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Abdominal spiral CT in children: which radiation exposure is required?

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Abstract We decided to test to what extent dose reduction is possible in abdominal spiral computed tomography (CT) in young children without loss of anatomic diagnostic information. A retrospective study was performed of 30 abdominal CT examinations of children aged 3 months to 7 years. These were divided into two groups: group A with reduced radiation exposure (tube current 50 mA, CT dose index $CTDI_{FDA}$ ≤0.83 mGy) and group B with standard radiation exposure (tube current ≥100 mA, $CTDI_{FDA}$ ≥1.66 mGy). Image quality was assessed using a four-part scale ('excellent', 'good', 'sufficient', 'poor') on visual image impression and visibility of 32 anatomical details. Five experienced radiologists read the CT scans independently who were blinded to the examination parameters. Differences in ranked data were evaluated with Wilcoxon's rank sum test. No difference between groups A and B was observed in visual image impression. Detail visibility was significantly lower in group A, but the differences were limited to right upper quadrant structures (portal vein, common bile duct, pancreatic head, adrenals) and to arterial branches. Significant differences in visibility rated as 'poor' were only found for the hepatic, splenic and renal arteries; all other structures showed no difference between groups A and B. A protocol with reduced radiation exposure (50 mA, $CTDI_{FDA}$ ≤0.83 mGy) allowed the demonstration of most anatomic structures in abdominal spiral CT in young children. For the precise demonstration of small details (e.g. structures of the right upper quadrant), a protocol with standard radiation exposure (≥100 mAs) was superior.

Keywords Computed tomography · Paediatric · Radiation dosage

Introduction

Computed tomography (CT) is a major source of radiation exposure from non-natural sources. Children are known to have a higher risk of radiation-induced diseases than adults. The radiation burden from a single CT examination is higher for children (12 %–15 %/mSv lifetime risk for mortality from malignant tumours) than adults (≤5 %/mSv lifetime risk) [1, 2, 3, 4]. However, even with the availability of imaging procedures using no ionising radiation such as ultrasound (US) and magnetic resonance imaging (MRI), CT remains an important technique in paediatric patients [5, 6].

Radiation exposure during CT examinations can be limited by the selection of appropriate scan parameters, i.e. tube voltage, tube current and pitch [7]. Many recommendations concerning these parameters have been published for examinations of adults. In children, less radiation exposure is required to obtain the same signal/noise ratio (SNR) due to their smaller body diameter and consequently lower radiation absorption. It is estimated that the radiation exposure can be reduced by 50% for every 4 cm decrease of body diameter to achieve a comparable SNR. Consequently, a reduction of radiation exposure from CT is possible in children. On the other hand, an inappropriate reduction of radiation exposure may lead to inadequate image quality.

Despite the importance of this issue, there are only a few reports on scan parameters in paediatric CT examinations. Due to the lack of published data, a decision as to imaging parameters in children is usually made arbitrarily by the radiologist in charge.

The aim of our retrospective study was to assess the effect of scan parameters on image quality in paediatric abdominal CT examinations in order to find CT protocols that combine adequate image quality with minimum radiation exposure in young children.

Patients and methods

This retrospective study included 30 paediatric CT examinations of the abdomen performed because of clinical indications from March 1996 to December 1998 at our institution whose hard copies could be retrieved from the film archive. Inclusion criteria were a patient age of maximum 10 years and the administration of intravenous contrast media during CT. A total of 30 CT examinations in 9 children aged 3 months to 7 years (mean 2.4 years) were enrolled in the study.

All examinations were performed on a Philips Tomoscan SR 7000 scanner (Philips, Eindhoven, the Netherlands). It was equipped with xenon detectors. A computed tomography dose index ($CTDI_{FDA}$) of 1.66 mGy/100 mAs for 5 mm collimation was measured with a 32 cm Plexiglas body phantom at a tube voltage of 100 kVp for this scanner [8].

