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SCIENTIFIC ARTICLE

Radiation dose reduction for musculoskeletal computed tomography of the pelvis with preserved image quality

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Abstract

Objective To analyze the impact of pelvic computed tomography (CT) technique optimization on estimated dose and subjective and objective image quality.

Materials and methods An institutional review board (IRB)-approved retrospective records review was performed with waived informed consent. Five CT scanners (various manufacturers/models) were standardized to match the lowest dose profile on campus via subjective assessment of clinical images by experienced musculoskeletal radiologists. The lowest dose profile had previously been established through image assessment by experienced musculoskeletal radiologists after a department-wide radiation dose reduction initiative. A consecutive series of 60 pre- and 59 post-optimization bony pelvis CTs were analyzed by two residents, who obtained signal-to-noise ratio for femoral cortex and marrow, gluteus medius muscle, and subcutaneous and visceral fat in a standardized fashion. Two blinded attending radiologists ranked image quality from poor to excellent.

Results Pre- and post-optimization subjects exhibited no difference in gender, age, or BMI ($p > 0.2$). Mean CT dose index (CTDIvol) and dose–length product (DLP) decreased by approximately 45%, from 39± 14 to 18± 12 mGy ($p < 0.0001$) and 1,227± 469 to 546± 384 mGy-cm ($p < 0.0001$). Lower body mass index (BMI) was associated with a larger dose reduction and higher BMI with higher DLP regardless of pre- or post-optimization examination. Inter-observer agreement was 0.64–0.92 for SNR measurements. Cortex SNR increased significantly for both observers ($p < 0.02$). Although qualitative image quality significantly decreased for one observer ($p < 0.01$), adequate mean quality (3.3 out of 5) was maintained for both observers.

Conclusion Subjective and objective image quality for pelvic CT examination remains adequate, despite a substantially reduced radiation dose.

Keywords Radiation dose reduction · Computed tomography · CT · Pelvis · Musculoskeletal

Introduction

Dose optimization techniques for medical diagnostic imaging have been popular during recent years. This movement has especially targeted computed tomography (CT) examinations because of their proportionally high doses. Such techniques include utilization of iterative reconstruction, current modulation, and decreased tube voltage. These approaches have been particularly used during examinations of chest, cardiac, pediatric, and trauma CT examinations [1–3]. As the extremities are relatively radioresistant [4], there exists a relative paucity of scientific literature describing dose optimization technique strategies in CT examinations performed for musculoskeletal (MSK) indications. However, it is important to note that CT imaging of certain regions, such as the pelvis, hips, shoulders, and spine frequently impart considerable radiation to vital structures, such as the reproductive organs, breast tissue, and the thyroid. The pelvis, in particular, houses some of the most radiosensitive structures, including the gonads and a large percentage of the body's hematopoietic marrow [4, 5]. Although magnetic resonance imaging (MRI) of the pelvis supersedes CT in its superior soft-tissue contrast, pelvic CT continues to play an important role in the diagnosis of osseous pathological conditions with the added benefits of lower cost, speed, and wide availability, particularly in emergency settings. Younger patients presenting with trauma often undergo CT examination as part of their Emergency Department

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workup. This also happens to be the population at a relatively higher risk for stochastic effects from ionizing radiation, and as such would especially benefit from reduced pelvic CT examination radiation dose [6].

We aimed to analyze the effect of dose optimization and standardization on radiation dose measurements and the resultant image quality specifically for unenhanced pelvis CT examinations performed for musculoskeletal indications (i.e., the "bony pelvis" CT). Our hypothesis was that radiation dose can be reduced to a standardized level of CT exposure across a five-CT scanner institution with subsequent change in signal-to-noise ratio (SNR) of various structures upon pre- and post-optimization evaluation, but with maintained adequacy of subjective image quality for diagnostic purposes.

Materials and methods

For this retrospective evaluation, with institutional review board (IRB) approval, informed consent was waived.

Quality improvement project

In a preceding step, and as part of a department-wide quality improvement project, a dose standardization and optimization initiative was launched in early 2015 according to the American College of Radiology (ACR) guidelines (http://doseoptimization.jacr.org). The focus of this preceding project was to identify and remedy egregious techniques while maintaining a certain level of diagnostic image quality, described below. No specific target dose or percentage dose decrease was initially chosen to avoid the risk of a patient obtaining a nondiagnostic examination. Subjective diagnostic image quality was assessed by experienced attending musculoskeletal radiologists (A.C. and L.T.) with 9 and 4 years of post-fellowship experience respectively. The assessment was performed separately by each radiologist in nonblinded fashion by a review of axial bone algorithm 5-mm reconstructions post-processed from three pre-optimization and three post-optimization routine clinical CT abdomen/pelvis examinations acquired on each of the five scanners (a total of 15 examinations). They assigned each examination a grade based on a Likert scale, with 5 representing excellent image quality, 4 representing very good image quality with minimal noise, 3 representing good image quality with some noise, 2 representing significant noise impairing quality, with maintained diagnostic quality for some but not all indications, and 1 representing a nondiagnostic examination. Of the scans with acceptable quality, department clinicians and physicists chose the scanner with the lowest CT dose index (CTDIvol), and then adjusted all available scanners to match this dose profile.

