Single- and dual-source chest CT protocols: Levels of radiation dose in routine clinical practice

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Thoracic CT; Dose; Adults; Dual source; Dual energy

Abstract
Purpose: To establish the radiation dose level for single- and dual-source thoracic CT scans in daily practice.
Materials and methods: The dose levels delivered during 634 consecutive examinations over a period of 2 months were recorded. The CT scans were performed using: (a) a standard protocol (single source, single energy [group 1]: n = 266; dual source, single energy [group 2]: n = 276; (b) with prospective ECG synchronisation [group 3]: n = 13; or (c) with dual energy [group 4]: n = 79. All the acquisitions included kilovoltage selection depending on the weight and automatic milliamperage modulation.
Results: The mean DLP of the standard protocols was 97.12 mGy cm (group 2; BMI = 23.1 kg/m²) and 211.1 mGy cm (group 1; BMI = 27.3 kg/m²), the choice of protocol depending on the diameter of the thorax relative to the diameter of the field of the second source, and therefore on the patient’s morphotype. When imaging included examination of the proximal and middle coronary arteries (group 3), the mean DLP was 105.5 mGy cm. Morphological and functional imaging (group 4) was obtained with a mean DLP of 404.3 mGy cm.
Conclusion: Depending on the objective of the protocol, the mean DLP varied from 97.12 to 404.3 mGy cm.

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Exposure to X-rays for medical, diagnostic or therapeutic purposes represents a large part of total exposure. In 2007, it was established that in France diagnostic procedures using ionising radiation led to a mean effective dose per inhabitant of 1.3 mSv, with estimated natural irradiation being 2.4 mSv/year [1]. The frequency distribution for these
procedures in France depending on the type of investigation, as established in 2007 by the French Institute for Public Health Surveillance (Institut de Veille Sanitaire), is 63% conventional radiology (excluding dental procedures), 24.7% dental radiology, 10.1% computed tomography (CT), 1.6% nuclear medicine and 0.6% interventional radiology [1]. CT plays a prominent role in total diagnostic exposure to X-rays, especially as it is now replacing a large number of conventional examinations: in 2007 in France, 58% of the total collective effective dose was from CT scans [1]. The subject of risks is a growing preoccupation, particularly the carcinogenic risks of ionising radiation. For a number of years radiologists and nuclear medicine doctors have been very concerned with reducing these risks, a matter which has become a legal obligation since the European directive 97/43 was adopted [2]. Apart from the essentials of justifying the examinations, radiologists have agreed to optimise the examinations performed. In thoracic CT, several means of optimisation have been considered such as the use of bismuth impregnated shielding [3], adjustment of settings depending on the patient’s morphotype [4–10], collimation adjustment [11], and the use of automatic milliamperage modulation [12–15]. The aim of our work was to establish the dose levels of irradiation in thoracic CT, recorded in daily CT practice in a specialised thoracic imaging department, and to compare them with the current French recommendations.

Materials and methods

Study population

In order to study the dose levels delivered in the daily CT scanning of adults in a thoracic imaging department of a university hospital, the population of this study was prospectively included over a period of two months (July 2010–August 2010). It included any adult outpatient or inpatient referred for a thoracic CT examination, with or without injection of contrast agent, but excluded patients referred for a puncture procedure or percutaneous drainage. Patients had been referred from outpatient day treatment units and conventional inpatient departments, other than intensive care.

Examination protocols

The examinations were performed using a single machine (Somatom Definition Flash, Siemens, Forchheim, Germany). There were four management protocols:

(a) single source, single energy, without ECG gating (protocol 1);
(b) dual source, single energy, without ECG gating (protocol 2);
(c) dual source, single energy with prospective ECG gating (protocol 3);
(d) dual source, dual energy (protocol 4).

For our team, protocols 1 and 2 are routine standard protocols for a thoracic CT examination. Protocol 3 is indicated when we wish to include morphological information on the coronary arteries in the standard thoracic CT examination, and protocol 4 is for any CT angio graphic examination requiring standard morphological information to be linked to study of the pulmonary perfusion. As regards the standard protocol, protocol 2 was preferred because of greater temporal resolution (75 ms vs. 140 ms) and higher pitch (pitch 3.0 vs. pitch 1.5) reducing the acquisition time to about one second for the entire length of the thorax; it did however depend on the circumference of the patient’s chest since the field of tube B is narrower than that of tube A, only covering 33 cm. Consequently, protocol 1 became the standard protocol by default for any patient with a thoracic diameter greater than 33 cm.

