Radiation Dose Reduction Strategy for SPECT/CT Bone Scan

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Radiation Dose Reduction Strategy for SPECT/CT Bone Scan

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Abstract

Purpose:

The aim of this study is to introduce the optimization method of CT parameters to reduce patient radiation exposure in bone SPECT/CT while maintaining image quality. The results of the new protocol were then compared to the results of the standard protocol saved in the nuclear medicine department`s data at King Abdullah Medical City.

Methodology:

***First part*:** Using Deluxe Jaszczak Phantom. The cylindrical phantom consisted of six bottles in a pie arrangement. These bottles were placed in the source tank. SPECT/CT scans were carried out with different x-ray tube current values (10, 20, 30, 40, 50, and 60 mA) at three different slices of thicknesses (2.5, 3.75, and 5mm). The contrast ratio (CR) and coefficients of variation (COV) in the SPECT images as well as the signal-to-noise ratio (SNR) and $CTDI_{vol}$ were all measured. An optimal acquisition protocol of SPECT/CT images with no artifacts on both CT and SPECT images, and acceptable CR, COV, and SNR values were obtained.

Second part: The study was done on patients who required a SPECT/CT bone scan of the spine area (thoracic spine (T1-T12) and lumbar spine (L1-L5)). Some patients were excluded from this study because of the image quality that was affected by several factors.

Different parameters obtained from the new reduced protocol were compared to old historical data saved in the system for patients who did the same image using the old standard protocol. The difference between the two systems was only in the current of the X-ray tube (the old 60 mA versus the new 40 mA).

Result:

The optimal set of parameters for bone SPECT/CT was determined based on a phantom part that has been implemented in clinical practice. Two groups of patients were examined according to the baseline and optimized protocols, respectively.

The new SPECT/CT protocol substantially reduced patients' radiation exposure as compared to the old protocol, while also maintaining the required diagnostic quality of SPECT and CT images.

Conclusions:

The newly established bone scan SPECT/CT protocol was implemented into clinical practice. It has significantly reduced patients' exposure dose as compared to the old protocol while maintaining the required diagnostic quality of SPECT and CT images.

Keywords: SPECT/CT, Optimization, Bone Scan, $CTDI_{vol}$

Declaration

"I undertook and composed this project, and it has not been accepted in any previous application for a degree. I also carried out the work described and all verbatim extracts have been distinguished by quotation marks and all information sources have been specifically acknowledged".

Date: April 2022

Literature Review

The goal of optimizing the patient`s radiation dose in medical diagnostics is to achieve high quality image in the most efficient manner. The CT is justified or appropriated for the stated clinical indication and is ,without doubt, the most important aspect of radiation dose optimization for SPECT/CT system .(Fahey & Stabin, 2014)(Ljubljana, n.d.)(Salvatori et al., 2019).

There are many previous studies interested in reducing patient exposure to ionizing radiation during the SPECT/CT, especially CT. Some studies focused on comparing two methods for nuclear image reconstruction, the adaptive statistical iterative reconstruction (ASiR) techniques and filtered back projection (FBP) CT reconstruction, without affecting the image quality of the bone scan images. Another group studied another method, where they changed the parameters of the CT part, such as the x-ray tube current, high voltage, and slice thickness without affecting the image quality of the bone scan images.(Chen et al., 2021)(Shibutani et al., 2021)(Montes et al., 2013)(Sibille et al., 2016)(Grosser et al., 2019)(Willemink et al., 2013)(Grosser et al., 2015)(Tulik et al., 2020).

Gupta et al. and Tulik et al. study was reducing patient exposure dose from SPECT/CT of the bone scan by optimizing the CT parameters without affecting the image quality of SPECT images with attenuation correction. However, a limitation of this is a focus on changing CT parameters only without using advanced reconstruction algorithms of CT with only one type of SPECT/CT device used in this study.(Tulik et al., 2020)(Gupta et al., 2017).

Sibille et al. and Grosser et al. study was reducing patient exposure dose from SPECT/CT by using CT reconstructed with filtered back projection (FBP) and adaptive statistical iterative reconstruction (ASiR). However, another limitation of these past studies is that results cannot be extrapolated to second-generation iterative reconstruction techniques such as MBIR. (Sibille et al., 2016) (Grosser et al., 2019).

These recent studies have provided insights into how we can reduce the CT dose for SPECT/CT images without affecting image quality.

In Saudi Arabia, there is no unified protocol between hospitals to control and select the parameters of the CT scan, but rather it is up to the nuclear medicine department in terms of the technical specifications of the nuclear medicine devices used while also following the recommendations of European or American protocols for practice guidelines for a bone scan.

