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Dose Optimization Studies by Selecting Kilovoltage in Oncologic Chest CT

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Abstract

In this work we have studied the adequacy of dose levels of irradiation in oncologic chest CT obtained in our daily practice. The secondary objective was to evaluate the effect on radiation dose of individual adjustment of kilovoltage in thoracic multidetector row computed tomography (MDCT) images acquired with both single and dual-source technology. The impact of lowering the kilovoltage in the diagnostic quality of these studies was also evaluated. 161 patients were included in the study. CT examinations were performed using two different equipments: a conventional CT scanner and a dual-source computed tomography. The average values of dose length product (DLP) obtained in our daily practice meet the recommendations of the existing referral guidelines. Lower values can be achieved through individual adjustment of kilovoltage and with dual-source CT technology, maintaining the diagnostic quality of these studies.

Keywords: Multidetector-row computerized tomography; Radiation

Introduction

Multidetector-row computerized tomography (MDCT) is at the moment the best method to detect pulmonary nodules (potential lung cancers) and to follow up oncologic patients. As a result, the number of MDCT exams for these purposes has increased exponentially in the last years, generating a large volume of images, working hours, and also higher levels of radiation dose.

There is a growing concern among health professionals, as well as in general population, about radiation dose in CT (computerized tomography) and its carcinogenic risks, and there are many scientific articles that refer to it [1-5]. As a result the field of management of radiation dose has grown significantly.

It has been pointed out that the diagnostic accuracy of CT could be maintained while reducing the radiation exposure; in fact, it has been claimed about the need of lowering the radiation dose "as low as reasonably achievable" (the ALARA principle) [1].

Different approaches have been proposed in order to reduce the dose [6], including adjustments of the milliamperage (automatic milliamperage modulation) [2] already introduced in the vast majority of MDCT (taking a plain x-ray as a scout view, these scanners estimate the mAs needed for obtaining a good image, on the basis of the different densities of the tissues) (Figure 1), as well as adjustments of kilovoltage (which has to be made still manually in many cases nowadays), depending on the patient morphotype [7] (as long as the radiation dose varies approximately with the square of the kilovoltage, it has been pointed out that reducing the kilovoltage is a potentially more efficient way to lower the radiation dose than reducing the milliamperage) [3,8], and also taking into consideration their age (in order to reduce these doses in children, even if that means obtaining images with lower quality) [9].

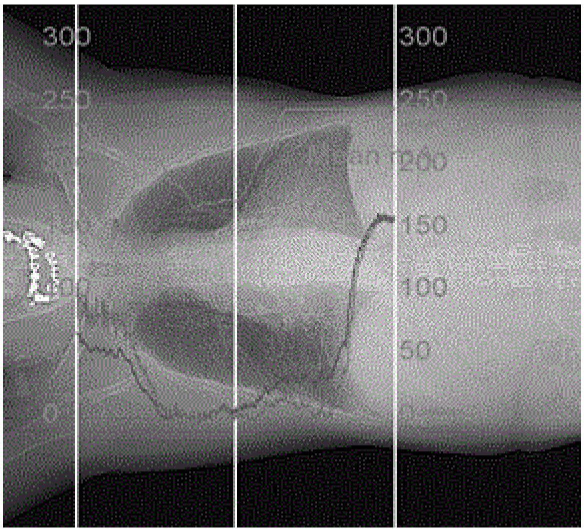

Figure 1: Automatic adjustment of milliamperage, based on the different radiologic densities of tissues in the survey x-ray.

As a result of using these reduction dose strategies, generally the noise also increases in the images, and this could hamper diagnostic purposes. Recently, several investigators have proposed iterative techniques for dose reduction, which are designed to reduce radiation dose maintaining a good image quality [1]. Furthermore, many actual MDCT scanners (like the Siemens SOMATOM EmotionForce, which we use in this study), benefice from advanced software which includes algorithms for iterative reconstruction and by using these programs is possible to obtain processed series of sharper images from lower quality acquisitions, and thus lower radiation dose (Figure 2).

