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Low-dose spiral CT: applicability to paediatric chest imaging

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Abstract *Background*. Spiral CT of the chest is an imaging technique with unequivocal indications and proven higher sensitivity and specificity than conventional chest X-rays. However, particularly in children, attempts should be made to reduce radiation exposure to a minimum.
Objective. To evaluate whether a low-dose technique in spiral CT scanning results in adequate diagnostic information.
Materials and methods. In a prospective study, 27 children (range 3 weeks to 14 years, mean 7 years) underwent a low-dose CT examination of the chest for various indications. The tube energy was 12.5 mAs ($n = 5$), 25 mAs ($n = 17$), 50 mAs ($n = 3$), or 75 mAs ($n = 2$) per slice. Two radiologists evaluated, in consensus, the CT scans with respect to their diagnostic value and comparison was made with 20 standard-dose chest CT examinations of adults (175 mAs per slice, mean age 56 years) with respect to technical image quality (noise and artefacts). In a second part of the study, dose measurements were carried out by means of exposing thermoluminescent dosimeters attached to a water/air phantom simulating a child's chest.
Results. All low-dose CT scans were of diagnostic image quality and no additional studies were necessary. The average image noise was significantly higher than in standard-dose CT examinations (SD 39.5 compared with 12.5 for unenhanced soft tissue, $P < 0.01$), but did not hinder accurate diagnosis. Artefacts were exclusively due to patient motion. Radiation exposure per slice was approx. 4 mGy at 25 mAs and 34 mGy at 250 mAs, regardless of slice thickness.
Conclusions. For all indications in paediatric CT scanning of the chest, low-dose technique provides adequate image quality without loss of diagnostic information. The radiation exposure is approximately 5–20 % of a standard-dose CT.

Introduction

Computed tomography (CT) of the chest has proved to be superior to chest radiography in the detection of a broad variety of mediastinal, chest wall and lung diseases. In particular, the initial stages of lung pathology may escape demonstration on plain X-ray film, requiring CT as an additional imaging modality. However, CT demands a considerably higher radiation dose than does conventional radiography. For paediatric imaging, it is of the utmost importance to reduce radiation exposure to the minimum appropriate for diagnosis. This study was undertaken to evaluate the applicability of a low-dose technique in spiral CT with the focus on image quality and diagnostic yield.

Materials and methods

Patients

We prospectively scanned the thorax of 27 children aged 3 weeks to 14 years. The main indications were detection of metastases, mediastinal or hilar lymphadenopathy, bronchial and interstitial diseases. All patients were examined with a Tomoscan AV spiral CT scanner (Philips Medical Systems, Eindhoven, The Netherlands) using a low-dose technique. The Slice thickness varied from 1.5 to 10 mm dependent on the size of the chest and pathology expected. If the duration of the spiral set was to exceed 20 s, the slice width was broadened or the pitch factor (table speed per 360° gantry rotation in relation to the nominal slice thickness) was increased from 1:1 to 2:1. The tube current was selected individually, according to the size of the body. The majority of the patients ($n = 22$) were examined using 25 mAs, 3 patients at 50 mAs and 2 at 75 mAs. In 5 of the 22 patients examined using 25 mAs, the pitch was increased to 2:1 resulting in an effective mAs value of 12.5 per slice. Four patients received i.v. contrast material through a peripheral access. The volume of contrast medium (in ml) was calculated from the body weight (in kg) multiplied by 1.5. Image noise was determined by means of a region-of-interest (ROI) analysis with an average size of 300 mm^2. In those patients who did not receive i.v. contrast medium, the ROIs were drawn over the heart, the ascending and descending aorta, and the results were compared with ROI measurements from 20 adult non-contrast CT scans (mean age 56 years) using 175 mAs per slice and identical ROIs. All CT images were reconstructed with a high-frequency lung reconstruction filter to achieve maximum spatial resolution. The Wilcoxon test was employed for statistical analysis.

Dose measurements

We scanned a 20-cm round phantom that consisted of a plastic body containing two pipes, each with a diameter of 2 cm. One pipe was placed in the isocentre and one was located 5 cm below the surface. The phantom contained half air and half water to approximately simulate absorption by lungs. Three calibrated lithium fluoride thermoluminescent dosimeters (TLDs) were exposed during each spiral scan. One TLD was placed on the surface of the phantom, and each tube was also loaded with a TLD. The whole phantom was scanned at 120 kV and a tube energy of 25 mAs, 100 mAs and 250 mAs, each setting with 3-mm, 5-mm, and 10-mm slice thickness. Additionally, the entry and exit dose of a scout view was measured at 120 kV, 50 mA and 3-mm beam collimation. Evaluation of the TLDs was carried out with a 2000 A/B-System (Harshaw), and dose measurements are expressed in mGy. Two TLDs were kept unexposed for baseline control. The beam filter of the CT unit was composed of 1 mm aluminium and 0.2 mm copper.