With the exception of acquisitions with ECG synchronisation (protocol 3) based on fixed kilovoltage and milliamperage, the choice of irradiation parameters of the other protocols depended on the weight of the patient in conjunction with the criteria summarised in Table 1 (protocols 1 and 2) and Table 2 (protocol 4). The main characteristics of the acquisition parameters of the four protocols are summarised in Table 3. In all cases, acquisition was always in the craniocaudal direction, in forced inspira tion with the arms raised above the head. Reconstructions (pulmonary and mediastinal images) were systematically in transverse adjacent, 1 mm slices, with a high spatial frequency algorithm (B50; pulmonary images) and a density resolution filter (B20; mediastinal images).

Study parameters

The following data were collected for each patient:

<p>| Table 1 | Selection of kilovoltage and milliamperage according to the weight of the patient for single or dual source, simple energy computed tomography (protocols 1 &amp; 2). |
|-------------------------------------------------|</p>
<table>
<thead>
<tr>
<th>Patient weight (kg)</th>
<th>Kilovoltage (kV)</th>
<th>Charge (reference mAs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 50</td>
<td>80</td>
<td>120</td>
</tr>
<tr>
<td>50–80</td>
<td>100</td>
<td>90</td>
</tr>
<tr>
<td>81–100</td>
<td>120</td>
<td>90</td>
</tr>
<tr>
<td>≥ 100</td>
<td>140</td>
<td>90–140</td>
</tr>
</tbody>
</table>

| kg: kilogram; kV: kilovolt; mAs: milliampere-second. |

| Table 2 | Selection of the kilovoltage and milliamperage according to the weight of the patient in dual energy computed tomography (protocol 4). |
|-------------------------------------------------|
| Patient ≤ 110 kg | Patient > 110 kg |
| Tube A: 80 kV; 300 mAs | Tube A: 100 kV; 250 mAs |
| Tube B: 140 Sn kV; 100 mAs | Tube B: 140 Sn kV; 100 mAs |
| 4D modulation of the milliamperage: inactivated | 4D modulation of the milliamperage: inactivated |
| Collimation: 32 × 0.6 mm Pitch: 0.5 | Collimation: 32 × 0.6 mm Pitch: 0.6 |
Table 3  Main characteristics of the acquisition protocols in routine clinical use.

<table>
<thead>
<tr>
<th></th>
<th>Protocol 1 Single source, single energy</th>
<th>Protocol 2 Dual source, single energy, without gating</th>
<th>Protocol 3 Dual source, single energy, with gating</th>
<th>Protocol 4 Dual source, dual energy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kilovoltage-milliamperage</td>
<td>% weight of the patient (Table 1)</td>
<td>% weight of the patient (Table 1)</td>
<td>120 kV - 200 mAs/rotation</td>
<td>% weight of the patient (Table 1)</td>
</tr>
<tr>
<td>Collimationa</td>
<td>64 × 0.6 mm</td>
<td>64 × 0.6 mm</td>
<td>63 × 0.6 mm</td>
<td>32 × 0.6 mm</td>
</tr>
<tr>
<td>Pitch</td>
<td>1.5</td>
<td>3</td>
<td>3.2</td>
<td>0.5—0.6</td>
</tr>
<tr>
<td>4D modulation milliamperage</td>
<td>Activated</td>
<td>Activated</td>
<td>Activated</td>
<td>Inactivated</td>
</tr>
</tbody>
</table>

a64 (or 32) rows of detectors used allowing, with floating focal spot in the z axis, reconstruction of 128 (or 64) slices per rotation.

- patient’s parameters: age (years), weight (kg) and height (m), needed to calculate the body mass index (BMI; kg/m²);
- CT examination: (b-1) indication for the CT scan; (b-2) protocol applied, without separating examinations with from those without injection; (b-3) impact of the noise level in the images, judged overall by whether or not the examination can be interpreted; this subjective noise analysis was done by senior radiologists in charge of the interpretation during clinical routine;
- dose delivered: dose length product (DLP) (mGy cm), CT dose index or CTDIvol (mGy). The accumulated DLP was the total DLP given in the ‘patient summary’ as shown on the console at the end of the examination. This value took into account acquisition over the whole thorax and any additional acquisition (volume or sequential; overall or part of the thorax) in the following situations: subsequent contrast injection (as an addition to acquisition initially programmed without injection; for obtaining a late phase acquisition); failure of the first acquisition (respiratory movement artefacts in severe dyspnoea; insufficient inspiratory apnoea); incremental acquisition during expiration or in ventral decubitus. Given the criticisms raised by calculation of the effective dose and uncertainties concerning the weighting factor to apply [16—19], we have not included effective dose calculations.

