily provided the time periods the scanner was not in use, and facilitated easy scheduling of routine quality control tests and other routine tasks in the department. A number of errors were identified and communicated to the staff; corrective actions were taken.



KEY WORDS

CT; dose; tracking software; optimisation; management



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1. Introduction

CT is widely used in diagnosis of disease and has been identified as the major contributor to the collective radiation dose to population from medical exposures [1-7]. Depending on clinical needs and technical protocols, patient radiation dose differs, even for the same anatomical region, clinical indication, technical protocol and sometimes even for the same CT unit [8-12]. Furthermore, high rates of repeated CT scans are reported in the literature (such as in trauma patients) with additional hospital charges and additional radiation exposure [13]. The urge to monitor medical practices in CT scanner has risen significantly. The effective dose (E) for the most typical CT examinations varies tremendously even for the same technical protocol or the same CT scanner (1 mSv-25 mSv) [8-23]. Therefore, the necessity of tracking patient dose data and CT scanning protocols is essential. It is worth noticing that CT radiation dose is linked to an increased risk of radiation-induced cancer [24-26].

To assess the radiation dose in CT, volumetric computed tomography dose index (CTDI_{vol}), dose length product (DLP) and E are the most widely used radiation dose indices [8, 10, 27]. In order to optimise radiological practices more efficiently in terms of radiation dose, the term Diagnostic Reference Level (DRL) is defined both in the European [28] and International [29] Basic Safety Standards (BSS). It is also clearly stated that medical X-ray equipment must have a means to inform the practitioner of the relevant parameters for assessing the patient dose and, even more important, to have the capacity to transfer this information to the record of the examination [29].

Due to the upcoming implementation of the EU BSS [29], the need for an automated dose monitoring solution rises. This can be an extremely time consuming and complex task. Nowadays, sophisticated software packages with friendly interface can assist to this task, resulting in a much easier and quicker way to monitor all data included in the Digital Imaging and Communication in Medicine (DICOM) header of the CT scanner or data recorded in the Picture Archiving and Communication System (PACS) of the hospital [30-37]. These studies focus on radiation dose data analysis.

One of the commercially available dose tracking software was recently installed in our CT department. Our study focused on evaluating the software features and capabilities and on assessing staff performance in every day routine. It also investigated whether the system can be used solely for

patient radiation dose analysis, or could also assist in the general management of the CT department.

2. Material and Methods

2.1 CT scanner and dose tracking software system

A dose tracking software (DOSE, Qaelum, Belgium) was recently connected to a Philips Brilliance 64 CT scanner (Philips Systems, the Netherlands), installed in 2013 in Konstantopoulio General Hospital in Athens, Greece. This is a software tool that has the capability to connect with a variety of medical ionising and non-ionising radiation units that are available in a hospital and to combine all available data into a single configuration where every examination is analysed and archived. The configuration provides a direct overview and makes information available at any time for all users, depending on their level of authority. Although initially intended to be connected to a number of X-ray modalities such as an angiography system, an older four (4) slice CT scanner and certain computed radiography systems, this could not be done in real practice. This was due to the fact that these devices are old and they could not export dose data in the DICOM formats that the software supports. It must be noted that our hospital does not have a PACS system and therefore the software was connected directly to the Philips 64-slice CT scanner.

2.2 Technical factors and dosimetric quantities collected

For each examination, the tube voltage (kV), tube output (mAs), Field of View (FOV), pitch, collimation, number of slices, series information, scanogram and operator's name are examples of clinical data that can be recorded. Regarding radiation dose metrics, CTDI_{vol} and DLP are the dosimetric quantities transferred from the CT scanner to the software workstation. The software uses the patient CT exam data and calculates E and organ doses. Organ doses are estimated using conversion factors derived from Monte Carlo simulations for a standard-size model. More specifically, the conversion factors are derived by an in-house Monte Carlo simulation model that has been developed based on vGate simulation tool. A reference adult phantom from the phantom library of MIRD is used for the simulations. The model calculates the organ doses for every body part examined according to typical z-ranges. Specifically, for every organ, dose profiles are generated. Simulated scans are performed per 1 cm in the z-direction for



Fig. 1a. The graph shows an evaluation of the number of examinations performed in the CT room and the average DLP as a function of hours and days in the week. The number of exams represents the size of the boxes; the mean accumulated dose length product (DLP) is colour coded.