The purpose of this study is to reduce patient's radiation dose exposure from SPECT/CT of the bone scan by optimizing the CT parameters without affecting the image quality of SPECT images with attenuation correction. The result of the new protocol will be compared to the results of the standard protocol which are saved in the department`s data.

Research Design

This study was conducted as an analytical clinical trial study at the Nuclear Medicine Department of King Abdullah Medical City. The study was approved by Institutional Review Board at the King Abdullah Medical City (approval no. 21-818).

In this study, new reduced-dose radiation protocol of SPECT/CT was designed. This new method was done for new patients who agree to be imaged using a lower dose technique. The new data was then compared to the old data in our system for SPECT/CT done on patients with the same types of cancers from 2019 to 2021 using a traditional dose of SPECT/CT bone scan imaging. The patients were enrolled in the study after signing the informed consent forms to be included in the new reduced dose protocol.

A total of 60 studies were done and divided into two groups: the Standard dose 'traditional' CT protocol and the lower dose 'new' CT protocol.

For the first group, the data was analyzed for 40 patients who had undergone standard protocol bone SPECT/CT imaging for cancer (male, n = 11; female, n = 29; median age, 57 years; range, 32 – 80 years; median BMI, 23.45 Kg/m^2 ; range, 19.6 -27.3 Kg/m^2). For the second group, the data was analyzed from 20 patients who had undergone new protocol of bone SPECT/CT imaging for cancer (male, n = 4 ; female, n = 16 ; median age, 54 years; range, 28–80 years; median BMI, 25.4 Kg/m^2; range , 21-29.8 Kg/m^2).

The Guideline for the bone scan was developed by The European Association of Nuclear Medicine (EANM) practice guidelines for bone scintigraphy. All examinations were performed on a Discovery NM/CT 670 camera (GE HealthCare).

Methodology

First part: a study on phantom (using the usual standard-dose protocol in our department versus reduced dose (new protocol).

Second part: The study was done on patients who required a SPECT/CT scan of the spine area (thoracic spine (T1-T12), lumbar spine (L1-L5)).

Some patients were excluded from this study because of several factors that can affect the image quality. Some of these factors are listed below.

Exclusion criteria:

- Artificial disc replacement surgery
- Vertebral fixation or lumbar spine fixation surgery
- Renal disease
- Obesity (BMI $\geq$ 30)
- Patients under 18 years and above 80 years
- Patients suffering from Claustrophobia
- Patients who require a SPECT/CT scan of the cervical spine (C1-C7), sacral spine (S1-S5), and coccyx.

Inclusion criteria:

- Patients 18 - 80 years
- BMI 18.5 – 29.9
- Cancer patients
- Patients who require a SPECT/CT scan of the spine area (thoracic spine (T1-T12), lumbar spine (L1-L5)).

Study procedures

THE FIRST PART:

- Phantom and Settings:

  A phantom that resembles a human bone tissue was used. The phantom was exposed to different radiation levels and factors such as; Tube current and slice thicknesses.

- Scanning Techniques:

  Using Deluxe Jaszczak Phantom™ Model ECT/FL-DLX/P phantom, the cylindrical Jaszczak was used to obtain image quality measures such as noise, tomographic uniformity, and contrast. We inserted six bottles in a pie arrangement. These bottles were placed in the source tank (as shown in figure 1). The CT number for bottles is -997 Hounsfield Unit (HU).

Figure 1: The phantom body with inserted.

The phantom body was filled with water mixed with ^{99m}Tc (a warm background simulating residual activity in a patient's body outside the skeleton). The bottles (simulating the abnormal and normal bone, three of them represented the abnormal bone and the others represented the normal bone) were filled with a solution of (K_2HPO_4) (dipotassium hydrogen phosphate) salt mixed with water and^{99m}Tc.(Dreuille et al., 1997)(Tulik et al., 2020).

The abnormal bone parts were filled with the solution at different concentrations activities of 300, 250 and, 200 kBq/mL while the normal bone parts were filled with the solution at a concentration activity of 50 kBq/mL. The body part was also filled with a ^{99m}Tc solution of 8 kBq/mL as a background (BG).(Shibutani et al., 2021)(Miyaji et al., 2020).

During the first step, a phantom image was acquired with the standard SPECT/CT protocol used at the Nuclear Medicine Department. This phantom and a SPECT/CT scan were performed with the LEHR collimators using 180 degrees configuration. After the acquisition, the data was reconstructed using the OSEM method 2 iteration / 10 subsets / Butterworth filter 10/0.48 with attenuation and scatter correction (CT data were used to create attenuation correction maps).

