Original paper

Triple-phase abdomen and pelvis computed tomography: standard unenhanced phase can be replaced with reduced-dose scan

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Abstract

Purpose: The aim of the study was to test the hypothesis that unenhanced phase does not require as high image quality as subsequent phases acquired after contrast administration in triple-phase abdomen and pelvis computed tomography (CT), and to assess if attenuation value (AV) measurements may be obtained from unenhanced images acquired with three-fold reduced radiation dose.

Material and methods: In the standard triple-phase abdomen and pelvis CT protocol (unenhanced, late arterial, and portal venous phase) we decreased the tube current time product only in the unenhanced phase. Arterial and venous phases were performed with the standard scanner settings used in our Institution for routine abdomen and pelvis CT. We compared the AV in manually drawn circular-shaped regions of interest (ROIs) obtained from reduced-dose and standard-dose unenhanced images in 52 patients. All ROIs were set in homogeneous parts of psoas muscle, fat tissue, liver, spleen, aorta, and bladder.

Results: There was no statistically significant difference in AV measurements for all considered areas. More noise does not alter the mean AV inside the ROIs. Radiation dose of unenhanced scans was reduced three times and the total dose length product (DLP) in the triple-phase study was decreased by 22%.

Conclusions: Unenhanced images performed with three-fold reduced radiation dose allows reliable AV measurements. The unenhanced phase does not require as high image quality as subsequent phases acquired after contrast administration.

Key words: tomography, X-ray computed, radiation protection, radiation dosage, abdomen, adult.

Introduction

According to the U.S. National Council on Radiation Protection, the exposure to ionising radiation from medical procedures has increased about six-fold since 1980. The widespread use of computed tomography (CT) results in the concern about patient protection against radiation [1]. In recent years many papers have been published on scanning parameter optimisation. The other authors investigated lowering the tube current time product, decreasing the tube voltage, de-noising iterative algorithms and automated tube current modulation (ATCM), which resulted in efficient reduction of radiation dose [2-6].

However, multiphase CT study is still an underestimated source of excessive radiation exposure.

According to Guite *et al.*, unindicated scans during multiphase CT may contribute to 33% unnecessary radiation exposure [7]. Most frequently, during a multiphase examination each phase is performed with constant scanner parameter settings and each phase multiplies the total patient dose. As a result, the total dose is doubled, tripled, or quadrupled with two, three, or four phases being performed [7-9].

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Some authors suggest not performing unenhanced abdomen CT because it contributes little to the radiological diagnosis [9, 10]. Nonetheless, the benefit of an unenhanced scan is the potential detection of urinary stones, pancreatic calcifications, and small bleeding. Secondly, with the unenhanced phase it is possible to measure tissue attenuation values. It is important, for example, in differentiation of adrenal masses: if the lesion contains fat, it is supposed to be a benign adenoma. Therefore, unenhanced phase and AV measurements may be crucial for the final diagnosis.

However, the unenhanced scan has only limited diagnostic value when it is followed by post-contrast phases. The differentiation of soft tissue structures and the detection of focal lesions is the best achievable with the arterial or venous phases. Thus, the image quality and the amount of image noise is much more important in post-contrast phases. From that observation our research hypothesis arises that unenhanced phase does not require such high image quality as arterial and venous phases do. The reduced dose protocols have proven high accuracy in the detection of calcium-containing stones and other high-contrast structures [11-13]. However, there are no other papers that assess the reliability of tissue attenuation values taken from noisy images.

The aim of this study was to reduce the radiation dose in routine, triple-phase abdomen and pelvis computed tomography and to assess if an unenhanced phase performed with three-fold reduced radiation dose is sufficient for attenuation value measurements.

Material and methods

The present study was approved by the Institutional Review Board, and informed consent was obtained from all patients. The case and the control group consisted of 52 patients who underwent abdomen and pelvis CT for routine indications. All examinations were performed in triple-phase protocol, before and after contrast administration: unenhanced, late arterial, and portal venous phase, using a Discovery 750 HD scanner (GE Healthcare). In every examination Automated Exposure Control (EAC) was enabled. The desired image quality and the radiation exposure was established with the Noise Index (NI) setting. NI is a parameter that corresponds to the relative noise in the image. In modern GE scanners the EAC systems modulate tube current time product according to user-defined NI, patient body dimensions, and average attenuation, in order to obtain the desired image quality.