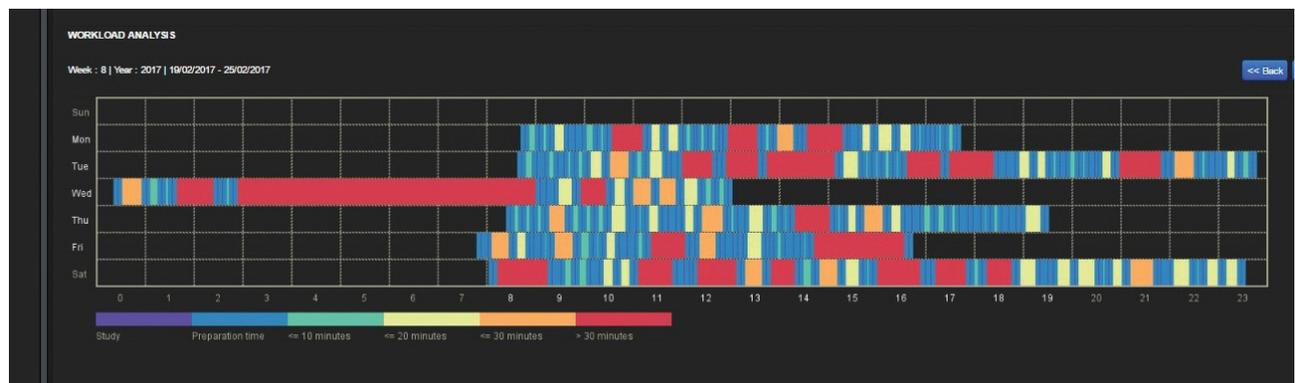


Fig. 1b. The graph shows the analysis of the weekly workload of the CT scanner as a function of hours and days in the week. The bar below the graph defines the colours related to the time periods of the usage. Starting from purple on the left ending to red on the right, the colour bars show: 1) the actual study, 2) the preparation time, 3) time gap of less than 10 min, 4) time gap of less than 20 min, 5) time gap of less than 30 min and finally 6) time gap of more than 30 min.

various photon energies up to 140 keV obtained by combining different energy values according to the realistic spectrum for a given tube voltage. For organs away from the scan range, extrapolation of sparse data is performed. Organ doses are derived by adding the values of the dose profile over the typical z-range (determined by typical examination types). The validation of the in-house model was already performed against commercially available dosimetric tools before the study to ensure accuracy of organ dose estimation [38].

2.3 Patient sample

The study included 6,010 CT examinations from 13th March 2016 to 14th March 2017. The study was performed according to the ethical standards as described by the Declaration of Helsinki. Initially an overall evaluation of all CT examinations and utility of the software was performed. Then a more focused analysis was performed for the most frequent CT exams independently of clinical indication. Due to the higher radiosensitivity of organs in examinations of the trunk, the authors decid-