The following parameters were used in SPECT / CT study:

- Energy windows (one for the photopeak of ^{99m}Tc (140 ± 7.5% keV) and the other for Compton down scatter correction (120 ± 7.5% keV)
- The SPECT acquisition used Matrix 128×128, 4.42 mm pixel size, and step & shoot mode.
- The CT acquisition used helical scan, Speed: 27.5 mm/rotation, pitch: 1.375/1, rotation time: 0.8 s, Slice thickness: 3.75mm, 120 kV, 60 mA and reconstructed using a 512 x 512 matrix, filtered back projection method (FBP).

The SPECT/CT image was considered as a reference point in further evaluation (the reference image).

In the second step, a series of CT scans were carried out with different x-ray tube with current values (10, 20, 30, 40 and 50mA) and different Slice thicknesses (2.5 and 5 mm).

➢ *Processing and Image reconstruction:*

The images were reconstructed on a *Xeleris 3 Volumetrix MI* workstation with the following parameters:

- Using the ordered subsets expectation maximization reconstruction (OSEM) algorithm with 2 iteration, 10 subsets and Butterworth filter 10/0.48 with attenuation and scatter correction (CT data were used to create attenuation correction maps).

➢ *Image quality evaluation and assessment:*

1. The SPECT/CT images are visually assessed by nuclear medicine specialists and medical physicists in a masked manner.
2. The image quality was scored on a three point scale : 3 = no visible artifacts in CT image, no noticeable deterioration of background uniformity in SPECT image, and all six hot sources visible; 2 = streak artifacts slightly visible in CT image and noticeable deterioration of background uniformity or at least five hot sources visible in SPECT image; 1 = streak artifacts visible in CT image and a significant deterioration of background uniformity and hot sources visibility in SPECT image (at least four hot sources still visible).(Tulik et al., 2020)(Grosser et al., 2019)(Park et al., 2014).
3. Quantitative analysis for SPECT images by calculating contrast ratio (CR) and coefficient of variation (COV).

- ***Contrast Ratio (CR)***

The contrast ratio of an image is the relative variations in counted densities between adjacent areas in the image of an object.

The contrast ratio (C) for a hot source is expressed as:

$$\boldsymbol{CR = \frac{(C_h - C_b)}{C_b}}$$

Where C_h and C_b are the total number of counts per mL for each hot source and the mean total number of counts in backgrounds, respectively.

- ***Coefficient of Variation (COV).***

The Coefficient of Variation (COV) is expressed as:

$$\boldsymbol{COV = \frac{SD_b}{C_b}}$$

Where SD_b and C_b are the mean standard deviation of counts in backgrounds and the mean total number of counts in backgrounds, respectively.

4. Quantitative analysis for CT images determined by calculating Standard deviation (SD) and signal to noise ratio (SNR).

- ***Signal to Noise Ratio (SNR).***

The Signal to Noise Ratio (SNR) for hot source is expressed as:

$$\boldsymbol{SNR = \frac{HU_h}{SD_{CT}}}$$

Where HU_h and SD_{CT} are the mean HU values in the hot source and the mean standard deviation of value in backgrounds, respectively.

5. Calculate CT dose index volume ($CTDI_{vol}$)

The $CTDI_{vol}$ values were automatically documented in a dose report.

THE SECOND PART:

- Patients and Settings:

We conducted the new reduced dose protocol for 20 patients who had undergone new protocol bone SPECT/CT imaging for cancer (male, n = 4 ; female, n = 16 ; median age, 61 years; range, 23–79 years; median BMI, 25.4 Kg/m^2 ; range , 21-29.8 Kg/m^2) .

Our new protocol was expected to reduce the exposure dose of the patient without affecting the necessary diagnostic information.

Different parameters that were obtained from the new reduced protocol were compared to old historical data saved in the system for patients that had the same image using the old standard protocol. The difference between the two systems was only by the X-ray tube current (the old 60 mA versus the new 40 mA).

The patients were included in the study after signing the informed consent forms to be included in the new reduced dose protocol.

The data for the old protocol was collected from the system so that we did not need to obtain any consents from patients who had already done the imaging using the old standard dose protocol.

- Scanning Techniques:

Two hours before the SPECT scan; all patients were given an IV injection of hydroxy methylene diphosphonate (HDP) with Tc99m. The average amount of injected ^{99m}Tc was 740 (range, 666 – 814) MBq. The patients were advised to be in well-hydrated states and have an empty bladder prior to the imaging.

The following parameters were used in SPECT /CT study:

- Low energy high-resolution (LEHR) parallel collimators.
- Energy windows (one for the photopeak of ^{99m}Tc (140 ± 7.5% keV) and the other for Compton down scatter correction (120 ± 7.5% keV).
- The SPECT acquisition use Matrix (128×128), 4.42 mm pixel size, and step & shoot mode.
- The CT acquisition use helical scan, Speed: 27.5 mm/rotation, pitch: 1.375/1, rotation time: 0.8 s, Slice thickness: 3.75mm, 120 kV, 40mA and reconstructed using a 512x 512 matrix, filtered back projection method (FBP).