Statistical analysis

Statistical analysis was performed using the SAS commercial program (SAS Institute, Cary, NC 25513; version 9.2). The results are expressed as means with standard deviations for quantitative variables and as frequencies and percentages for qualitative variables. The DLP according to the standard protocols was compared in a Student test. For protocols 2 and 3, we used the Mann-Whitney U test. For comparing the DLP according to the different BMI levels, we used the analysis of variance test. Qualitative parameters were compared with a Chi² or Fisher exact test. A P value less than 0.05 was considered to be significant.

Results

Characteristics of the population studied

The population examined during the study period consisted of 634 patients (400 men, 234 women), divided into three age categories: ≤ 35 years old, n = 68 (10.73%); 35—65 years old, n = 341 (53.79%) and ≥ 65 years old, n = 225 (35.49%). The mean BMI was 25.11 kg/m² ± 5.38 (range: 14.06—52.05). Fig. 1 summarises the distribution of indications for CT examinations in the population studied, dominated by oncology.

![Figure 1. Distribution of indications for computed tomography examination in the population studied (n = 634).](image-url)
Characteristics of the protocols used

Fig. 2 gives the distribution of kilovoltages in our population for the single energy protocols performed (in dual energy the kilovoltage is fixed). Fig. 3 summarises the distribution of the protocols used. The majority of examinations were performed at 100 kV (56.1%) and 120 kV (36%), the examinations performed at 80 kV and 140 kV each making up 3.9%. In all cases, the overall quality of the CT examinations was readable.

Doses delivered

Dose delivered according to technique

In the overall population, the mean value (±SD) of the DLP and the volume CTDI was 184.12 ± 155.66 mGy cm (range: 10–849, median: 124) and 5.02 ± 5.25 mGy (range: 0.54–33.49). The noise level of the examinations was not considered to have any impact on the diagnostic value of them for the 634 patients examined. Fig. 4 summarises the mean values and the 95% confidence intervals of the means of the DLP according to the examination protocol used. As regards the standard protocols, the mean DLP value of protocol 2 (dual source, single energy) was significantly lower than that of protocol 1 (single source, single energy) (P < 0.0001). The DLP values of protocol 2 (dual source, single energy) were significantly lower than those of protocol 3 (dual source, single energy with gating) (P = 0.0045). The mean value (±SD) of the DLP of dual energy examinations was 403.4 ± 79.33 mGy cm.

Dose delivered according to the indication for the examination

Fig. 5 summarises the mean DLP level (and the 95% confidence intervals) depending on the indication for the CT examination. The mean values were between 155.2 and 185.8 mGy cm excluding indications for vascular diseases, systematically performed in dual energy unless the patient was dyspnoeic and thus unable to hold his breath for approximately 10 seconds (mean duration of a whole thorax dual energy acquisition).

Dose delivered according to the body mass index (BMI) category

Fig. 6 summarises the mean DLP values (and the 95% confidence interval) according to the BMI categories. Significant differences were observed between the doses delivered depending on the BMI category (P < 0.0001).

Discussion

Before analysing the doses delivered in the CT examinations in this study the practical conditions of this activity need first to be considered. The recruitment underlying this study was of patients referred by departments specialising in respiratory pathology, other than intensive care. The latter was voluntarily excluded from the study because of notable differences in positioning the patient (arms alongside the body) and his or her environment on the examination table (multiple catheters, respirator, syringe pumps), frequently...
making it necessary to use a high kilovoltage (140 kV). It should be noted moreover that half of the examinations were of a suspected or known oncological condition, including screening and monitoring of suspect pulmonary nodules, an initial assessment of bronchopulmonary cancers, monitoring them under neoadjuvant or palliative chemotherapy or following other treatments (surgery, radiotherapy), and detecting early post-operative complications. Lastly, the special feature of this study concerns the use of dual source CT scanning which performs particularly well in terms of temporal resolution, acquisition time and applied energy so that respiratory pathology can be explored by means of four main examination protocols.

In the above conditions and for a population with a mean BMI of 25.11 kg/m², the mean value of the accumulated DLP was 184.12 mGy cm which, converted into effective dose, gives an estimate of the dose delivered of around 3 mSv (184 mGy cm × conversion factor: 0.017). These results are the direct consequences of extensive use of low kilovoltages, since 56% of examinations were performed at 100 kV and 4% at 80 kV, selecting them being directly linked to the patients’ morphotypes. Although this study did not include any analysis of the objective noise of the images, evaluation of the overall quality of the examinations did not find any examination to have been less than optimal due to excessive graininess of the images. The relationship seen between BMI and dose delivered suggests that the regulations or recommendations per anatomical region explored should, among other adjustments, be indexed to the patient’s morphotype. It is interesting to note that the mean DLP measured in our entire population is lower than the current diagnostic reference levels (DRLs) for thoracic CT imaging which, in terms of DLP, are fixed at 500 mGy cm [ministerial order dated 12 February 2004]. Our results are also below the recent proposals by the French Radioprotection and Nuclear Safety Institute (IRSN) which, in its 2007-2008 report of the analysis of data on updating DRLs in radiology [DRPH 2010–15] [20], proposes to reduce the value of the DRL in DLP terms to 475 mGy cm. Added to values recently published in the literature of 7 to 8 mSv for a thoracic CT scan without contrast injection [21] and 15 mSv for a CT thoracic angiogram [22], our results show how great a saving in dose can be made by adjusting parameters linked to systematic use of automatic modulation of the milliamperage on a dual source machine.