All pre- and post-dose reduction examinations, including those in the preceding quality initiative, were performed on one of three 64-slice Toshiba Aquilion scanners (64 detectors of 0.5 mm each, 32-mm collimator), a 64-slice Philips Brilliance (64 detectors of 0.625 mm each, 40-mm collimator), or a 256-slice Philips Brilliance iCT (128 detectors of 0.625 mm each, 80-mm collimator). The Toshiba scanners, which were imaging the majority of the patient volume (95% pre-implementation), underwent the most dramatic changes, as they were previously utilizing a fixed dose technique for bony pelvis CT examinations, with a programmed kVp of 135 kVp, variable rotation time of 0.5 to 1 s, and a pitch of 0.828. This technique was changed to current modulation with a decreased programmed set point of 120 kVp (135 kVp for examinations containing metal, which was not evaluated in this study). The automatic exposure control (AES) preset, termed "Sure Exposure Quality" by Toshiba, was turned on, utilizing the "low-dose" setting, with Quantum Denoising Software (QDS), the standard Toshiba bone kernel (FC30), 5-mm slice thickness, and a standard deviation (SD, Toshiba nomenclature to indicate the target noise in a water phantom with equivalent X-ray absorption to the patient) of 15. All Toshiba scanners were standardized to 0.5-s rotation and 0.828 pitch. Iterative reconstruction or advanced processing was utilized on the Toshiba scanners neither before nor after dose optimization changes were implemented owing to a lack of availability. The two Philips scanners utilized differing settings from each other before this standardization and optimization project. The 256-slice scanner was set at 185 keV effective mAs for its AES set point with no iterative reconstruction, using the Y-Sharp (YC) kernel. The 64-slice scanner was already utilizing iDose3 iterative reconstruction, also with the Y-Sharp (YC) kernel. Rotation time for both scanners was set at 0.75 s, which remained unchanged. The pitch for the 64-slice Philips scanner was increased from 0.392 to 0.641, whereas the pitch for the 256-slice scanner remained unchanged at 0.8. As part of this standardization project, the 256-slice Philips scanner was updated to use iDose3 with no change in kernel. A reference mAs of 150 keV was chosen to mimic the current unenhanced abdomen/pelvis protocol, which provided desired image quality when a bony pelvis was reconstructed from these examinations, as assessed by the attending musculoskeletal radiologists and described previously. All scanners utilized for this project are ACR accredited and undergo routine quality control evaluation as per the ACR guidelines, including annual linearity checks (Table 1).

Once the quality of images created using these updated techniques was approved by the musculoskeletal radiologists' qualitative assessment, with a Likert score threshold of at least 3 out of 5, the optimized CT parameters were accepted. Before implementation of these changes into clinical practice, scanners with substantial changes underwent verification of SNR

Table 1 Pre- and post-reduction CT parameters

	Pre-reduction parameters					Post-reduction Parameters				
	Tube voltage (kVp)	Rotation time (s)	Pitch	Iterative reconstruction	Automatic exposure control	Tube voltage (kVp)	Rotation time (s)	Pitch	Iterative reconstruction	Automatic exposure control
Toshiba Aquilion (64-slice)	135	0.5 to 1	0.828	Not available	Off	120	0.5	0.828	Not available	On, SD = 15
Philips Brilliance (64-slice)	120	0.75	0.859	Utilized	On, 150 mAs/slice	120	0.75	0.641	Utilized	On, 150 mAs/slice
Philips Brilliance (256-slice)	120	0.75	0.392	Not utilized	On, 185 mAs/slice	120	0.75	0.804	Utilized	On, 150 mAs/slice

and contrast-to-noise ratio (CNR) with phantom scanning under the supervision of an institutional physics team headed by an experienced medical physicist (J.G.). This was to ensure that the same estimated dose was being delivered by each of the five scanners. Following these setting changes, routine MSK pelvis CT examinations were performed on all five scanners as per clinical request using the optimized protocols. For this study, quantitative and qualitative reviews were performed of patients who underwent pelvis CT following dose optimization compared with patients scanned before implementation of this dose standardization quality initiative to assess potential changes in dose and image quality.

Inclusion criteria

Institutional McKesson Picture Archiving and Communication System (PACS) and EPIC electronic medical records were data-mined as part of an IRB-approved retrospective records review to obtain a consecutive series of 268 unenhanced pelvis CTs ordered as a "CT bony pelvis" performed between 14 December 2013 and 26 November 2014 (before dose optimization implementation), and 235 pelvis CTs performed between 23 January 2015 and 9 December 2015 (after dose optimization implementation). This set of CT examinations includes outpatients, inpatients, and Emergency Department patients.

Exclusion criteria

Examinations excluded from analysis were those where the patient age was less than 14 years or greater than 60 years to limit the study to adults with less chance of decreased bone mineralization acquired with age, which may confound measured or perceived change in SNR or image quality. Additional exclusions were for metallic foreign body or hardware in the field of view, which could result in streak artifact, increase the required kVp per protocol, or change the measured SNR. Examinations that were incorrectly labeled for the body region imaged, had incomplete demographics listed in the electronic medical record, or lacked archived soft-tissue windows on PACS were also excluded. Based on these criteria, 60 of the pre-optimization examinations and 59 of the post-optimization examinations were selected for analysis (Fig. 1). The clear majority of chosen examinations were performed for pelvic and/or hip fracture evaluation, as indicated by the clinical history provided.