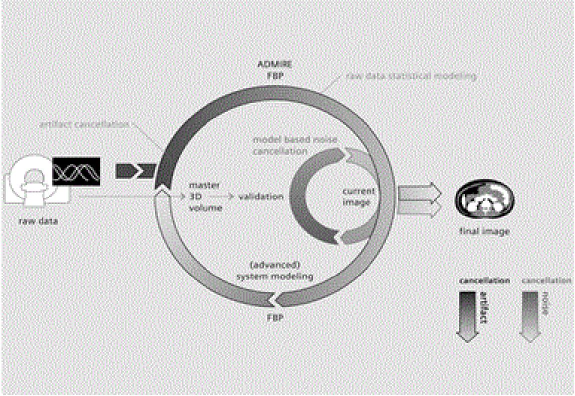

Figure 2: Siemens algorithms for iterative reconstruction.

Following the recommendations of the existing guidelines [10], we designed this study, its objectives being twofold. Firstly, to determine the radiation doses delivered at the moment at our diagnostic imaging department in daily clinical practice, comparing them with the current recommendations; and, secondly, to evaluate the effect on radiation dose of individual adjustment of kilovoltage in thoracic MDCT images acquired with single and dual-source technology.

Materials and Methods

Examinations were performed in Santiago de Compostela and Lille, with a 6-slice CT scanner "SOMATOM-Emotion6", and a third generation dual-source computed tomography (DSCT) scanner "SOMATOM-Force" (Siemens Medical System, Forchheim, Germany). The study was approved by the ethics committee. Informed consent from patients was also required in agreement with national regulations.

The CT protocol consisted on non-gated acquisitions over the entire thorax, obtained in a cranial-caudal direction, with the patients scanned in the supine position and after deep inspiration. In all cases, the injection protocol consisted on the administration of an iodinated contrast medium, and the acquisition was always with the arms above the head.

The acquisition parameters were as follows. EMOTION6: collimation 6 × 1.0, slice thickness 1.25 mm, 110/130 kV (kilovoltage), 48-107 mAs (milliamperage). FORCE: collimation 64 × 0.6, slice thickness 1 mm, 100-150 kV, 65-300 mAs.

Data were reconstructed at 1.25 mm (Emotion6) and 1 mm (Force) contiguous transverse CT scans of the entire thorax, viewed in both the soft tissue (window width, 450 Hounsfield Units; HU, window center, 50 HU), soft reconstruction, and lung parenchyma (window width, 1600 HU; window center, -600 HU; high spatial frequency algorithm) window settings. The images were obtained in DICOM (Digital Imaging and Communication in Medicine) file formats directly from the CT modality. All patient data were removed from the images.

The protocol was applied on CT scans performed in 161 patients. The database consisted on 105 patients scanned using the Somaton-Emotion 6, split in two groups: 66 patients scanned with the 130 kV protocol, those with a body mass index (BMI)>23 kg m^{-2}, 39 patients scanned with the 110 kV protocol (patients with a BMI <23 kg m^{-2}), and 56 patients scanned using the Somatom Force (a dual-source MDCT). These patients were included in just one group, since this scanner uses authomatic kilovoltage modulation (the SOMATOM Force delivers up to 2 × 1300 mA, offering voltages from 70-150 kV in steps of 10 kV, automatically selected through CARE kV, based on patient body habitus and examination type).

The criteria to determine whether a CT scan was eligible for inclusion in the database were as follows:

1) The scans were performed by an experienced chest radiologist from the different institutions that collaborated in the project.

2) All the acquisitions included kilovoltage selection (manual, depending on the weight on the Emotion6 groups, and automatic on the SomatomForce group), and automatic milliamperage modulation (in all cases).

We recorded the data of all 161 patients from the three study groups (Emotion6-130 kV, Emotion6-110 kV, and SomatomForce), and designed a statistical analysis of the DLP (Dose Lenght Product) and CTDIvol (Volumetric Computed Tomography Dose Index) values obtained. Based on these data, we calculated the values of effective dose.

Also, in the case of the two Emotion6 groups, we also estimated the individual SSDE (size specific dose estimate) values. Finally, we designed an objective analysis of image quality establishing a comparative between the 110 kV and 130 kV groups.

Results

An estimated minimal number of patients were necessary to detect a difference for the means of DLP values. On the basis of 161 patients, statistical analysis was performed and results of DLP were expressed by means, standard deviations, and as frequencies, percentiles and percentages (Table 1). Comparative analysis was obtained using Microsoft Excel®.