In this study we modified the abdomen and pelvis CT protocol and changed the Noise Index to the value of 59 for unenhanced phase only. The subsequent arterial and venous phases were performed with the Noise Index 22. Our intention was to decrease the radiation dose during the unenhanced phase by three times. In the control group, patients were scanned with constant Noise Index NI 22 for each phase. The planned exposure in the Case
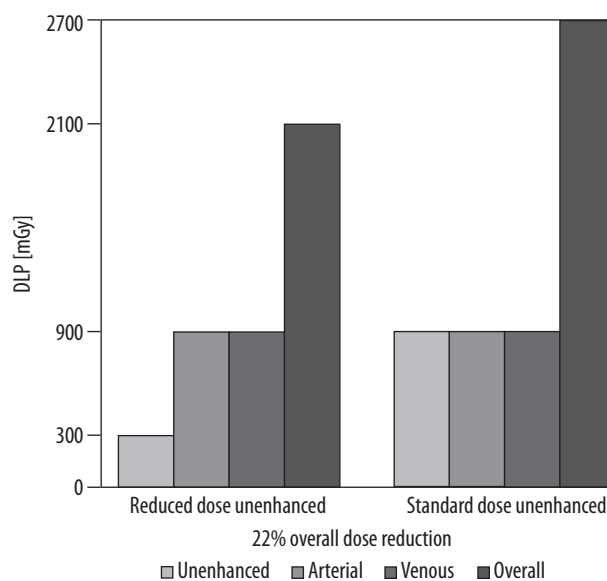

Figure 1. Study design: the planned radiation dose during modified triple-phase abdomen computed tomography (CT) compared to the standard CT performed in our Institution. The bars represent dose length product (DLP, mGy–cm) in unenhanced, arterial, venous phase and the total dose

and Control group is presented in Figure 1. The scanning parameters are listed in Table 1.

We compared differences in the attenuation value (AV) between reduced-dose and standard dose scans using the region of interest (ROI) method. For every patient one author drew circular-shaped ROIs of 10 mm diameter in six locations. The ROIs where set in the psoas muscle and the fat tissue at the level of the lower pole of the left kidney; the liver, spleen, and aorta at the level of the lower border of T12 vertebra; and the bladder at the level of its largest cross-sectional area. Each ROI was set carefully to encompass the tissue homogeneity and to avoid visible vessels.

In the radiation dose analysis we evaluated the computed tomography dose index (CTDIvol, mGy) and the dose length product (DLP, mGy–cm).

Table 1. Scanning protocols in triple-phase abdomen and pelvis computed tomography. In the case group unenhanced phase performed with reduced dose. In the control group, all three phases performed with standard scanner settings

	Case	Control
Tube potential	120 kVp	
Automated exposure control	Enabled	
Noise index*	59.1/22.0/22.0	22.0/22.0/22.0
Detector configuration	64 × 0.625 mm	
Pitch	0.984 : 1	
Reconstructed slice thickness	0.625 mm	
ASIR	Enabled	

*Noise index in unenhanced/arterial/venous phase
ASIR – Adaptive Statistical Iterative Reconstruction

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Table 2. The tissue attenuation values in unenhanced phase obtained with three-times reduced radiation dose compared to standard dose scan. Unenhanced phases are derived from triple-phase abdomen and pelvis computed tomography

	Reduced dose		Standard dose		p-value
	Mean	SD	Mean	SD	
Muscle	51.0	6.0	50.0	7.5	NS
Fat	−107.1	6.6	−99.0	12.8	NS
Air	−998.0	4.8	−998.7	3.4	NS
Aorta	30.3	10.8	34.5	8.9	NS
Liver	50.4	10.0	43.5	20.5	NS
Spleen	43.5	7.5	45.1	5.3	NS
Bladder	6.0	9.2	10.9	11.0	NS

The data were analysed with R statistical software (R-Core team, Wien, Austria) [14]. The mean AV values were checked for normality with Shapiro-Wilk test and then compared with *t*-test with Welsh modification for unequal variances. The graphs were drawn with the R graphics package.

Results

There was no statistically significant difference in AV in all measured areas between reduced-dose and standard-dose scans. Decreased dose resulted in higher noise and an increase in the standard deviation in measured ROIs. However, more noise did not alter the mean attenuation value within ROIs. The AV in the case and control group and their distribution are presented in Table 2 and in Figure 2.