Objective data analysis

Two radiology residents (E.B. and E.Z.) independently assessed SNR in various regions of interest (ROI) for each examination on McKesson workstations. The ROI was drawn with an approximately 30-mm^2 area using the McKesson PACS elliptical ROI tool for all measurements to standardize

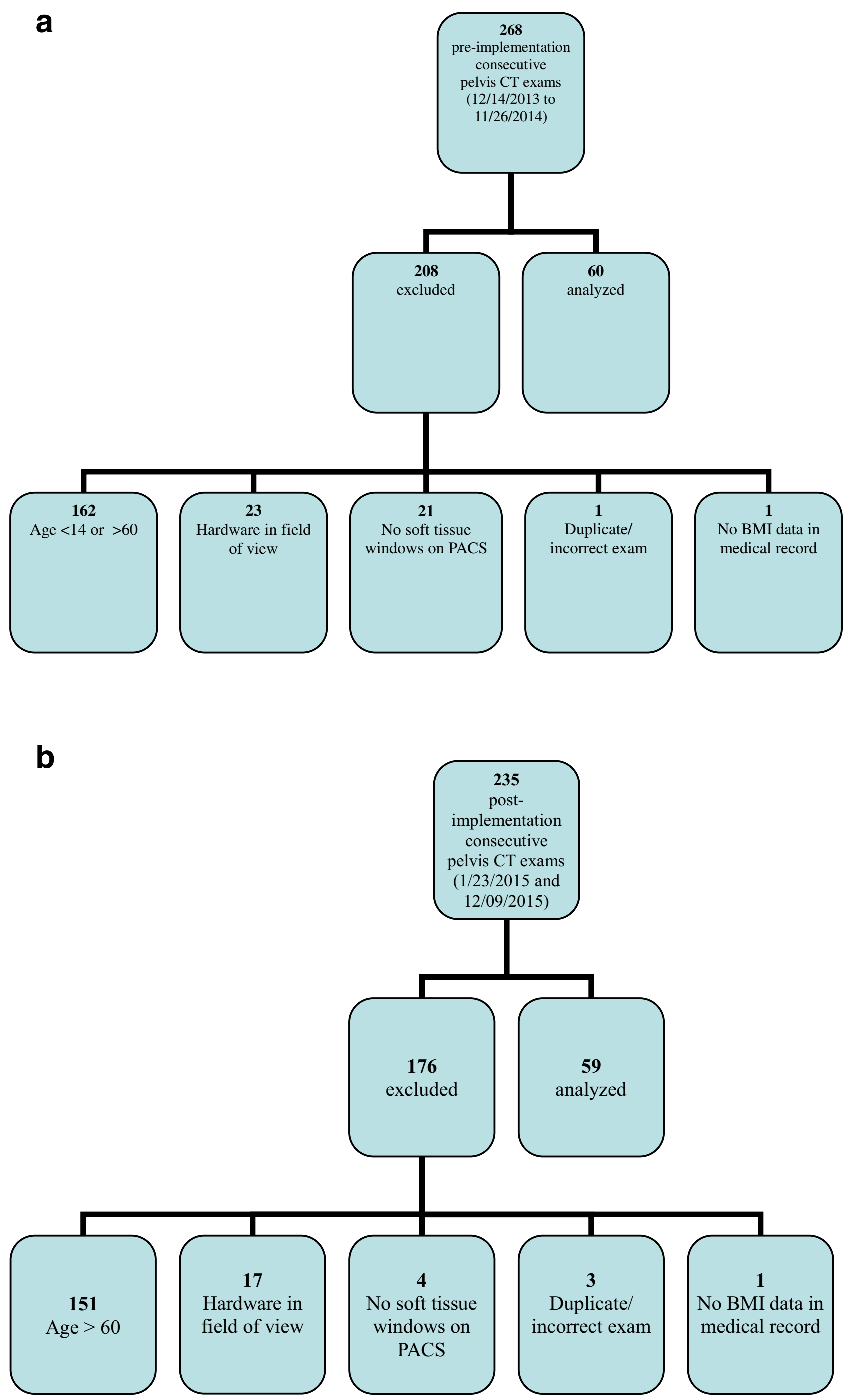

Fig. 1 Flowcharts demonstrating examination selection for retrospective review. **a** Pre-optimization patient selection. **b** Post-optimization patient selection

the methodology. SNR was obtained on each pre- and post-optimization CT in the patient's right proximal femoral cortex and marrow on bone algorithm windows, and in the patient's right gluteus medius muscle, visceral fat, and subcutaneous fat on soft-tissue algorithm windows (Fig. 2). This measurement was calculated by dividing the average Hounsfield units of a standardized circular ROI by its standard deviation, at pre-defined slice positions in similar pre-defined anatomical locations, including the right proximal femoral diaphysis for cortex and marrow measurements, and the right gluteus medius muscle, anterior abdominal wall subcutaneous fat, and right-sided visceral fat, avoiding vessels, lymph nodes, and bowel, with all soft-tissue measurements obtained in the same pre-defined slice. CT dose index volume (CTDIvol) in mGy and dose–length project (DLP) in mGy-cm were recorded for each examination as surrogates for estimated patient dose. Patient demographics and body mass index (BMI) were obtained from the electronic medical record for each patient.