Results

Image analysis

In all patients, the images obtained using low-dose technique provided sufficient image quality for diagnosis. We did not need to repeat scans with higher scan energy. Figures 1a and b demonstrate a CT scan through the mid chest that was obtained with a tube energy of 225 mAs prior to implementation of the low-dose protocol. Later, we used only 25 mAs and Figs. 1c and d show the comparable slice at the identical level. The markedly increased image noise is only noticeable on the mediastinal window setting (window/level, 400/50), yet still allowing differentiation of mediastinal structures and detection of anatomical details. The measured average image noise was significantly higher on low-dose images, with a SD of 39.5 compared with 12.5 for standard dose images ($P < 0.01$).

Table 1 Dose measurements (mGy) related to the slice thickness

Tube energy	TLD location	Slice thickness			
		3 mm	5 mm	10 mm	Average
25 mAs	Surface	3.8	4.2	4.0	4.0
	5 cm below	4.3	4.4	4.5	4.4
	Isocentre	4.2	4.7	4.1	4.3
100 mAs	Surface	12.6	14.2	12.0	12.9
	5 cm below	15.0	15.0	14.8	14.9
	Isocentre	15.7	16.4	15.9	16.0
250 mAs	Surface	30.9	36.5	35.9	34.4
	5 cm below	35.7	41.8	36.5	38.0
	Isocentre	38.0	38.2	37.5	37.9

Dose measurements

A summary of all dose measurements is provided in Table 1. We found the expected linear relation between skin dose and tube energy. A setting of 25 mAs resulted in an average dose of 4.0 mGy, which is approximately 12 % of the average dose at 250 mAs (34.4 mGy). The radiation dose in the isocentre was considerably higher than the surface dose independent of the slice thickness. However, a larger number of examinations would be required to allow adequate statistical analysis. The scout view entry and exit doses were 0.6 mGy and 0.1 mGy, respectively.

For a pitch of 1:1, the slice thickness had no influence on the dose measured. We did not measure the dose with pitches, greater than 1:1 because in settings with higher pitches, there is the possibility that a 2 × 2-mm TLD would travel through the scan plane while the X-ray tube is not facing it. TLD measurements would then be too low and not reflect the true average skin dose.

Discussion

According to recent data [1], approximately 30 % of the radiation exposure from medical imaging modalities is attributable to CT, although CT examinations represent only 3 % of all imaging studies. Radiation exposure, therefore, remains the predominant issue in CT. The radiation dose delivered by CT differs greatly from that of