We achieved significant radiation dose reduction of unenhanced phase. The mean radiation dose in the study group was: CTDI, 7.5 and DLP, 317 mGy–cm, whereas in the control group it was as follows: CTDI, 19.1 mGy and DLP, 972 mGy–cm. The radiation dose of unenhanced scans was reduced by three times. In both protocols the scans acquired after contrast administration were performed with equal CTDI, 19.1 mGy and DLP 972 mGy–cm. The total radiation dose (DLP) was 2262 mGy for the reduced-dose protocol, and 2918 mGy for routine CT. In the presented triple-phase abdomen and pelvis CT, the overall radiation dose (DLP) was reduced by 22%.
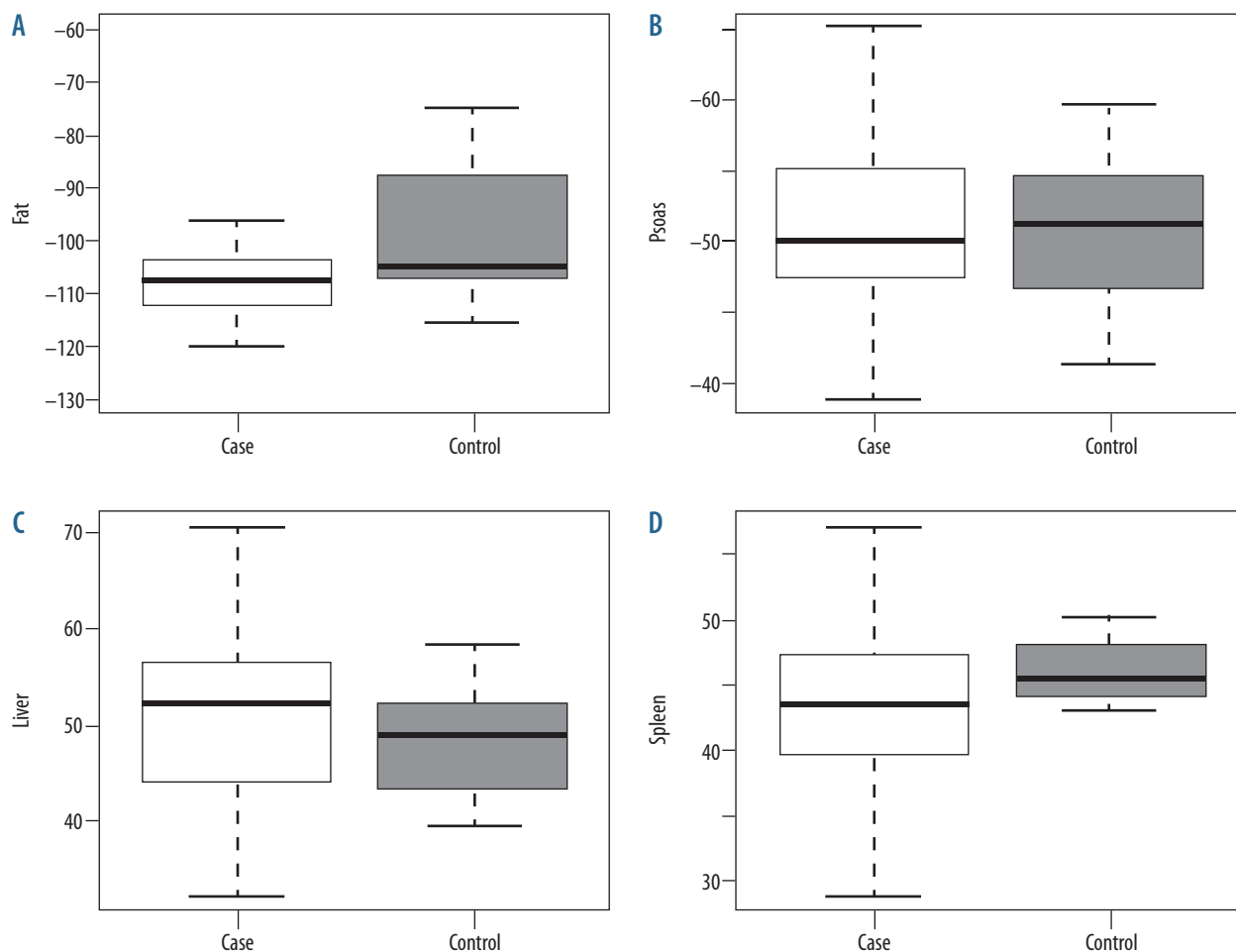