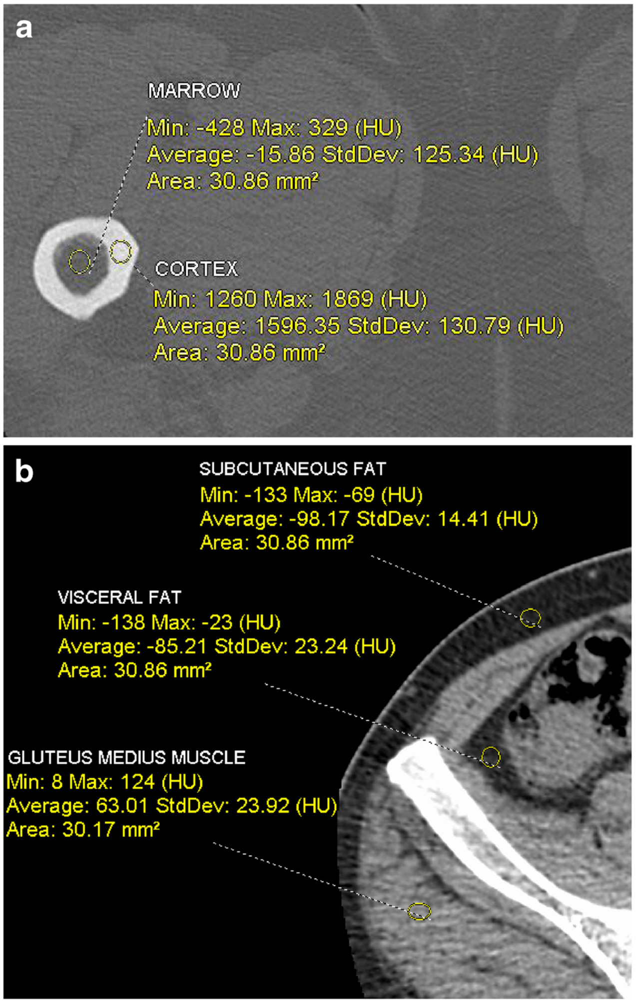

Fig. 2 Sample region of interest Hounsfield units and standard deviation measurements on axial pelvis CT. **a** Femoral cortex and marrow on bone windows. **b** Gluteus medius muscle, visceral fat, and subcutaneous fat on soft-tissue windows

Subjective data analysis

Two MSK-fellowship trained attending radiologists (H.O. and L.T.) with 10 and 7 years of experience as faculty respectively, were blinded to the clinical information and dose parameters of the CT examinations. They separately ranked the subjective image quality for pre- and post-optimization examinations based on the appearance of the normal cortex and bony trabeculations using the same previously described 1 through 5 Likert scale, with 5 representing excellent image quality and 1 representing a nondiagnostic examination (Fig. 3). CT pelvis pre- and post-optimization examinations were reviewed in a random order on institutional McKesson PACS with medical-grade monitors under standard reading room lighting conditions. The images were viewed on bone algorithm axial reconstructions to simulate the clinical practice of reading a bony pelvis CT. Reconstructions were available on PACS as either 2 or 3 mm. The analysis was performed utilizing on one scroll through all slices on a fixed window of 3000 and level of 300 without the ability to adjust the window/level, zoom, or utilize other image manipulation tools.

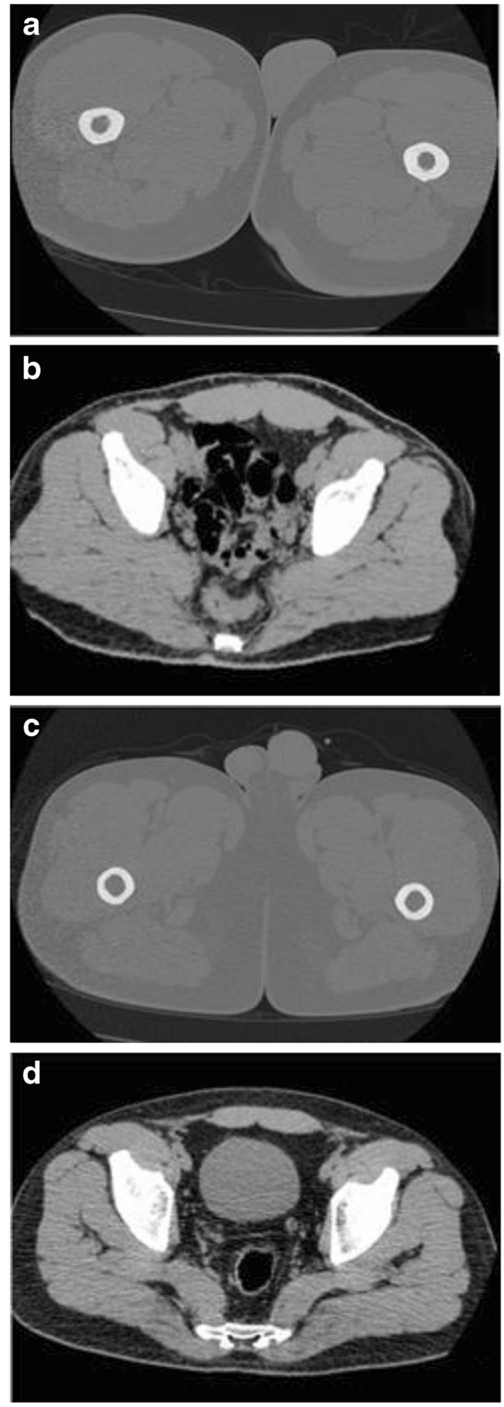

Fig. 3 Examples of pre- and post-optimization examinations with relevant patient and dose data. **a**, **b** Pre-optimization pelvis CT in a 35-year-old with BMI of 29 kg/m^2, CT dose index (CTDI)vol 35.9 mGy, dose–length product (DLP) 1,194.1 mGy-cm. Reader 1 quality score = 3, Reader 2 quality score = 3. **c**, **d** Post-optimization pelvis CT in a 32-year-old with BMI of 27 kg/m^2, CTDIvol 10.3 mGy, DLP 291.5 mGy-cm. Reader 1 quality score = 3, Reader 2 quality score = 2

Statistical analysis

Wilcoxon rank and Chi-squared tests were used for continuous (age and BMI) and categorical (gender) variables respectively, to test the differences in patient demographic distributions between pre- and post-dose optimization examinations. SNR and qualitative data were tested for mean score differences using an analysis of covariance (ANCOVA) model. Intraclass correlation (ICC) and Kappa correlations were also obtained for interobserver performance. For ICC correlations, poor correlation is represented by a coefficient less than 0.40, moderate between 0.40 and 0.59, good between 0.60 and 0.74, and excellent between 0.75 and 1. Kappa correlations are configured such that 0.0 to 0.2 indicates slight agreement, 0.21 to 0.40 fair agreement, 0.41 to 0.60 moderate agreement, 0.61 to 0.80 substantial agreement, and 0.81 to 1 almost perfect agreement [7]. A p value of <0.05 was considered statistically significant.