- Processing and Image Evaluation:

The images were reconstructed on a *Xeleris 3 Volumetrix MI* workstation with the following parameters:

- Using the ordered subsets expectation maximization reconstruction (OSEM) algorithm with 2 iteration, 10 subsets and Butterworth filter 10/0.48 with attenuation and scatter correction (CT data were used to create attenuation correction maps).

- Image quality evaluation and assessment:

1. The SPECT/CT images were visually assessed by two nuclear medicine consultants, nuclear medicine specialist, and medical physicist in a masked manner.
2. The image quality of each SPECT/CT data was determined by using Image qualities that were judged independently for cases from each group on a 5-point ordinal scale (Likert score) to evaluate the image quality based on the following criteria: non-diagnostic image (grade 1), sub-optimal diagnostic and limited clinical information (grade 2), diagnostic and acceptable image quality (grade 3), diagnostic and good image quality (grade 4) and diagnostic and excellent image quality (grade 5). (Park et al., 2014)(Picone et al., n.d.)
3. Quantitative analysis for SPECT images done by calculating contrast ratio (CR) and coefficient of variation (COV).

- ***Contrast Ratio (CR)***

The contrast ratio of an image is the relative variations in count densities between adjacent areas in the image of an object.

The contrast ratio (C) for hot source is expressed as:

$$\boldsymbol{CR = \frac{(C_L - C_b)}{C_b}}$$

Where C_L and C_b are the total number of counts for the area of the lumbar spine (hot source) and the mean total number of counts in backgrounds, respectively.

- ***Coefficient of Variation (COV).***

The Coefficient of Variation (COV) is expressed as:

$$\boldsymbol{COV = \frac{SD_b}{C_b}}$$

Where SD_b and C_b are the mean standard deviation of counts in five backgrounds and the mean total number of counts in five backgrounds, respectively.

4. Quantitative analysis for CT images obtained by calculating Standard deviation (SD) and signal to noise ratio (SNR).

- ***Signal to Noise Ratio (SNR).***

The Signal to Noise Ratio (SNR) is expressed as:

$$\boldsymbol{SNR = \frac{HU_b}{SD_b}}$$

Where HU_b and SD_b are the mean HU value in the background and the mean standard deviation value in the backgrounds, respectively.

5. Calculate CT dose index volume ($CTDI_{vol}$).

The $CTDI_{vol}$ or Patient exposure was calculated in both groups according to a report by the American Association of Physicists in Medicine Task Group (AAPM TG) 204. A size-specific dose estimate (SSDE) was calculated for each patient.(No.204, 1369).

Statistical Analysis Plan

In the first part, Excel spreadsheets were used to compare the mean CR, COV, SNR, and $CTDI_{vol}$ values determined for the reference image and images obtained using the exposition parameter sets.

In the second part, the paired Wilcoxon/Mann–Whitney test or Student's t-test was used to compare two independent groups depending on the data distribution. All statistical tests were two-tailed, and p values were considered statistically significant when $P < 0.05$. These data were statistically analyzed using IBM SPSS Statistics software (Version: 28.0.1.1).

Results and Discussion

The use of SPECT/CT scan has been significantly increased nowadays. Many strategies and studies have been improved to reduce the patient radiation doses of SPECT/CT without effect on image quality. In this project, we aim to improve the reduction of the radiation dose of SPECT bone scans while also maintaining image quality. This study was done in two parts; phantom study and a Patient's study.

The first part: phantom study

There are many studies, that has described a fillable phantom containing a material with a density corresponding to bone tissue.(Shibutani et al., 2021)(Tulik et al., 2020)(Miyaji et al., 2020)(Dreuille et al., 1997). In this part, the idea of a fillable phantom reflecting realistic bone scintigraphy conditions (accumulation of radiopharmaceuticals in dense structures) was modified to simulate bone scan patients. The best set of exposure parameters in terms of image quality and exposure was determined.

- Image quality evaluation and assessment:

The results of the visual assessment and image quality of the phantom SPECT/CT images obtained for various combinations of CT exposure parameters are presented in table 1.

X-ray Tube Current (mA)

Slice Thickness (mm)	*10*		*20*		*30*		*40*		*50*		*60*	
	SPECT	CT	SPECT	CT	SPECT	CT	SPECT	CT	SPECT	CT	SPECT	CT
2.5	3	1	3	1	3	2	3	2	3	3	3	3
3.75	3	1	3	1	3	2	3	3	3	3	RI	
5	3	1	3	1	3	3	3	3	3	3	3	3

Table 1: Visual assessment and IQ of the phantom SPECT/CT images, RI: reference image

- Quantitative analysis:

Detailed results (mean values with of CR, COV and SNR) and $CTDI_{vol}$ values in the SPECT/CT images for each analyzed parameter sets) are presented in table 2 and 3.