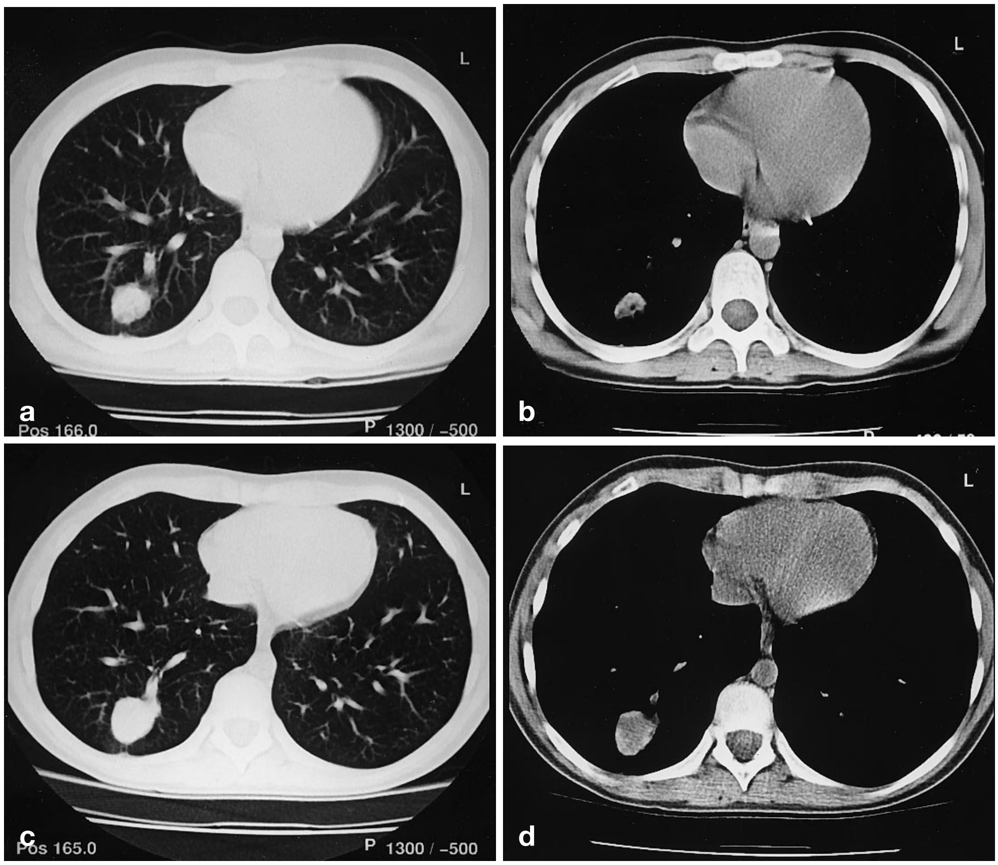

Fig. 1 a–d A 9-year-old boy with a solitary pulmonary metastasis from osteosarcoma. Standard-dose CT technique (175 mAs) on **a** lung and **b** mediastinal window settings. **c,d** Follow-up CT 3 months later using a low-dose technique (25 mAs) demonstrating growth of the metastasis. Note the significantly increased image noise which is only noticeable on the mediastinal window settings (**d**)

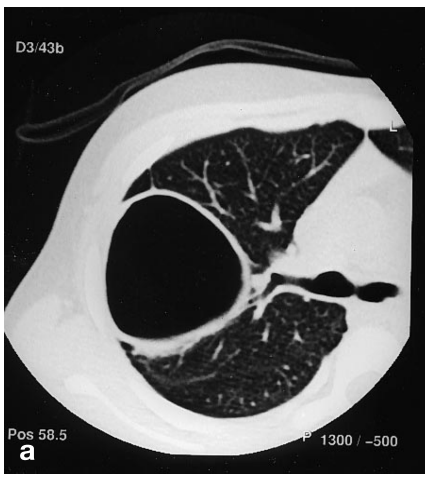

Fig. 2 Low-dose CT (25 mAs) through the chest of a 6-year-old girl with hereditary IgE deficiency. The communication between the bronchogenic cyst and the respective segmental bronchus is clearly visualised

Fig. 3 A 14-year-old girl with mediastinal lymphadenopathy. Using a low-dose technique (75 mAs), image noise in the mediastinal structures is clearly increased compared to standard-dose technique, but the image is still diagnostic

projection radiography [2]. Besides strictly limiting the indications for pediatric CT to those in which diagnostic information cannot be obtained from an alternative non-radiating imaging modality such as ultrasound or magnetic resonance, there are several means of decreasing the radiation dose as proposed by other authors [3–7]:

– limiting the number of slices to the volume of interest
– use of thinner slices with an interscan gap
– decreasing the tube current (mA) to a minimum

Restricting the CT examination to the volume of interest is only possible in rare cases in which the pathology is either known or very likely to be present only in one specific part of the lung. In the majority of conditions involving the entire lung, restricted CT is inappropriate since diagnostic information may be missed in those areas that are not being imaged.

Evans et al. [4] reported a 40 % dose reduction by narrowing the beam collimation from 10 mm to 3 mm with the scan interval kept constant at 10 mm. Similar results were reported by Mayo et al. [5], who compared the skin dose of contiguous 10-mm slices with 1.5-mm slices and 8.5-mm interscan gap, and found a dose reduction of about 88 % with the thinner slices. Both authors used an incremental CT technique, based on scans obtained in the axial plane at predefined table positions. By contrast, spiral CT is based on a linear transport of the patient table through the gantry while continuously applying X-rays from the rotating tube [8, 9]. The main difference between both scanning techniques is the gap-less volume acquisition in the spiral mode. Although volume acquisition provides the advantage of uninterrupted scanning during a single breathhold, it does not allow dose reduction from the use of interscan gaps.