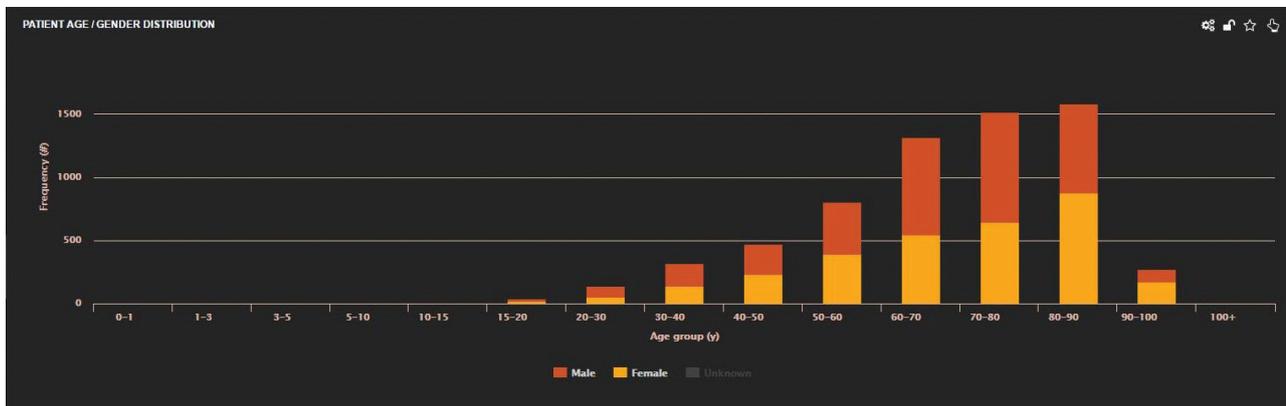


Fig. 2. Distribution (%) of patient sample according to age is presented. The yellow bar represents the female patients and the orange bar the male patients.

ed to focus on these exams for further analysis. In order to estimate organ doses, the examinations were divided in 3 broad anatomical part categories: Chest, Abdomen and Chest/Abdomen/Pelvis (CAP) CT examinations.

3. Results

3.1 Overall evaluation

The percentage of men and women were 41% and 59%, respectively. The software offered easy and quick statistical overview of all clinical and technical data of CT examinations. This overview could be provided for a specific date, for a time period within the day, or for a whole date range selected by the user. An example of this workload overview can be seen in **Fig. 1a and 1b**. **Fig. 1a** shows the evaluation of each hour and day of the week in the CT room, in terms of number of performed examinations and average DLP. The number of examinations is shown by the size of the boxes; the mean accumulated DLP is colour coded. It is practically a moment evaluation chart of the actual usage of the CT scanner plotted together with the corresponding DLP on a certain day and hour. Thus, the volume and dose trends are visualised to facilitate the analysis. The more red the box becomes, the more radiation dose (in terms of DLP) is given to the patients the specified time of the day. As the box becomes bigger in size, the higher is the number of exams. This provided a valuable overview of the workload statistics which occasionally required discussion with the related staff and in some cases, corrective actions. **Fig. 1b** shows a weekly workload analysis graph, that practically monitors the activity in blue and green colours and also the inactivity of the CT scanner (orange and red colour). Reg-

ular evaluation of this graph helped optimise the use efficiency of the scanner. It also allowed making changes in the number of technologists in every day routine for better management of the department. This also identified in a more structured way the time periods the scanner was not in use, in order to schedule routine quality control tests.

The software allowed evaluation of patient demographics, in multiple ways depending on the operator or hospital management needs. **Fig. 2** shows part of patient demographics analysis. It presents the distribution of patient sample according to age, separately for men and women. It shows that most of patients are in the range of 60-90 years, whereas the percentage of patients in the 40-60 years range is much smaller. This could be partially explained by the fact that European population is aging and a rise of chronic diseases is recorded [39].

As far as technical protocols and parameters used are concerned, a very large variability of CT protocols was noticed. Forty six (46) different scanning protocols were recorded for 16 different anatomical regions. These protocols are related both to anatomical region and clinical indication. It must be noted that effective dose and organ doses estimation are related to anatomical region and not clinical indication. The analysis revealed mistakes in the technique mainly related to the technical protocol (extra image series, longer scans than actually needed, wrong protocol used, or even choosing the correct protocol but typing the wrong name). All these errors were communicated to the operators and helped in the optimisation of procedures and better organisation of the department.

Table 1. Median value and range of volumetric Computed Tomography Dose Index (CTDIvol), Dose Length Product (DLP) and Effective dose (E) are shown for 3 types of CT examinations.