Initially, a collimation of 10 mm, 1 s rotation time, pitch 1 to 2 and a reconstruction interval of 5 or 10 mm were used. During 1997 the examination protocol was changed to 5 mm collimation and 5 mm reconstruction interval; the other parameters remained constant. The tube voltage was 100 kVp. Different settings for the tube current were selected by the respective radiologist in charge in order to reduce the patient's radiation exposure. Due to lack of information from the literature, this was chosen individually.

In order to evaluate the image quality depending on the scan protocol, two groups were formed for further analysis (Table 1):

- Group A with reduced radiation exposure. Inclusion criterion was a tube current of 50 mA, corresponding to a $CTDI_{FDA}$ of ≤0.83 mGy.
- Group B with standard radiation exposure. Inclusion criterion was a tube current of at least 100 mA (range 100 – 225 mA), corresponding to a $CTDI_{FDA}$ of ≥1.66 mGy.

All examinations were printed on 17 × 14' laser film with a layout of 3 × 5 or 4 × 5 images per film. Hard copies were reviewed by five board-certified radiologists (SD, PL, TML, KL, KP) independently who were blinded to the patient data and scan parameters.

Assessment of image quality is based on several aspects such as visual image impression, spatial resolution, contrast resolution, artefacts, etc. Our study focused on image impression and detail visibility, which is a function of both spatial and contrast resolution.

Table 1 Number of CT examinations by slice thickness and radiation exposure

Protocol	Slice thickness	
	5 mm	10 mm
Group A: reduced radiation exposure (50 mAs, pitch 1–2)	5	7
pitch 1	3	7
pitch 2	2	0
Group B: standard radiation exposure (≥100 mAs, pitch 1–2)	12	6
pitch 1	2	6
pitch 1.6	1	0
pitch 2	9	0

Standardised reporting forms on the visibility of anatomical structures have been reported for the assessment of image quality [9]. We developed a reporting form to assess the visual image impression as well as the visibility of 32 anatomical features (Table 2). One form was filled out for each CT study by each reader. A four-part scale was used (excellent, good, sufficient, poor). If a detail was not depicted, it was rated as 'poor', whereas details outside the scanned volume were considered as missing values. The average of all 32 values for individual detail visibility was calculated for each CT study and each reader (the average is referred to as 'detail visibility' below). Hence, a total of 150 observations for detail visibility and image impression could be assessed. In addition, the visibility of all anatomical structures was assessed individually.

Statistic analysis was performed on the pooled data of all readers. Prior to analysis, all data for visibility of anatomical features, detail visibility, and image impression were ranked for each reader in order to reduce the effect of interobserver variability. Group A was compared to group B using the Wilcoxon rank sum test on ranked data. Significance was considered to be $p < 0.05$.

Kappa values for interobserver variability were calculated for overall image impression and for detail visibility for each pair of observers. The values for detail visibility between readers were rounded to integer values in order to achieve comparability with Kappa statistics. Kappa values ≤0.20 were interpreted as 'poor', 0.21–0.40 as 'fair', 0.41–0.60 as 'moderate', 0.61–0.80 as 'good' and ≥0.80 as 'excellent' interobserver agreement [10].

Results

The effect of collimation on image quality was evaluated regardless of the radiation dose applied ($n = 17$ for 5 mm collimation, $n = 13$ for 10 mm collimation). Neither the ranked values for image impression ($p = 0.74$) nor the values for detail visibility ($p = 0.26$) showed differences due to collimation in our data. Therefore, we decided to pool the data of examinations with different collimations for further analysis.