The dosimetry for the different protocols shows that the least irradiating standard protocol uses the dual source, single energy system (protocol 2). It is however necessary to consider the significant difference observed between this protocol and single source, single energy scanning (protocol 1) in line with the differences in patient morphotype between these two groups. Indeed, dual source CT can only be used if the patient’s thoracic circumference allows it, the field of tube B being narrower than that of tube A and only covering 33 cm. If the thoracic circumference does not fit, it is because the patient’s morphotype is larger, which automatically results in a higher kilovoltage being selected thus leading to delivery of a higher dose. Nevertheless, at identical irradiation and pitch parameters, dual source CT acquires the height of the thorax more rapidly than single source scanning and thus reduces the dose, even taking

Figure 5. Mean values and 95% confidence intervals of the dose length product mean (mGy cm) according to the indication.

Figure 6. Mean values and 95% confidence intervals of the dose length product mean (mGy cm) according to body mass index category (kg/m²), all protocols considered together.
into account the excess z sweep of a high pitch. While the standard examinations of this study were all performed in volume mode, the sequential mode is still very useful for diffuse bronchopulmonary diseases in patients with a long life expectancy, where monitoring can be satisfactorily fulfilled by a sample of millimetre slices spaced every 10 or 15 mm. In this context, Bendaud et al. demonstrated that doses may be reduced by 76% while still providing the required clinical information [23]. Although helical prospective ECG gating (protocol 3) is more irradiating than non-synchronised dual source, single energy CT (protocol 2), the mean DLP of 105.4 mGy cm is not in fact an obstacle to its use in respiratory disease [24]. The low dose of these two types of examination opens up prospects for integrated cardiothoracic imaging in respiratory patients, 80% of whom have one or more cardiovascular risk factors. Finally, we should note that the mean DLP of dual energy acquisitions is approximately 400 mGy cm. While this dose is indisputably higher than the doses of single energy examinations, it must be qualified by the superiority of the data provided under these acquisition conditions, linking classic morphological with pulmonary microcirculation information [25]. It would therefore be more logical to compare the dose delivered in dual energy CT with that of a classic CT thoracic angiogram combined with pulmonary perfusion scintigraphy. Let it be noted, however, that in our study, the effective dose of a dual energy CT angiogram can be estimated as approximately 6.86 mSv (404 mGy cm × conversion factor: 0.017 mSv), much lower than the dose in single source CT angiograms previously mentioned in the literature (15 mSv) [20]. Finally, it is interesting to consider the dual energy perspectives currently being explored, the aim of which is to optimise CT angiograms through virtual monochromatic spectral imaging [26—28]. Optimal attenuation can be obtained for all the vascular compartments of the thorax with a dose lower than that reported in this study (280 mGy cm vs. 403.4 mGy cm), at the same time using a low concentration (170 mg/mL) of contrast agent [28]. Several limitations of this study need to be highlighted. The first concerns the working conditions in a university hospital environment. In evaluating the clinical impact of new technologies, all radiologists apply pre-established examination protocols, excluding the possibility of testing the influence of the radiologist’s experience in the dose delivered. The second limitation concerns the lack of integration of new dose-reducing technologies, which are currently available, such as iterative reconstructions, automatic modulation of the kilovoltage and the possibility of working at 70 kV for people with a low BMI. Exploiting these new options ought indisputably to allow the doses described in this paper to be reduced. Finally, since a high pitch produces an apnoea time in the order of a second or less, particularly useful for patients who are short of breath, its excessive overranging should be compensated by more rapidly positioning protective shields.

Conclusion

The mean DLP of each group of patients who had a CT scan was well below the recommended diagnostic reference levels for the same anatomical region. Nevertheless, due to the results of this study that varied with age, sex, morphotype, type of disease and adaptation of the technology to the disease, it is our considered opinion that there should be no single diagnostic reference level.

Disclosure of interest

The authors declare that they have no conflicts of interest concerning this article.

References