	<i>N ps</i>	<i>CTDIvol (mGy)</i>	<i>DLP (mGy.cm)</i>	<i>E (mSv)</i>
Routine Chest	437	10.5 (1.4-45.2)	388.5 (51.5-1,040)	7.78 (1.0-20.8)
Routine Abdomen	410	14.8 (4.9-38.01)	706.4 (136.4-767.8)	12.0 (2.4-35.8)
Chest_Abdomen_Pelvis	566	15.3 (6.3-62.7)	1510 (290.9-5,700)	26.0 (4.9-96.9)

Table 2. Local DRLs in terms of CTDIvol and DLP are defined and presented in this table.

	<i>CTDIvol (mGy)</i>	<i>DLP (mGy.cm)</i>
Chest	11	390
Abdomen	15	710
Chest_Abdomen_Pelvis	15	1510

Table 3. Local DRLs are compared to national and international DRLs.

Chest		
	<i>CTDIvol (mGy)</i>	<i>DLP (mGy.cm)</i>
Local DRLs 2017	11	390
National DRLs 2014	14	480
European DRLs 1999	-	650
UK DRLs 2011	12	610
Abdomen		
	<i>CTDIvol (mGy)</i>	<i>DLP (mGy.cm)</i>
Local DRLs 2017	15	710
National DRLs 2014	-	-
European DRLs 1999	-	780
UK DRLs 2011	14	910
CAP		
	<i>CTDIvol (mGy)</i>	<i>DLP (mGy.cm)</i>
Local DRLs 2017	15	1510
National DRLs 2014	17	1020
European DRLs 1999	-	1000
UK DRLs 2011	14	1000

3.2 Dose evaluation

Table 1 shows median value and range for CTDIvol, DLP and E for routine chest and abdomen, as well as CAP examinations. Minimum dose values were found for Chest CT, followed by Abdomen CT and CAP exam. CTDIvol values did

not have big differences between exam protocols. On the other hand, DLP almost doubled from Chest to Abdomen and more than tripled from Chest to CAP exam. For E, the value increased about 1.6 times from Chest to Abdomen and 2 times from Chest to CAP exam. The large range in DLP and