Analysis of differences in image quality between groups A and B revealed no difference in image impression ($p = 0.12$) but a significant difference in detail visibility ($p = 0.001$). Mean values and standard deviation of analysis of all individual anatomical structures

Table 2 Differences in visibility of anatomical structures, number of 'poor' ratings, and number of 'sufficient' or 'poor' ratings between groups A and B (ranked values). Significances are displayed for Wilcoxon rank sum test (*NS* not significant)

Structure	Difference in		
	Visibility	'Poor' rating	'Sufficient' or 'poor' rating
Liver contour	NS	NS	NS
Intrahepatic portal vein branches	0.002	NS	0.044
Liver veins	NS	NS	NS
Extrahepatic portal vein	0.028	NS	NS
Splenic vein	NS	NS	NS
Superior mesenteric vein	NS	NS	NS
Extrahepatic bile duct	0.028	NS	NS
Gall bladder	NS	NS	NS
Pancreatic head	0.042	NS	0.044
Pancreatic body	NS	NS	NS
Pancreatic tail	NS	NS	NS
Pancreatic duct	NS	NS	NS
Spleen	NS	NS	NS
Right adrenal	0.001	NS	0.017
Left adrenal	0.028	NS	NS
Right kidney	NS	NS	NS
Left kidney	NS	NS	NS
Right parapelvic fat	NS	NS	NS
Left parapelvic fat	NS	NS	NS
Ureter	NS	NS	NS
Abdominal aorta	0.044	NS	NS
Coeliac trunk	0.001	NS	0.038
Hepatic artery	0.000	0.000	0.000
Splenic artery	0.000	0.000	0.005
Renal arteries	0.000	0.001	0.005
Superior mesenteric artery	0.000	NS	NS
Inferior mesenteric artery	0.025	NS	0.012
Internal iliac artery	NS	NS	NS
External iliac artery	NS	NS	NS
Inferior cavic vein	NS	NS	NS
Renal veins	NS	NS	NS

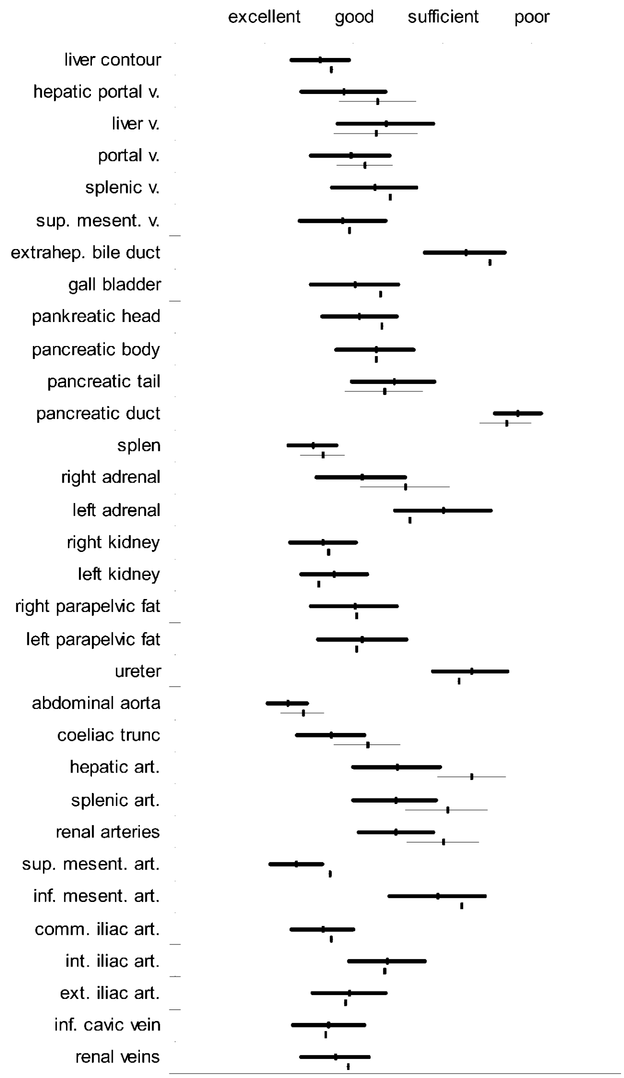

Fig. 1 Average and standard deviation of ratings for anatomical structures for low-dose group A *(thin lines)* and standard dose group B *(thick lines)*

are presented in Fig. 1. Significant differences between both groups were found for structures of the right upper abdomen (pancreatic head, common bile duct and portal vein), both adrenals and arteries in the upper abdomen (Table 2). If the visibility of arteries – which are not often the focus of interest in children – is excluded from the analysis, a difference in detail visibility was no longer noted ($p = 0.19$).