Figure 2. The tissue attenuation value in unenhanced phase obtained with three-fold reduced radiation dose (Case) compared to standard dose scan (Control). The unenhanced phases are derived from triple-phase abdomen and pelvis computed tomography

Discussion

After the modification of scanning parameters during unenhanced phase only, we achieved 22% overall reduction of radiation dose in triple-phase abdomen and pelvis CT. We found that unenhanced phase performed with decreased dose is sufficient for attenuation value measurements. This result is of clinical importance because unenhanced phase does not require as high image quality as subsequent phases acquired after contrast administration.

Our results are consistent with physical theory of CT scan. Using an Automatic Exposure Control (AEC) system, it is possible to decrease tube current time product very effectively [15, 16]. A lower number of electrons hitting the anode results in decreased number of emitted X-ray photons but does not alter their energy. As a result, the AEC modifies the image noise but does not affect the tissue attenuation value [17]. The AEC systems act continuously during scanning and alter tube current according to the longitudinal and angular position of the X-ray tube, taking into account body average attenuation. In order to maintain desired image noise, obese patients require higher tube current time product and consequently higher doses.

Some authors suggest eliminating unenhanced scan from the routine abdominal protocol and performing it only on the radiologist's demand [3]. It may be obtained on another day by calling back the patient or during one patient's visit, when a radiologist monitors every examination being performed. Both approaches are time consuming and more expensive than standard multi-phase examination with unenhanced, arterial, and venous phases during one visit, and it might be not possible in busy imaging departments.

In paediatric CT imaging it has been suggested that unenhanced CT be completely eliminated.

Donnelly *et al.* concluded that unenhanced imaging is unnecessary in most paediatric patients [18]. Similarly, da Costa e Silva *et al.* found that performing only arterial phase for oncologic imaging in children has equal sensitivity in tumour characterisation with consequent reduction of radiation dose by 50% compared to dual-phase CT [10].

Nonetheless, we believe that unenhanced phase has clinical value, although it may be achieved with decreased radiation dose. A similar idea was described by Goldman et al. The authors presented two multi-phase protocols for liver and pancreas imaging where unenhanced phase was decreased, obtaining a DLP as low as 79 mGy–cm [19]. The Authors suggested thicker slice reformatting, i.e. 5 mm slice thickness; such an approach is very effective in lower-

ing radiation exposure. Thicker reconstructed slices result in less noise because more photons contribute to image formation [20, 21]. However, the limitation of the thicker slices is the loss of the submillimetre resolution that may be achieved with a multidetector scanner.

In our study we did not intend to achieve very aggressive dose reduction of unenhanced phase, but rather we aimed to assess if unenhanced phase performed with reduced dose would suffice the clinical demand. It is not only our experience that any change in CT protocols can be strongly objected by radiologists not involved in the dose-reduction process [22]. We believe that a dose-optimisation process could be effective when small changes are introduced and sufficient time is given to other radiologists to become familiar with the new pattern of images.

The limitation of our study is the relatively small group of 52 patients. In every case the quality of unenhanced scans was acceptable and there was no case of non-diagnostic examination. However, further studies on large groups of patients are needed to assess the potential problems and difficulties that could arise from decreased-dose images.

Secondly, we did not assess subjective or objective image quality, like other studies on radiation protection do, because we presented a diverse approach to dose reduction. We intentionally decreased image quality of unenhanced images because their imperfections or possible defect can be compensated with post-contrast phases.

Finally, our conclusion that mean attenuation value may be measured from the scan performed with reduced radiation dose is true only at the constant tube potential. If the radiation is reduced with lower levels of tube potential, the tissue attenuation values change. The decrease in the tube voltage alters the photon's energy and consequently the tissue attenuation coefficients [23]. For that reason, the rules of enhancement pattern and Hounsfield Unit threshold values cannot be straightforwardly translated from 120 kVp to other tube potential levels [13].

Conclusions

The presented triple-phase abdomen and pelvis CT protocol with unenhanced phase performed with reduced dose provides clinically sufficient images and allows a significant total radiation dose reduction.

Conflict of interest

The authors report no conflict of interest.

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