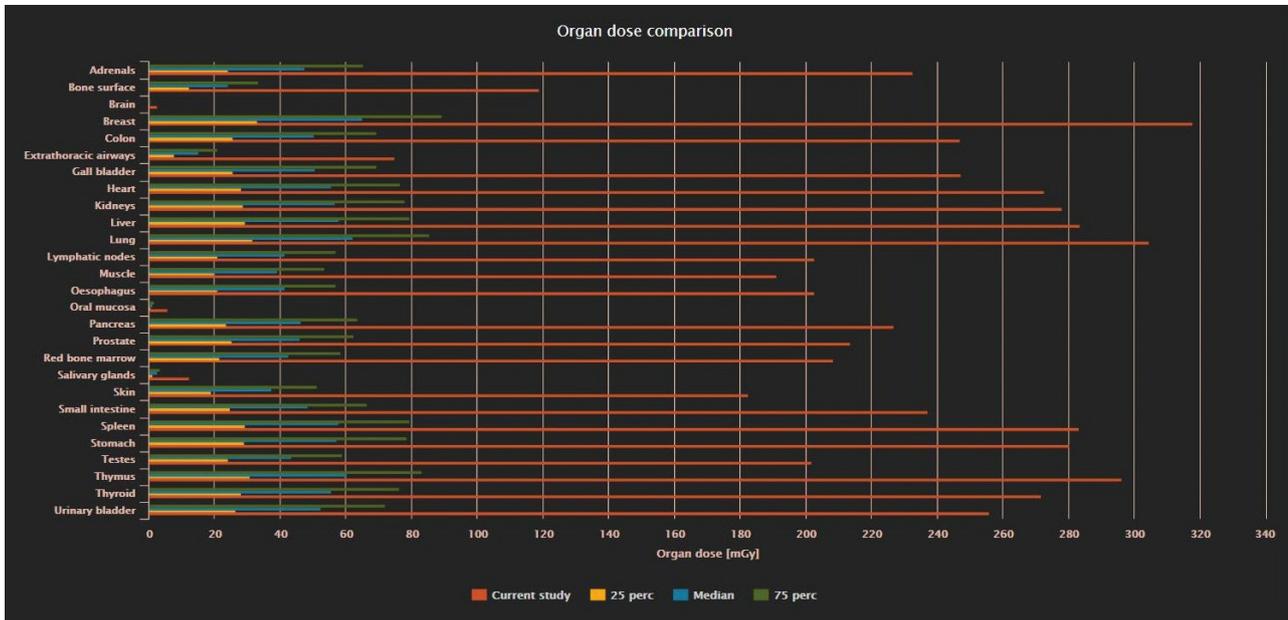


Fig.3a. Organ doses in mGy are shown for a) a patient with high dose values (orange bars) compared to 25% (yellow bars), median (blue bars) and 75% (green bars) organ doses of the whole patient sample and for b) a patient with low dose values.
a) Male patient, CAP examination, E: 96.9 mSv, b) Male patient, CAP examination, E: 6.5 mSv.

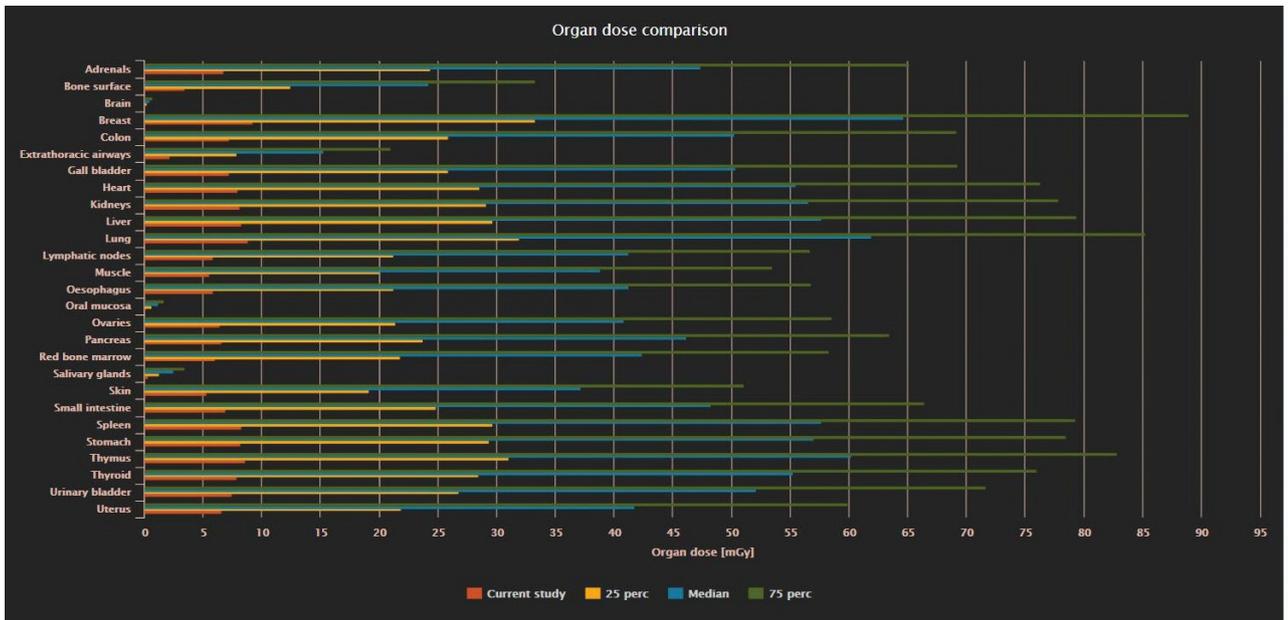


Fig.3b. Male patient, CAP examination, E: 6.5 mSv.