X-ray Tube Current (mA)

Slice Thickness (mm)	***10***		***20***		***30***		***40***		***50***		***60***	
	Mean SNR	$CTDI_{vol}$	*Mean SNR*	$CTDI_{vol}$	*Mean SNR*	$CTDI_{vol}$	*Mean SNR*	$CTDI_{vol}$	*Mean SNR*	$CTDI_{vol}$	*Mean SNR*	$CTDI_{vol}$
2.5	11.37	0.54	16.35	1.09	20.04	1.63	23.19	2.17	27.28	2.72	28.34	3.26
3.75	14.84	0.54	20.03	1.09	24.69	1.63	26.84	2.17	31.01	2.72	36.93 *RI	3.26 *RI
5	17.62	0.54	22.47	1.09	28.34	1.63	33.55	2.17	36.47	2.72	38.65	3.26

Table 2: Mean SNR values and $\boldsymbol{CTDI_{vol}}$ values of the phantom CT images, RI: reference image**.**

X-ray Tube Current (mA)

Slice Thickness (mm)	***10***		***20***		***30***		***40***		***50***		***60***	
	Mean CR	*Mean COV*	*Mean CR*	*Mean COV*	*Mean CR*	*Mean COV*	*Mean CR*	*Mean COV*	*Mean CR*	*Mean COV*	*Mean CR*	*Mean COV*
2.5	5.85	0.0164	5.83	0.0165	6.19	0.0169	5.77	0.0165	5.67	0.0162	5.55	0.0161
3.75	6.02	0.0165	6.41	0.0167	6.41	0.0167	5.85	0.0164	5.85	0.0164	5.87 *RI	0.0164 *RI
5	6.07	0.0167	5.99	0.0167	5.99	0.0164	5.59	0.0161	5.80	0.0164	5.79	0.0163

Table 3: Mean CR and COV values of the phantom SPECT images, RI: reference image

Figure 2 and 3 presented the CR and COV values for SPECT images and Figure 4 and 5 present the SNR and $\boldsymbol{CTDI_{vol}}$ values for CT images.