	Emotion	**Emotion**	**Force**
	130 kV	110 kV	100-150 kV
MEAN (mGy*cm)	328.48	188.95	96.2
SD	88.64	68.58	67.64
MAX (mGy*cm)	578	578	292
MIN (mGy*cm)	177	103	23
p50 (mGy*cm)	317	180	80.4
P75 (mGy*cm)	380.2	204.5	153.4
N	66	39	56

Table 1: Radiation dose parameters (DLP) using 130 kV, 110 kV (Emotion 6), and dual-source technology (Somatom Force).

Next, we obtained the values of effective dose, by using the conversion factor described by the European Guidelines for Computed Tomography for chest CT (0.014 mSv/mGy*cm).

On the other hand, the SSDE values were obtained using the tabulated data reported by the AAPM (American Association of Physicists in Medicine) [11], based on the CTDIvol values, as well as the thoracic diameters of the patients. These values were calculated only on the Somatom Emotion 6 groups. We express the mean values of these parameters on Table 2.

	Emotion	**Emotion**	**Force**
	130 kV	110 kV	100-150 kV
DLP (mGy*cm)	328.48	188.95	96.2
Effective dose (mSv)	4.6	2.65	1.35
CTDIvol	9.02	5.62	n/A
SSDE (mGy)	11.54	6.99	n/A
N	66	39	56

Table 2: Mean radiation dose parameters (DLP, mSv, CTDIvol and SSDE) using 130 kV, 110 kV, and dual-source technology.

All protocols demonstrated to use mean doses of radiation that were lower than those recommended by European experts (for a typical chest scan performed with a single detector scanner, the recommended DLP is 375 mGy*cm) [12], but we found great differences between them.

	130 kV (mean)	**130 kV (SD)**	**110 kV (mean)**	**110 kV (SD)**
Tracheal noise (ROI SD)	18.17	2.86	22.5	2.78
Vessel HU(ROI mean)	313.33	103.15	361.75	80.2
Vessel noise(ROI SD)	67.98	44.66	78.67	15.73
Muscle HU(ROI mean)	57.17	7.26	58.5	5.85
CTR ratio	3.77		3.85	

Table 3: Comparison of the levels of noise obtained using Somatom Emotion with 110 kV and 130 kV protocols (CTR=VHU-MHU/VN).

Using the standard Somatom Emotion 6,130 kV single-source protocol, we obtained mean radiation doses just a little below the recommended levels, since the mean DLP, 328.48 mGy*cm, is just 12.5 % better. However, we found that more than 25 % of patients with the 130 kV protocol were in fact receiving radiation doses which exceeded the recommendations.

On the other hand, we found that by lowering the kV from 130 to 110 kV the mean DLP lowered by 42.5%.

But the best values were indeed obtained by using the Somatom Force dual-source scanner, since with this protocol the mean DLP was reduced by nearly 70% in comparison with the 130 kV single-source protocol. Moreover, none of the patients even approached the recommended level, and the maximum value was as low as 292.1 mGy*cm. This is very important because even if our 110 kV protocol demonstrated to be useful for lowering the radiation dose, it could not be appropriate for patients with a BMI over 23 kgm-2 Instead, the Somatom Force scanner protocol can be used in any patient, being able to achieve doses even lower than 37.5 mGy*cm (10% of the doses of reference) in the case of the thinner patients.

Finally, we found that, by using the 110 kV protocol in patients with lower body mass, the SSDE was reduced by 39.43%, which means that the individual adjustment of kilovoltage based on the BMI not only prevents thinner patients from receiving the excess of radiation that the 130 kV protocol would represent. Moreover, they also suffer a lower radiation dose, in comparison with the 130 kV group.

Another objective of our study was to define if the diagnostic quality of the images obtained using the two protocols (130 kV and 110 kV) of the Somatom Emotion 6, was similar. Firstly, we evaluated the levels of noise existing in the studies acquired using the Somatom Emotion MDCT, and we found that the level of noise, measured as the SD of the density (Hounsfield Units) at the tracheal lumen, was higher in the 110 kV group (18.17 vs 22.5). But the level of noise isn't enough to judge the diagnostic quality of the images, which improves markedly by using iodine intravenous contrasts, and could be a more important factor.