E values especially in CAP reflected the protocol variability. This could be partially explained by different number of series (pre-contrast, post-contrast studies, multiphase studies, etc.) depending on clinical indication and physician choice. Another reason was the different scan range applied by some operators. This was further investigated

and results are presented in the last paragraph of this section. In general, all findings were discussed with radiologists and technologists and corrective actions were taken.

Table 2 defines typical local DRLs in terms of CTDIvol (mGy) and DLP (mGy.cm). They are defined based on the methodology described in the European Commission

Table 4. Mean E (mSv) per patient is compared with typical E and/or range of values found in the recent literature. It must be noted that patients in our hospital have a pre-contrast and a post-contrast part (one scan before and one scan after contrast both for chest and abdomen examinations).

Study	Chest	Abdomen	Chest/Abdomen/Pelvis
Current study 2017	7.8	12.0	26.0
Shrimpton 2016 [18]	14	16	19
Mettler et al. 2008 [19]	7 (4-18)	8 (3.5-25)	/
NCRP report 60, 2009 [21]	4-18	/	/
Christner et al. 2010 [22]	3.2-9.3	/	/
Da-Ming Yeh et al. 2013 [23]	3.0-7.3	21.5	19.7

Guidance document on DRLs for medical exposures [40].

Table 3 presents the comparison of typical local DRLs to national and international data found in the recent literature. It is noted that in almost all cases our local values are lower than both national and international data. The only local DRL higher than international data was for the CAP exam. As CTDIvol was comparable with the literature data, it is obvious that the scanning length was the reason for the higher CAP DLP.

Table 4 presents the comparison of E with international literature [18, 19, 21-23]. It must be noted that our data are based on the fact that our routine examinations are performed with a pre-contrast and a post-contrast scan. Some of the papers listed in the table [23] specify values both per scan and per patient. Others do not clarify if values reported are for one or two scans (pre contrast or both pre and post contrast scans). It is evident that this plays a very important role for the final value of E. The large variability of doses reflects the large differences in technical protocols that most often depend on clinical indication, or the differences in scan length (usually the choice of operator).

The software also offers individual organ doses (mGy) estimation in routine basis. Apart from individual patient organ doses, the software calculates the 25 percentile, median values and 75 percentile for the organ doses. There is also the possibility to calculate these values for the whole sample of patients or apply a filter based on the specific body part or the same description of the examination. An example is given in **Fig. 3a and 3b**. In **Fig. 3a**, organ doses are shown for a male patient undergoing a multi phase CAP examination receiving an E of 96.9 mSv. The figure shows the organ doses in orange bars compared to the 25%

of the whole patient sample distribution (yellow bars), the median (blue bars) and 75% (green bars). In **Fig. 3b**, organ doses are shown in a similar way for a male patient undergoing a single phase CAP examination receiving a low E dose of 6.5 mSv. The bar graphs of the 2 figures clearly show that organ doses in a high dose exam can reach values over 300 mGy in more than one organ (breast, lung, etc.) whereas there are CT examinations in which no organ receives a dose above 10 mGy (**Fig. 3a**). This tool was used in specific patient to patient dose evaluation and as an educational means for optimisation purposes. In certain cases, it was helpful to estimate quickly organ doses in women of reproductive age in case of anxiety following a CT exam (this reassured the patient that radiation dose was minimal).

DLP is the dose value that represents more efficiently the differences between radiographers due to the differences in scan length (**Fig. 4**). Chest CT is a straightforward standard examination, which is performed in a similar way in terms of DLP by all radiographers. Abdomen and even more the CAP examinations vary in terms of DLP, due to the different scan region. This was also communicated and further discussed with radiographers and radiologists. As the software has a simulation tool that estimates organ and effective dose for different technical CT factors, it was used for educational purposes to show in a more efficient way the effect of scan length (as well as all technical CT factors) in radiation dose.