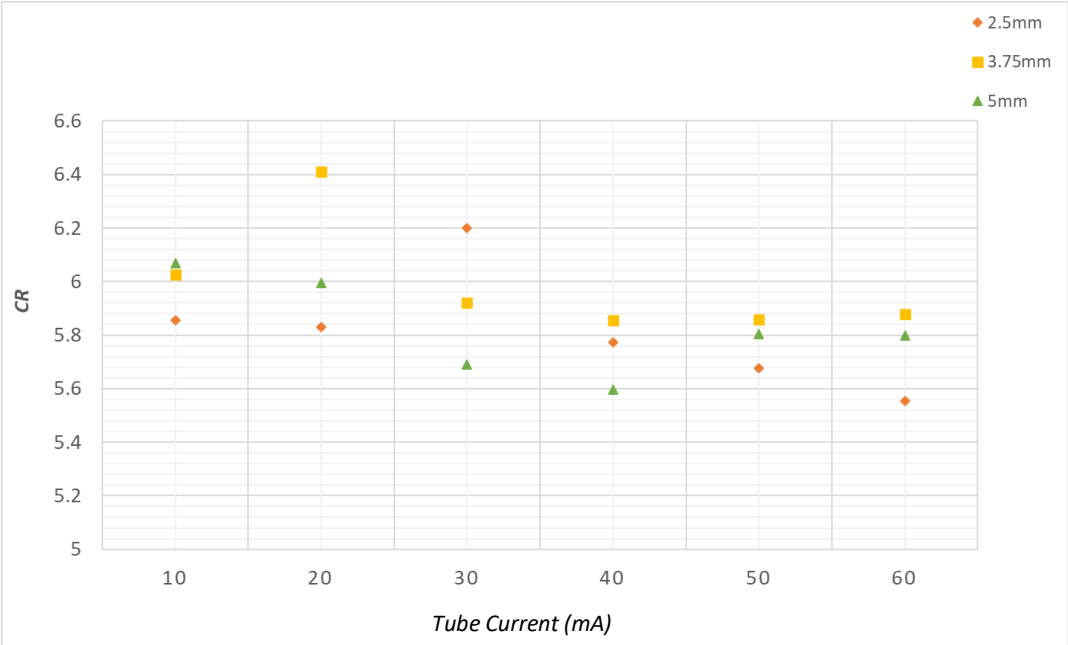

Figure 2: Mean CR values of the phantom SPECT images

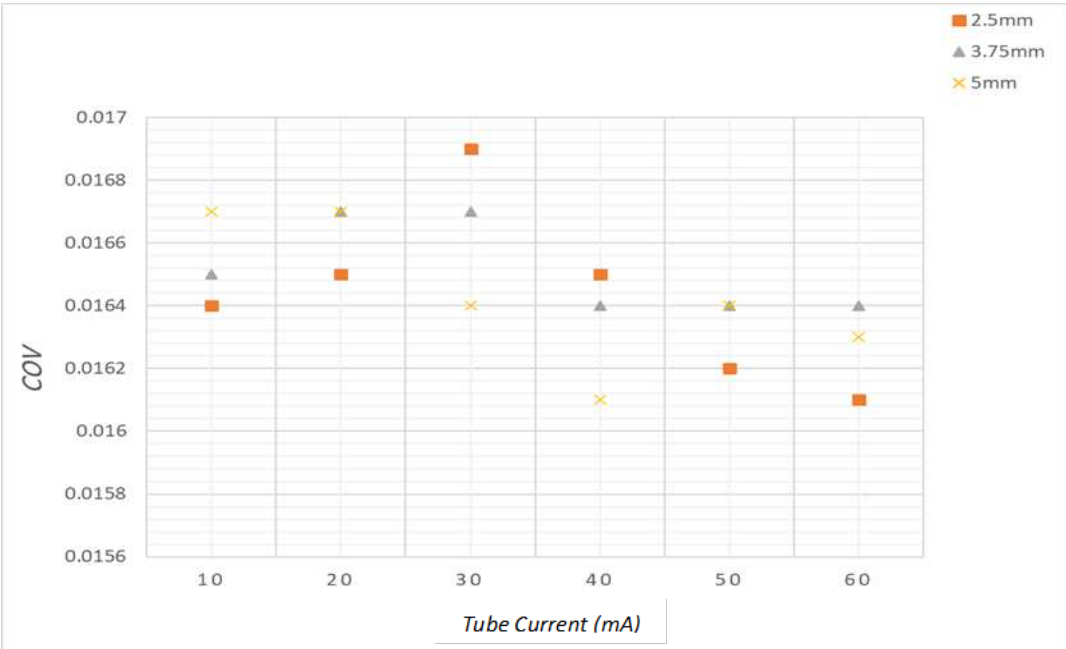

Figure 3: Mean COV values of the phantom SPECT images

In the SPECT, according to the result in fig (2 and 3), we found that there was no statistically significant difference in average contrast ratio (CR) and coefficient of variance (COV) between different CT parameters. This result is expected because we fixed the SPECT parameters and did not change anything from the old protocol.

In CT images, there was a significant difference in the SNR and $CTDI_{vol}$ for different CT parameters such as tube current and the slices thicknesses (as shown in fig 4 and 5).

According to the result in table 2, there is a relationship between the SNR and the slice thickness in the CT, for as the slice thickness in the CT increased, the SNR increased as well. For example, when the slice thicknesses were 3.75 mm and 5mm (at current 40mA), the mean SNR were 26.84 and 33.5, respectively. In addition, when the slice thicknesses were 3.75 mm and 5mm (at current 30mA), the mean SNR were 24.69 and 28.34, respectively. However, we cannot choose the slice thickness of slice 5mm in the imaging of the spine area because the anatomy information related to this area during the scan protocol may be lost.