Results

Demographics

The patients included 49 women with a mean age of 43.9 ± 13.4 and 70 men with a mean age of 42.1 ± 11.9 years. The mean BMI of all patients was 29± 7 kg/m^2. No differences in gender, age or BMI were observed between pre- and post-optimization patients, indicating similar patient demographics in both groups ($p > 0.2$; Table 2). For uniformity purposes, a separate evaluation of Toshiba scans (most scans) was also performed. There were 47 women and 60 men with mean ages and BMI of 43.0 and 29.52 respectively, with no differences in gender, age or BMI between pre- and post-optimization patients (p 0.17, 0.92, and 0.25 respectively). Therefore, if a demographic such as BMI or age were exerting a significant influence on dose, SNR, or image quality, it would affect both groups equally.

Table 2 Patient demographics

Demographic		Dose optimization		All	p value
		Pre	Post		
N		60	59	119	
Gender					0.21975
Female	*n*	28	21	49	
Male	*n*	32	38	70	
Age (years)	Mean	42.7	42.85	42.77	0.91951
	SD	12.4	12.73	12.52	
BMI (kg/m^2)	Mean	29.36	29.12	29.24	0.38335
	SD	6.16	7.9	7.05	

BMI body mass index, *SD* standard deviation

Dose optimization

Utilizing Wilcoxon rank sum tests, there was a significant decrease in median and mean radiation dose between pre- and post-optimization examinations ($p < 0.0001$; Table 3). Median and mean CTDIvol decreased from 35.9 to 14.2 mGy (40%) and 39 to 18 mGy (46%) respectively. Median and mean DLP decreased from 1,102 to 458 mGy-cm (42%) and 1,227 to 546 mGy-cm (44%) respectively. For Toshiba scans, the median and mean CTDIvol decreased similarly from 35.9 to 15.3 mGy and from 40.5 to 18.3 mGy respectively. Median and mean DLP decreased from 1,108 to 459 mGy-cm and from 1,257 to 559 mGy-cm respectively.

BMI and dose correlations

An ANCOVA model was applied to test the effects of pre- and post-dose optimization BMI, age, and gender on the DLP. In addition, DLP was log-transformed to correct for right skewness. The log-transformed values corresponded to the ratio on the original scale.

There was a significant interaction between BMI and dose reduction ($p = 0.0051$), suggesting that mean dose reduction might be different depending upon BMI. On average, a lower BMI was associated with a larger dose reduction and higher BMI with higher DLP regardless of pre- or post-optimization parameters (Figs. 4 and 5).

Quantitative image evaluation

Cortex mean SNR increased significantly for both observers (7.5± 3.8 to 9.3± 3.8, $p = 0.01$; 9.1± 4.7 to 10.4± 3.7, $p = 0.02$ respectively). The visceral fat mean SNR decreased significantly for Observer 1 (−6.7± 2.7 to −5.5± 1.7, $p = 0.002$) but not Observer 2 (Fig. 6). When adjusted for patient demographics (age, gender, and BMI), muscle mean SNR decreased to a significant extent for Observer 1, from 2.95 ± 1.3 to 2.85 ± 1.1 ($p = 0.0012$), but not for Observer 2 (from 3.38± 1.59 to 3.29± 1.19 adjusted $p = 0.085$). The mean SNR values for the remaining evaluated tissues for both observers did not show any significant difference between pre- and post-dose optimization data sets, with adjusted p values ranging from 0.09 to 0.84.

In a separate evaluation of Toshiba scans, very similar trends were seen with respect to the mean SNR of the cortex and visceral fat (Table. 4).

Qualitative image evaluation

There was a significant reduction in image quality for Observer 2 ($p < 0.01$) between pre- and post-optimization examinations. There was no significant reduction in image

Table 3 Mean and median dose optimization

Dose parameter	Dose value				p value	p value
	Pre		Post			
	Mean (±SD)	Median (minimum to maximum)	Mean (±SD)	Median (minimum to maximum)		Adjusted by BMI, age, and gender
CTDIvol (mGy)	39.44 (13.46)	35.9 (9.48–76.9)	17.48 (11.58)	14.24 (6.62–61.65)	<0.0001	<0.0001
DLP (mGy-cm^2)	1,227.21 (469.08)	1,102.6 (324–2,651.8)	546.06 (383.7)	458 (197.8–2,258.2)	<0.0001	<0.0001