In order to assess the degree of image quality reduction by lower radiation exposure, data were tested on differences in anatomical structures rated as 'poor' and in structures rated as 'sufficient' and 'poor' (Table 2). Only the hepatic, splenic and renal arteries were significantly less often visible (rated as 'poor') on CT scans with reduced radiation exposure. For all other structures, no significant difference was found. Differences in structure visibility rated as 'sufficient' or 'poor' were found for the coeliac trunk, hepatic, splenic, inferior mesenteric and renal arteries, intrahepatic portal vein branches, pancreatic head and right adrenal, whereas for all other structures no significant difference was shown. Thus, standard radiation exposure resulted in a significantly higher proportion of details rated as 'good' and 'excellent' only for the few structures mentioned above.

As an example, two CT scans of a 6-year-old boy are presented in Fig. 2, obtained 7 weeks apart at standard (a) and reduced (b) radiation exposure settings, both providing sufficient diagnostic information.

Kappa statistics (Table 3) revealed poor to moderate interobserver agreement for overall image impression (mean Kappa value 0.36 ± 0.16) and fair to excellent agreement for detail visibility (mean Kappa value

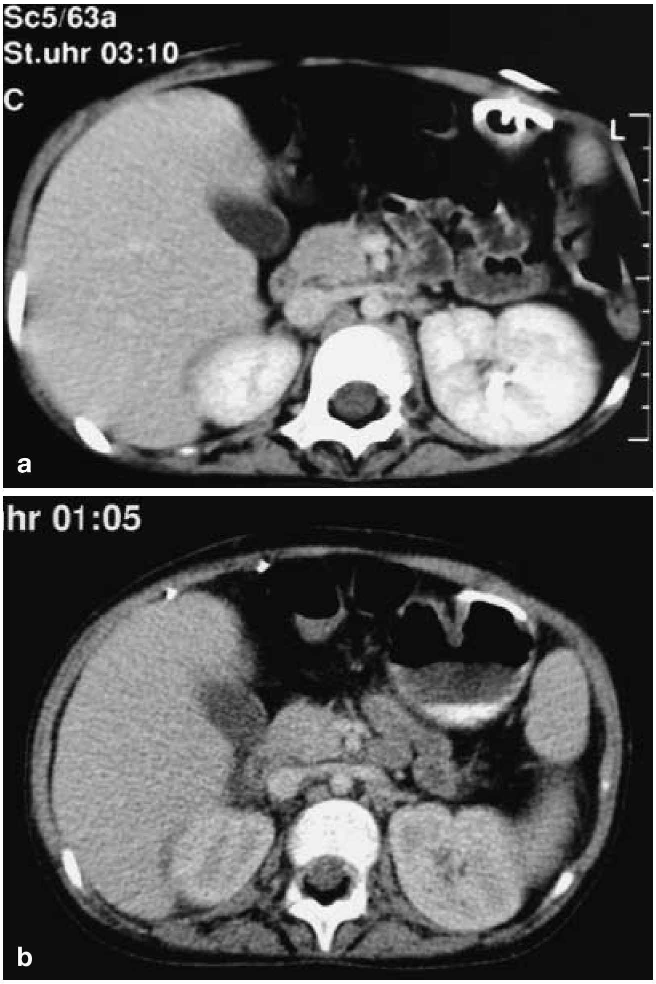

Fig. 2 a, b Two contrast-enhanced computed tomography (CT) scans of the same 6-year-old boy done 7 weeks apart (obtained because of fever of unknown origin): (**a**) obtained with 100 kVp, 175 mAs, pitch 1, rated 1.40 ± 0.55 for image impression and 1.46 ± 0.26 for detail visibility; (**b**) obtained with a low-dose protocol (100 kVp, 50 mAs, pitch 1) with 29 % of radiation exposure compared to (**a**), which was rated 2.40 ± 0.55 for image impression and 2.16 ± 0.38 for detail visibility. Both scans provide sufficient diagnostic information