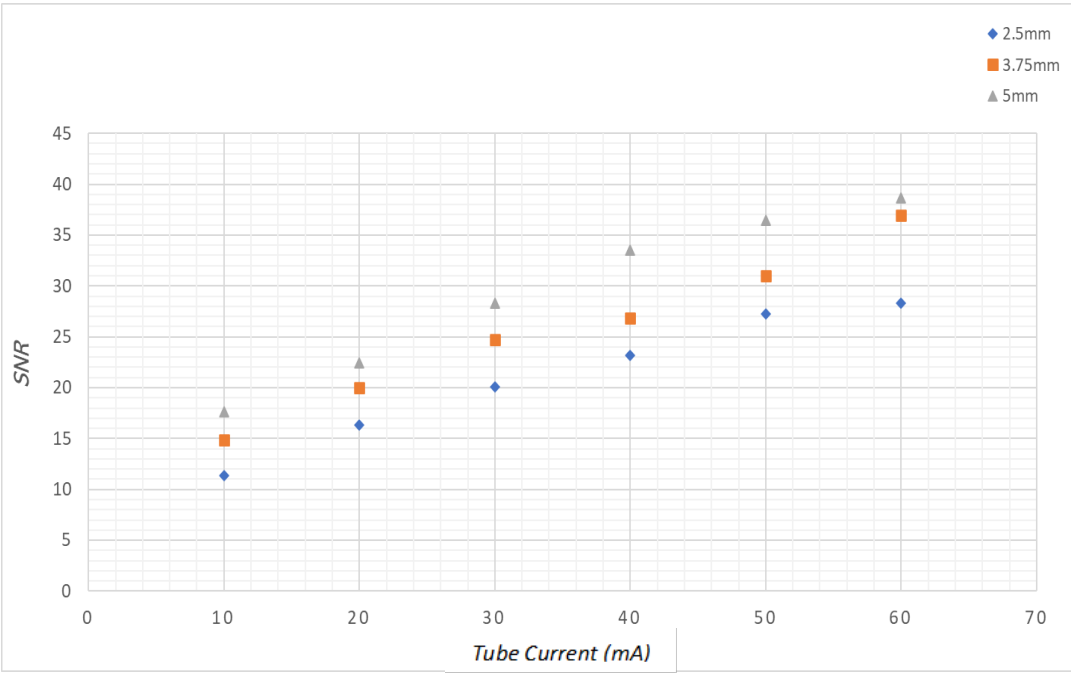

Figure 4: Mean SNR values of the phantom CT images

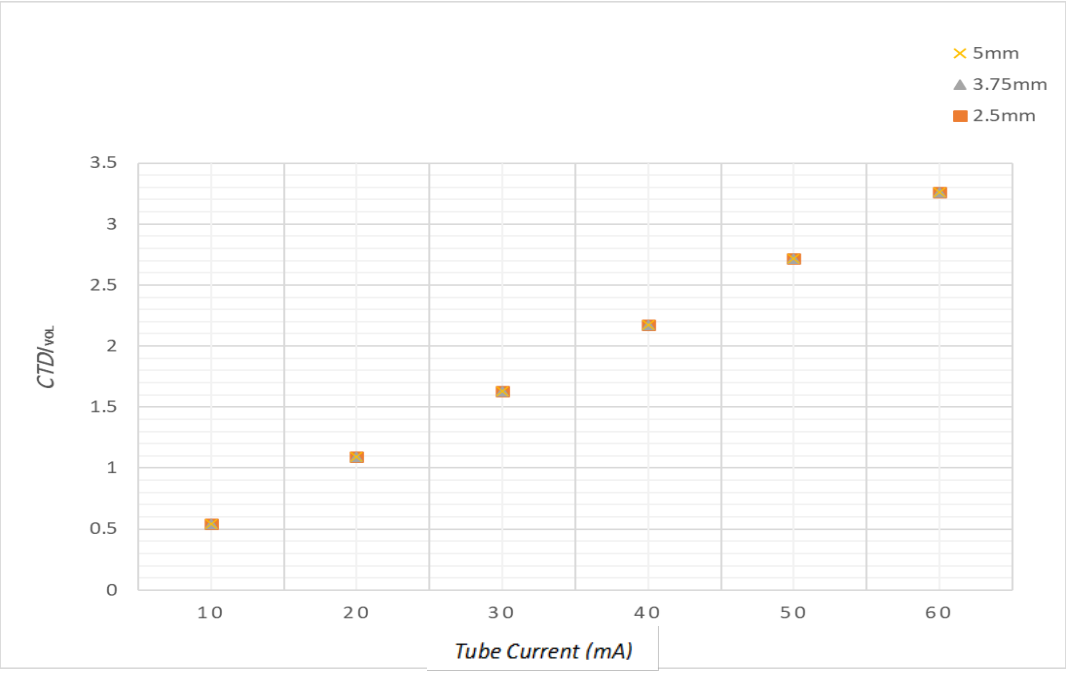

Figure 5: $CTDI_{vol}$ values of the phantom CT images

Because the first few image qualities were poor by visual evaluation or quantitative analysis, the new protocol was not established in our department and we proceeded with the procedure with the old standard doses.

After assessment and analysis of images in the first part, the CT parameters of the bone SPECT/CT protocol for the lumber spine area were changed from 120 kV and 60 mA to 120 kV and 40 mA without changing the SPECT parameters.

The second part: Patient's study

- Image quality evaluation and assessment:

The study population was divided into two groups. The first group (male, n = 11; female, n = 29; median age, 57 years; range, 32 – 80 years; median BMI, 23.45 Kg/m^2 ; range, 19.6 -27.3 Kg/m^2) was examined according to the baseline (old) SPECT/CT protocol. The second group II: (male, n = 4; female, n = 16; median age, 61 years; range, 23 – 79 years; median BMI, 25.4 Kg/m^2 ; range, 21-29.8 Kg/m^2) was examined according to the optimized (new) SPECT/CT protocol.