CTDI CT dose index, *DLP* dose–length product

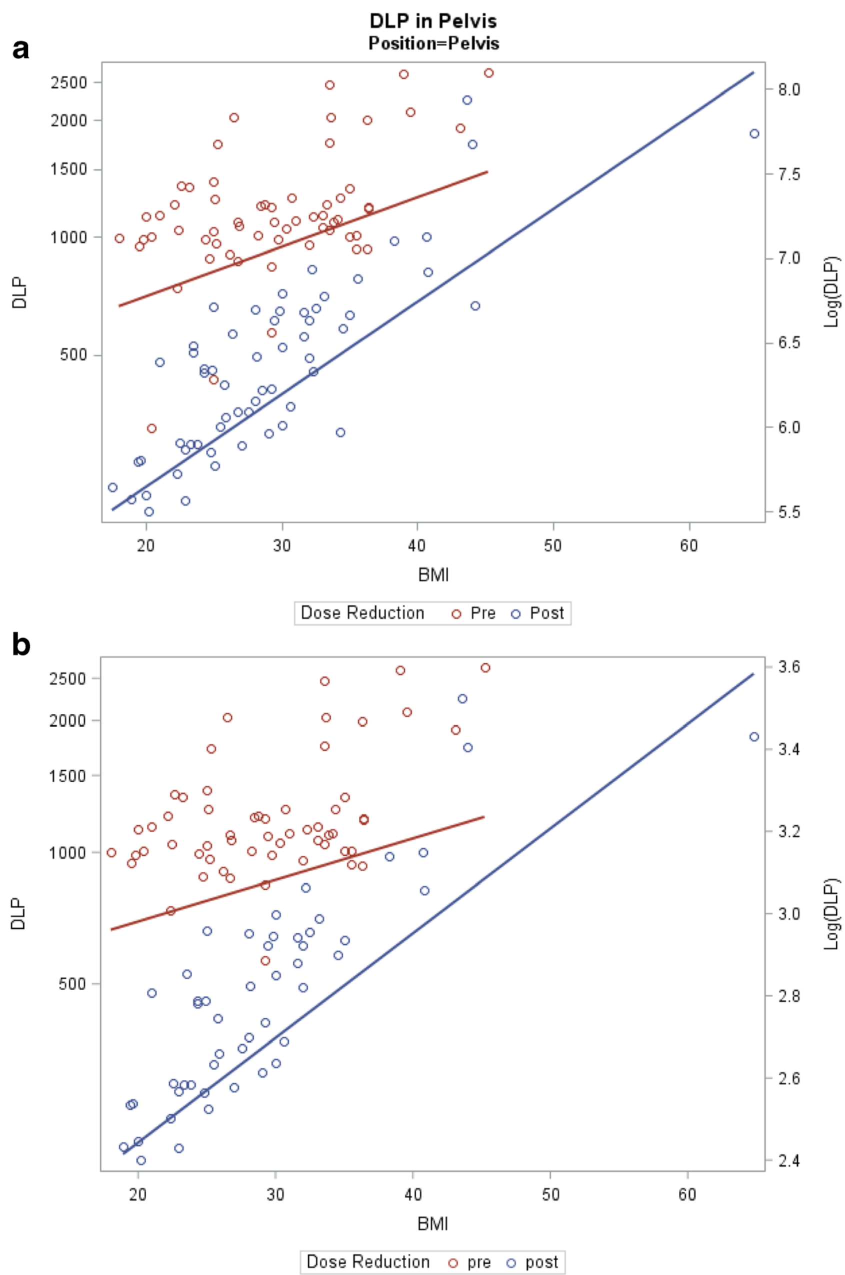

Fig. 4 **a** Relationship between DLP (mGy-cm) and BMI (kg/m^2) for pre- and post-dose optimization examinations. Analysis of covariance (ANCOVA) showed that the interaction of BMI and dose reduction was statistically significant ($p = 0.0051$). **b** Relationship between DLP (mGy-cm) and BMI (kg/m^2) for pre- and post-dose optimization examinations on Toshiba scanners. ANCOVA showed that the interaction of BMI and dose reduction was statistically significant ($p < 0.0001$)

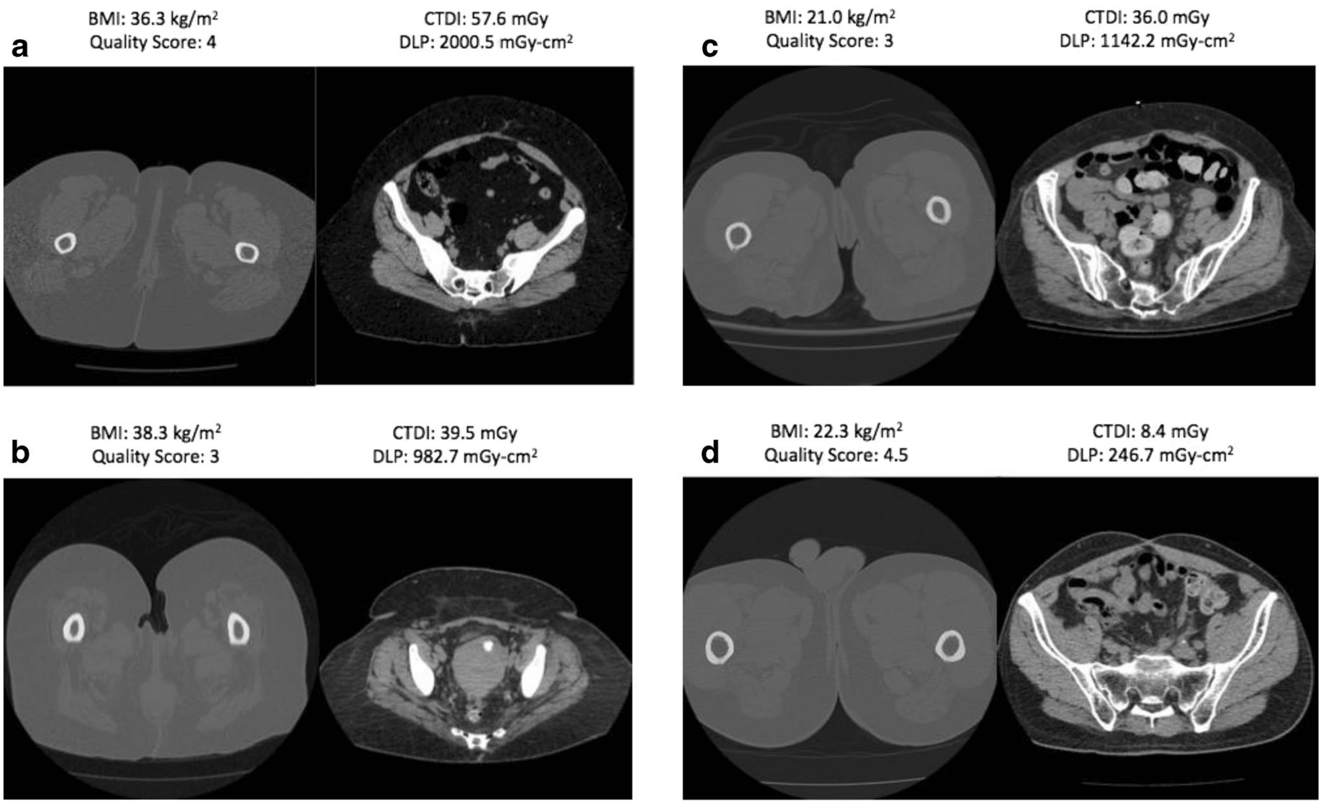

Fig. 5 Examples of pre- and post-reduction radiation dose and image quality in **a**, **b** high and **c**, **d** low BMI patients