In order to investigate that possibility, we calculated a contrast-to-noise ratio, defined as the Vessel HU density mean minus the Muscle HU density mean, divided by the Vessel noise (SD ot the density mean), was just slightly higher in the 110 kV group (3.77 vs 3.85) (Table 3).

The results obtained indicate that, in contrasted images, the power to differentiate between two structures which enhance in different degree is similar in the 110 kV and 130 kV groups.

So, even if there is a significative difference in the levels of noise, that difference doesn´t affect the diagnostic quality in the contrasted images, which was in fact similar in both groups of study. However, we have to consider the fact that the BMI of these two groups of study was different, and as a result, the quality probably would be significantly lower if we used the 110 kV protocol in patients with a BMI>23.

Discussion

Lung cancer is a leading cause of cancer-related deaths in the world. Accurate diagnosis and staging are critical factors in order to choose the best treatment, as well as in the evaluation of prognosis of patients with bronchogenic carcinoma [12]. As a result, the total amount of chest CT performed for these purposes will probably rise significantly. It is therefore necessary to develop strategies to keep the radiation values well below the recommended dosemetric levels [13,14].

In this work, we have described and validated our experience in daily practice. We have used the results of dosemetric measurements to estimate the radiation dose at our hospital and compared them with those from another radiology department, therefore evaluating different MDCT scanners. In our results, we found that we can significantly reduce the radiation dose delivered to the patients during the CT exam of the chest with weight adapted low kilovoltage protocols. And, nonetheless, this weight adapted low kilovoltage protocol was fully compatible with the diagnostic task of CT examinations.

Also, we evaluated the SSDE, a recently proposed indicator that grants better knowledge about the radiation dose delivered to patients taking in count their morphotypes [11]. The results obtained are encouraging, as long as they indicate that low kV scans performed in thinner patients lead to proportionally lower radiation doses in comparison with patients with higher BMI.

It is difficult to establish comparison among protocols obtained and tested over different databases. Comparing with the reference values from the recommendations of the expert group of the European Commision, our results (4.6 and 2.65 mSv) [15,16] are in good agreement with the accepted values, and they are lower than the reference dose value defined by the European Communities for routine chest CT [17]. Our values are also lower than the reference effective dose s for CT scans reported from the Fleishner Society [18]. Our results are also in good agreement with those of Héliou et al. [19], Treier et al. [20], and Broucker et al. [3].

This study suffers from several limitations. Firstly, the study population was limited. In addition, the examinations were chosen at random and might not reflect a perfect average type of routine examination. And yet something more should have been taken into consideration: it would be interesting to study the impact of the system on a general population.

Besides, another relevant aspect would be to calculate their consecutive doses (for comparative studies). In fact, it is advisable to monitor the studies for temporal changes; therefore, we should analyze the variations on these radiation doses. This will be the objective of our future investigations.

No quantitative definition exists to indicate how low the dose in CT must be. Likewise, no precise definition of the term standard dose exists. In fact, the meaning of low dose is subject to considerable variation over time: the currently considered low dose will become the clinical standard in a very foreseeable future [21]; considerable variation that can also be related to the different equipments and techniques that can be utilized. In this study we have pretended to acquire a better knowledge about the radiation doses delivered at our departments, from different equipments, in order to improve our daily practice, trying to reduce them as low as possible, and, also, evaluating the possibilities offered by the new generation MDCT scanners.

We will continue to explore different ways of combining the appropriate techniques for our acquisition protocols, exploiting all the options to allow the doses to be reduced. Of interest of this is that RECIST (response evaluation criteria in solid tumors) requires follow-up studies of every other cycle of chemotherapy. As a result, the CT effectiveness in patient management in combination with its technological advances resulted in an increased in the frequency of these type of examinations, rendering the CT the modality with the highest radiation burden among most diagnostic examinations [22]. But the ALARA principle should always be applied, and we must take the lead in promoting this principle [23,24].

Conclusions

The average values of DLP obtained in our daily practice meet the recommendations of the existing referral guidelines. We can obtain lower values through individual adjustment of kilovoltage, maintaining the diagnostic quality of our studies. Also, patients with low BMI enrolled in scanners performed with a 110 KV protocol can benefit with lower radiation doses in comparison with the higher BMI patients included in the 130 kV group. The best results require MDCT scanners with automatic kilovoltage and miliamperage selection, as well as methods for iterative image reconstruction.

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