4. Discussion

The dose management system proved to be an effective, powerful tool that facilitated the evaluation of gener-

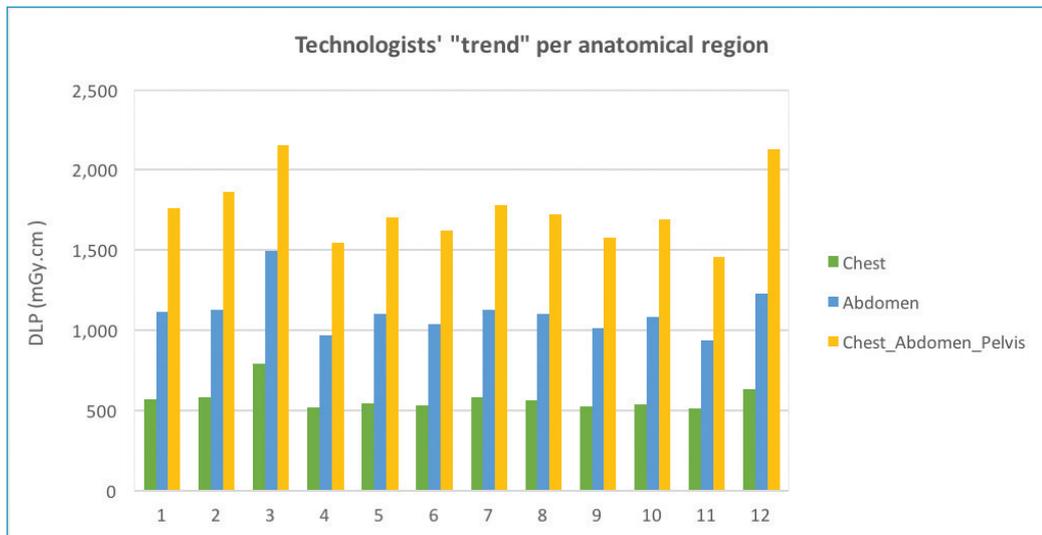


Fig. 4. Radiographer “habits” in relation to DLP are shown.

al practice and workflow of the CT department and revealed the habits of operators, so that corrective actions are made for the benefit of the patient. Before installing the software, analysis of data was a cumbersome process that required manual entry of values, with significant outflow of resources and the risk of typing errors. The fact that all these had to be done manually patient by patient was the main reason why it could not be done in a systematic way.

One could argue that the implementation of a dose management system is a cost for the hospital, especially with the current financial situation in Greece. This cost, which usually increases with the number of X-ray devices or examinations performed, includes not only the installation but also the maintenance. However, the gain of the hospital is also important. In this study, we highlighted some parts of the benefit, mostly in terms of improvement of workload, personnel efficiency and patient dose evaluation. As far as radiation doses are concerned, assessment of examination doses in terms of CTDIvol and DLP for a certain number of patients is presented and discussed extensively in the international literature for at least 20 years. The use of the dose tracking tool to eval-

uate the whole sample and not only a limited number of patients helped to easily identify weaknesses and mistakes in our every day routine. The immediate estimation of E and organ doses proved to be a valuable tool in this process. It allowed us to take a deep dive into the patient data for optimisation of safety, quality, training and practice of the department.

The traditional estimation of average CTDIvol, DLP and E and comparison with national or international values seems no longer relevant, if one considers the numerous and very different technical protocols applied for different clinical indications for the same anatomical region. Furthermore, the number of scanning phases depends also on the clinical indication which is basically the main determining factor of radiation dose. Various clinical indication-specific CT technical protocols have been developed to help tailor CT dose and image quality on the basis of specific clinical indications. It seems essential to define diagnostic reference levels for each of these clinical indications for more accurate comparison of practice. **R**

Conflict of interest

The authors declared no conflicts of interest.

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