quality scores for Reader 1. Adequate mean quality was maintained for both readers, with 3.32 out of 5 for Observer 1 and 3.31 out of 5 for Reader 2. (Fig. 7). On assessing the Toshiba scans, the mean quality was 3.16 out of 5 for both readers with a significant reduction in mean quality ($p < 0.00$ and $p = 0.02$) as with all scans.

Interobserver performance

For the SNR measurements, inter-observer agreement was 0.64–0.92, as calculated by ICC analysis, indicating good to excellent agreement. For the qualitative image assessment, weighted Kappa was 0.74, indicating substantial agreement.

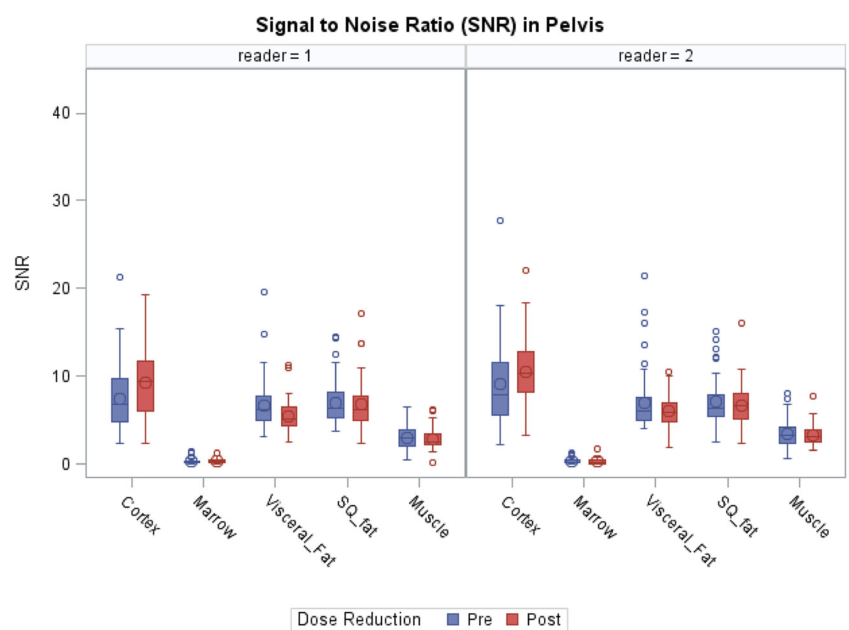

Fig. 6 Whisker plots of pre- and post-optimization SNR values for each region of interest performed by Observers 1 and 2. Analysis demonstrated that cortex SNR increased significantly for Observers 1 and 2 and visceral fat SNR decreased significantly for Observer 1

Table 4 Mean SNR changes on Toshiba scanner images

		Dose				p value	p value with adjustment
		Pre		Post			
		Mean	SD	Mean	SD		
1	Cortex	7.21	3.42	8.81	3.45	0.0202	0.0168
	Marrow	0.26	0.23	0.26	0.21	0.9845	0.9103
	Muscle	2.95	1.31	2.66	0.96	0.4488	0.4625
	SQ fat	6.74	2.25	6.06	1.93	0.0771	0.0873
	Visceral fat	6.68	2.76	5.13	1.30	0.0002	0.0001
2	Cortex	8.58	3.94	9.60	3.10	0.063	0.0592
	Marrow	0.28	0.22	0.22	0.21	0.0277	0.0381
	Muscle	3.35	1.54	3.10	0.94	0.9819	0.9292
	SQ fat	6.79	2.17	6.02	1.67	0.0508	0.0694
	Visceral fat	6.81	3.25	5.84	1.83	0.0549	0.0484

For Toshiba scanners, ICCs were 0.65–0.90 for SNR and the weighted Kappa was 0.81.

Discussion

This study confirmed that the subjective image quality for pelvic CT examination remains adequate, despite a substantially reduced radiation dose, and demonstrates a practical method of achieving substantially reduced radiation doses at a large, multicenter institution with heterogeneous equipment. The focus of this project was not targeted at achieving the lowest dose possible, but to standardize the estimated dose to the lowest dose parameters being utilized at this institution at the time of initiation of this project. However, this allowed for a decrease in dose of up to 46% overall for this institution's scanners. Although we did not evaluate diagnostic performance assessment, the high Likert scale results on qualitative evaluation and substantial interobserver performance also confirm readable image quality on the optimized CT scans. This effect is similar to those of studies performed in other regions of the body, including the head, chest, and abdomen [8]. Previous studies also utilized various techniques to achieve dose optimization based on various scanner manufacturers and models, including the implementation of iterative reconstruction [9, 10]. One of the Philips CT scanners used for this study consistently utilized iterative reconstruction during both the pre- and the post-dose optimization time periods, whereas this technology was not available on the Toshiba scanners.