The higher sensitivity of spiral CT for detecting pulmonary nodules has been thoroughly discussed by many authors [10–13]. Nodules smaller than the slice thickness can be missed on incremental CT, largely because of differences in the degree of inspiration between slices. Such misregistration is avoided with spiral CT. Cox et al. [14] demonstrated that children who are unable to co-operate benefit most from spiral acquisition.

There is an almost linear correlation between the tube energy (in mAs) and skin dose. In our study, the dose ranged from 3.8 mGy at 25 mAs to 36.5 mGy at 250 mAs. Reducing the tube current results in increased image noise. Numerous other factors, besides tube current, determine the amount of noise – the reconstruction method (360° or 180°), sharpness of kernels and filters, slice thickness, kilovoltage, beam filtering, sensitivity of the X-ray detectors, quality of amplifiers etc. Generally, increased image noise due to low mAs can be compensated for by applying a soft reconstruction kernel, but spatial resolution of the reconstructed image will be reduced at the same time. Selecting a 360° reconstruction method instead of 180° is a further method of compensating for image noise at the expense of spatial resolution along the patient's longitudinal (Z) axis and at the expense of a narrow slice sensitivity profile [15]. Furthermore, reducing the slice thickness for better Z-axis resolution results in increased image noise, since fewer photons reach the X-ray detector.

Lowering the tube voltage has been tried for dose reduction, but the resulting 'softer' quality of the X-ray beam leads to a higher proportion of energy absorbed by the body relative to the energy reaching the X-ray detectors. To our knowledge, no study has been carried out to evaluate the effectiveness of lowering the kilovoltage in comparison to lowering the milliamperage for dose reduction in spiral CT in children.

In this study the measurements of image noise were compared in two demographically different patient groups, children and adults. We opted to implement such a study design since, after initial experience with the low-dose protocol in children, it appeared unethical to expose children to higher doses (while low-dose images were judged diagnostic) solely for the purpose of providing comparable technical image data. Image noise is higher in adults because larger amounts of tissue contribute to overall X-ray absorption. In that respect, applying the standard-dose technique in children would have resulted in even lower noise levels than in adults, and would have only increased the measured difference in noise level between the standard and low-dose technique.

Image noise mainly affects low-contrast resolution. Scans of objects with large differences in the attenuation values, such as the lungs, are less sensitive to image noise if wide window and level settings are applied for viewing. Zwirewich et al. [7] found that high-resolution CT scans of the lung parenchyma acquired with 40 mAs yielded equivalent anatomically detailed information compared with scans acquired with 400 mAs. We also did not observe significant information loss, even on scans obtained with 25 mAs if viewed in the lung window setting (window/level, 1300/-500). The mediastinal window settings, however, demonstrated the full extent of image degradation, which can be severe enough to prevent meaningful interpretation of the image. Consequently, when the assessment of mediastinal lymphadenopathy was of diagnostic relevance, we increased the tube current to 50 or 75 mAs, which yielded acceptable image quality even in the mediastinal window.

Spiral CT offers another useful technique for reducing radiation in addition to lowering the milliamperage: the table speed during the acquisition can be increased with only minimal effect on image quality. Increasing the pitch from 1:1 to 2:1 results in a broadening of the slice sensitivity profile of approximately 30 % based on a 180° reconstruction algorithm with the consequence of a higher degree of partial voluming. Regarding the effect of increased pitch on image quality [9] the image noise will not be increased with higher pitches, but signal-to-noise ratio may be reduced due to decreased lesion attenuation, especially if the lesion is smaller than the nominal slice thickness [16]. Wright et al. demonstrated that for initial staging of metastatic disease with suspected pulmonary nodules the pitch should not be greater than 1.5:1 [17]. Higher pitches increase the risk of under-staging the disease. We selected a pitch of 2:1 in five patients, all of whom underwent CT for follow-up of pulmonary metastases during chemotherapy.

Although scattered radiation originating from inside the body also contributes to overall dose and, theoretically, should be increased with thinner slices and, consequently, longer volume exposure times, we did not measure any difference in the skin or isocentre dose between 10-mm, 5-mm or 3-mm slices. However, due to the small number of TLD measurements (three per slice thickness and tube setting), small changes in radiation dose of less than 10 % would have fallen within the range of measurement error of the TLDs and would not have been detected.

In summary, it is possible to reduce radiation dose in paediatric chest imaging at least by a factor of three compared with standard chest CT examinations of adults. There is no clear definition about which mA setting may be regarded as the ideal low-dose technique. However, we conclude that for spiral CT scanning, values of 25–75 mA suffice for examining the paediatric chest.

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