The SPECT/ CT image quality evaluation between groups I and II was not significantly different, with an equal median Likert score of 3 (min 2, max 4) in both techniques and groups.

- Quantitative analysis:

According to the result in table 4, the quantitative SPECT evaluation showed no difference in contrast CR between the groups with a median CR of 4.52 (min 2.14, max 19.31) for the old protocol and 4.38 (min 1.28, max 10.72) for the optimized protocol; and a median SD_{SPECT} of 52.97 (min 30.42, max 78.41) for the old protocol and 41.57 (min 31.62, max 66.47) for the optimized protocol respectively. This result is expected because we fixed the SPECT parameters and did not change anything from the old protocol. However, the few differences here were attributed to the different physiology of patients' bodies and a median COV of 0.015 (min 0.010, max 0.031) for the old protocol and 0.020 (min 0.012, max 0.030) for the optimized protocol.

SPECT part	*Group*	*Min*	*Max*	*Median*	*P*
CR	I	2.141	19.314	4.521	0.386
	II	1.289	10.728	4.389	
SD_{SPECT}	I	30.422	78.412	52.977	0.038
	II	31.629	66.474	41.577	
COV	I	0.0101	0.0319	0.0156	0.068
	II	0.0126	0.0308	0.0204	

Table 4: SPECT images quantitative analysis

The results in table 5 illustrated that the quantitative CT evaluation showed no difference in SD_{CT} and SNR between the groups with a median SD_{CT} of 27.39 (min 16.33, max 38.35) for the old protocol and 26.66 (min 19.35, max 36.7) for the optimized protocol; and a median SNR of 1.67 (min 0.655, max 3.11) for the old protocol and 1.93 (min 0.993, max 3.35) for the optimized protocol respectively.

The median new $CTDI_{vol}$ according to AAPM TG 204 for group I 4.07 (mean 4.13 mGy) was significantly higher than for group II 3.038 (mean 2.95 mGy). In the table below (Table: 5), the related quantitative CT images (table 5).

CT part	Group	Min	Max	Median	P
SD CT	I	16.33	38.35	27.39	0.734
	II	19.35	36.7	26.66	
SNR	I	0.655	3.11	1.673	0.157
	II	0.993	3.35	1.93	
New $CTDI_{vol}$ (mGy)	I	3.064	5.085	4.075	< 0.001
	II	2.343	3.385	3.038	

Table 5: CT images quantitative analysis

The selected set of parameters was applied to the bone scan. It was experimentally established that using the new optimization protocol considerably reduced patient exposure while preserving diagnostic image quality.

Limitations of the Research

A noteworthy limitation of our study is that the results we report apply to one SPECT/CT system (Discovery NM/CT 670) and used FBP CT reconstruction method.

Another issue is determining the type of patients and the area of bone scan that will be included in the study.

Suggested Future Considerations

In future studies: firstly, this strategy of optimization for bone scan should be repeated on other SPECT/CT devices and comparing between two machines with the same modulation and different performance specifications.

Secondly, the optimization protocol applied to all patient's bone scan without determination of the area except for patients in artificial disc replacement surgery, vertebral fixation or lumbar spine fixation surgery, renal failure and obesity (BMI ≥ 30).

Thirdly, calculating the new $CTDI_{vol}$ for old and new patients of nuclear medicine by AAPM TG 204 method and comparing between old and new $CTDI_{vol}$.

Finally, using the potential of iterative CT reconstruction for optimized dose management. Many researchers have focused on iterative CT reconstruction of bone tissue in which the signal to noise ratio is naturally high and to further reduce patient exposure. (Sibille et al., 2016)(Grosser et al., 2019)(Willemink et al., 2013)(Grosser et al., 2015).

Conclusions

In conclusion, in this study, we defined a procedure that gets a comprehensive diagnostic information and cancer patient exposure during bone scan SPECT/CT. The established bone scan SPECT/CT protocol was implemented into clinical practice. It has significantly reduced patient exposure dose as compared to the old protocol while also maintaining the required diagnostic quality of SPECT and CT images.

Compliance with Ethical Standards

The ethical approval was approved by Institutional Review Board at the King Abdullah Medical City (approval no. 21-818).

Informed consent: The patients were enrolled in the study after signing the informed consent forms to be included in the new reduced dose protocol. We will not obtain any consents from patients who are already did the imaging using old standard dose protocol, as we will collect data saved in the system as the data already available in the system and will be collected retrospectively.

Conflict of Interest: The authors and co-authors have no conflicts of interest to declare and there is no financial interest to report.

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