Table 3 Kappa statistics for interobserver variability for overall image impression and detail visibility (values rounded to integer): *0* indicates no agreement between two observers, *1* indicates perfect agreement

Overall image impression:				
	Reader 1	Reader 2	Reader 3	Reader 4
Reader 2	0.08			
Reader 3	0.26	0.58		
Reader 4	0.52	0.38	0.19	
Reader 5	0.48	0.31	0.26	0.52
Detail visibility:				
	Reader 1	Reader 2	Reader 3	Reader 4
Reader 2	0.74			
Reader 3	0.34	0.56		
Reader 4	0.48	0.77	0.70	
Reader 5	0.66	0.81	0.62	0.74

0.64 ± 0.14). The moderate overall agreement justifies the use of ranked data for all analysis.

Discussion

Some proposals for a paediatric abdominal CT protocol have been published [5, 11]. Frush and Donnelly recommend a tube current of 90–140 mA for abdominal examinations which may be reduced if spatial resolution is not an issue [5].

Our data support this suggestion. CT scans performed with at least 100 mA were superior in detail visibility compared to scans with reduced radiation exposure. However, these advantages were limited to a few anatomic structures like abdominal aortic branches, structures of the hepatoduodenal ligament and the adrenals. Dose reduction decreases contrast resolution, resulting in impaired depiction of small structures with similar density. These structures, however, were still visible (except some aortic branches which seldom contain relevant diagnostic information).

According to the results of our study, a standard dose protocol with 100 mA was appropriate for the evaluation of hepatic vessels, biliary system and retroperitoneum (i.e. pancreatic head and adrenals), and CT-angiographic purposes. For all other indications, examination with dose reduction (e.g. 50 mA) provided sufficient anatomic information.

A further reduction of radiation exposure can be expected from the use of solid-state instead of gas detectors (the CT scanner used for this study was equipped with xenon detectors) and from new developments like anatomically adapted tube current modulation [12, 13, 14].

Limitations of the study

The effect of a reduction of radiation exposure on low-contrast resolution was not specifically addressed in this study. However, low-contrast resolution in the abdomen is mainly important for the detection of focal liver lesions which are usually examined with ultrasound and MRI in children [6]; CT is not commonly used for this indication. Liver imaging with CT in children mainly involves depiction of vessels [15, 16], which was assessed with our measurement of image quality.

Our assessment of image impression and detail visibility focused on anatomical structures and did not evaluate the pathology potentially visible on the images. This is due to the fact that most examinations were follow-up studies after tumour resection and did not demonstrate any diagnostically relevant pathology. Hence, the effect of reduced radiation exposure on the visibility of pathological changes cannot be clarified with this study.

As this study had a retrospective design, several different protocols were used, and for the purpose of analysis, these protocols were reduced to two groups independent of the patient's size. Therefore, this study does not provide information on the effect of patient geometry on a possible reduction of radiation exposure.

A moderate reduction of radiation exposure for abdominal spiral CT in children aged 0–10 years did not lead to inadequate image quality in our study. For most applications a protocol using 50 mA ($CTDI_{FDA}$ ≤ 0.83 mGy) was appropriate. Only if high-contrast resolution was required a protocol with 100 mA ($CTDI_{FDA}$ 1.66 mGy) was necessary, i.e. for examination of liver vessels or structures of the right upper quadrant.

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