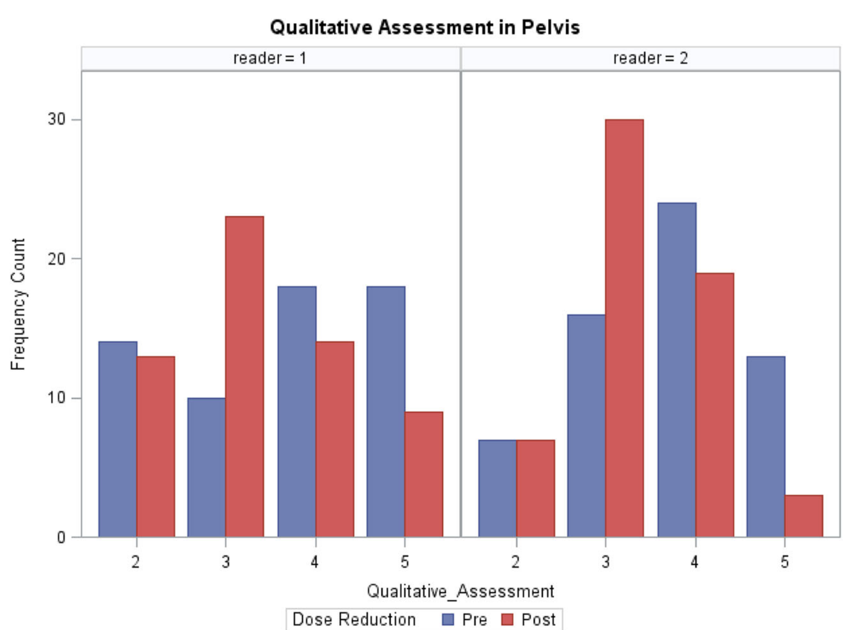

Fig. 7 ANCOVA analysis bar graphs of qualitative assessment for Observers 1 and 2 for pre- and post-dose optimization examinations. Analysis demonstrated a significant reduction in image quality for Reader 2 ($p < 0.01$) with adequate mean quality (3.3 out of 5), but no significant reduction for Reader 1

There was good to excellent interobserver performance in the determination of the SNR of various structures despite optimization of radiation doses to more than one-half of pre-implementation exposure levels. This is especially important for young patients who are commonly evaluated with trauma pelvis CT examinations [11, 12], thus avoiding excessive unnecessary exposure to the radiosensitive pelvic organs.

The measured increase in mean cortex SNR following dose optimization implementation could confer benefits such as improved detection of fractures. The variability in SNR for the cortex is complex to predict, given the interaction of kVp with noise, and also the dependence of Hounsfield units on bone density [13]. This interplay makes the exact effect of the impact of radiation dose reduction on cortical SNR difficult to determine owing to the heterogeneity of kVp and bone mineral density in this study. In addition, minor variations in placement of the ROI between observers, in addition to patient variations, could also account for error and an artifactual increase in SNR. Intraobserver variability was not measured as a part of this study, but could convey useful information if integrated into future projects. The decrease in mean visceral fat and mean adjusted muscle SNR on reduced dose examinations could imply decreased sensitivity for the detection of subtle lesions, although the clinical significance of this finding has not been substantiated. The lack of difference between mean SNR values for the remainder of measured tissue types is likely due to the relative insensitivity of soft tissue to kVp [13] and suggests that using dose optimization techniques would infer minimal, if any, impact on image interpretation. However, further studies exploring the possible effects of reduced dose examinations on diagnostic accuracy are needed.

We found that a lower BMI was associated with larger dose reduction, indicating greater benefit to these patients. This was an expected and, in fact, desired outcome, as dose is an explicit function of patient size. Before implementation of dose standardization at our institution, the kVp was adjusted according to the discretion of individual CT technologists. Following standardization, these changes were built into the protocols (e.g., AES). A higher BMI was associated with higher DLP regardless of pre- or post-optimization scan parameters. Some of the CT scanners that were part of this study were operating at a fixed mAs, so that all patients received the same CTDIvol regardless of their size. Therefore, for the Toshiba scanners, smaller patients received a greater benefit from utilizing automatic exposure control than the larger patients. For scanners where automatic exposure control was utilized, it was applied to all patients. Because the CT scanner generators can only produce a certain current range at a given kVp and fixed rotation time and pitch, patients with a higher BMI reached the upper limit for their scans, resulting in artificial truncation of their CTDIvol [14, 15]. The protocol changes implemented as a part of this study lowered the dose for all patients, but less so for larger patients because their doses were already less than prescribed by the automatic exposure control setting. Similar findings have been reported in dose optimization studies of abdominal and cardiac CT examinations [15, 16]. Although BMI does not provide a perfect correlation with CTDIvol because of the wide variability in body shape, it is more accurate than height or weight alone [14].

Being a retrospective study and owing to radiation implications, the benefit of comparing image quality for the same patient pre- and post-implementation of dose optimization techniques was not a feasible option. In addition, examinations with metal in the field of view were excluded from this study, and because the presence of metal increases patient dose, this could represent a future re-evaluation, including exploration of metal reduction techniques, such as OMAR (Metal Artifact Reduction for Orthopedic Implants) on Philips scanners, or the use of spectral CT. Potential future directions for further study include evaluation of the effect, if any, of reduced dose pelvic CT examinations on diagnostic accuracy. Also, utilizing DLP and CTDIvol do not measure the actual patient dose, but these parameters are linear with patient exposure and thus can be used as surrogates to provide useful information.

The results of this study can be widely applied to clinical practice for similar CT dose standardization and optimization initiatives, which would potentially benefit the patient population in terms of decreased cumulative radiation dose, while avoiding compromise of diagnostic image quality. To conclude, the subjective image quality for pelvic CT examination remains adequate, despite a substantially reduced radiation dose. It remains to be seen whether there is an effect on the diagnostic accuracy of various musculoskeletal pathological conditions.

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Compliance with ethical standards

Conflicts of interest The authors declare that they have no conflicts of interest.

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