

Assessment of CT Imaging Protocols Impacts on Calculation of Point Dose in Water Phantom Using Radiotherapy Treatment Planning System

Gholamreza Fallah Mohammadi ^{1,*} , Ehsan Mihandoost ²

¹ Department of Radiology, Faculty of Allied Medicine, Mazandaran University of Medical Sciences, Sari, Iran

² Radiotherapy Center, Imam Hospital, Mazandaran University of Medical Sciences, Sari, Iran

*Corresponding Author: Gholamreza Fallah Mohammadi
Email: rezfallah@gmail.com

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Abstract

Purpose: Point dose calculation in the Treatment Planning System (TPS) is performed using Computed Tomography (CT) images because CT images data have the tissue electron density information. The effect of CT imaging protocols on the calculation of point doses in TPS is one of the most important subjects that was evaluated in this study.

Materials and Methods: CT scan imaging was performed from cylindrical water phantom using three scanner systems and different imaging technical parameters. The CT images data were irradiated in TPS to delivering a 200 cGy radiation dose to the center of the phantom with 6 and 15MV X-Ray photon energy with multiple radiation fields and Monitor Unit (MU) were separately calculated. In the TPS, a virtual water phantom with the same characteristic as CT image phantom was simulated and irradiated with similar conditions. The difference in MU values obtained from two irradiation methods in TPS was compared with Wilcoxon nonparametric test.

Results: Variations of mA, kV, Pitch, slice thickness, and kernel as CT imaging parameters have not significantly affected radiotherapy point dose calculation (<2%). CT imaging protocols as a thin slice, 80 kV, and sharp kernel have the greatest difference between CT image-based calculation and designed phantom calculation in TPS where wedge field and 6 MV photon energy were used.

Conclusion: The use of CT images obtained with multiple protocols can be used without having a significant effect on the dose calculations of the treatment planning system.

Keywords: Computed Tomography Scan; Imaging Protocol; Point Dose; Radiotherapy.

1. Introduction

Organ dose calculations in radiotherapy, helical tomotherapy, and proton therapy have been based on computed tomography images for 37 years [1, 2]. CT scan image has anatomical information of the patient's body and tissue electron density data: therefore, it is the best tool for the tumor and targets volume determination, and dose calculation process in the radiotherapy Treatment Planning System (TPS). Some radiotherapy centers use CT scan imaging data from their own department, but some other radiotherapy departments may use CT images obtained from other CT scan imaging centers with different models and different imaging parameters for patient treatment and dose calculations. Attenuation properties of tissue in the photon radiation field are defined as Hounsfield Unit (HU). The accuracy of the calculation of the dose distribution in radiotherapy is based on the electron density data of the tissues [3]. In TPS, the HU is usually converted to relative electron density (e_{lp}) using appropriate and predetermined calibration curves [4]. The calculated HU for each tissue depends on the amount of energy (quality) of the X-Ray, so the calculated HU is different for the tissue given in the various CT scans due to the inherent X-Ray tube filter. Even for a specific scanner, depending on the type of tube filtration and the amount of kV, HU calculated can vary [5, 6]. Based on clinical purposes, the CT scan imaging protocols as slice thickness, X-Ray tube current (mAs), FOV, kV, convolution kernel and other parameters can be different. Image quality is directly affected by imaging protocols. In radiotherapy departments in the selection of CT scan imaging protocols, common imaging parameters are usually used for all patients [7, 8], because the change in imaging parameters can affect the HU calculation, which will result in the calculations of dose in the TPS with an error. All activity of radiotherapy physicist concentrates on accurate dose calculation in the treatment process and one of the most important parameters in dose calculation in TPS is electron density of tissue that must be extracted from CT scan image. The study of image quality and the effect of CT scan imaging protocols on the point doses calculated in TPS is one of the most important subjects in which little research has been done on it. In this study, the effect of important imaging parameters such as kV,

mA, slice thickness, convolution kernel, and pitch from several CT scan systems on the point dose calculated using TPS at the center of water phantom (human body equivalent phantom) was investigated.

2. Materials and Methods

In this study, a cylindrical water phantom with a diameter of 32 cm and a length of 14.5 cm was used for CT scan imaging (Figure 1).

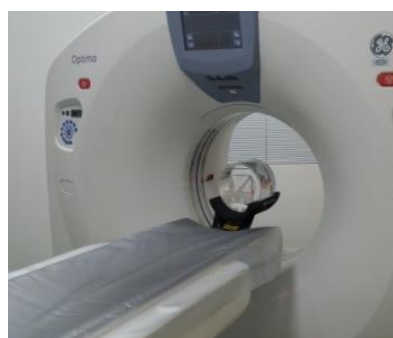


Figure 1. Imaging of cylindrical water phantom placed in isocenter of CT scanner system with different protocols in this study

Phantom was imaged using three CT scan models as Siemens Emotion 16slice, GE Light speed 16 slices and GE Optima 32 slice. For water phantom imaging, several technical parameters including kilo voltage, milliamperes, slice thickness, convolution kernel (reconstruction filter), and pitch were used. Technical parameters were selected based on protocols applied in CT imaging of body among different centers that sent CT images data to the radiotherapy department for treatment planning. CT imaging parameters included several kV (80, 120, and 140), several slice thicknesses (1.25, 2, 5 and 10mm), two pitches between 1 and 2, several mA and two kernel (smooth and sharp). The scan length area was as long as the phantom length. For calculation of dose and phantoms irradiation, treatment planning system as Core PLAN algorithm, in the radiotherapy department of Imam Khomeini Hospital in Sari, Iran was used. In order to ensure the accuracy of the TPS in dose calculation, an audit test was performed on the phantom of water. A phantom with geometric characteristics similar to the real cylindrical water phantom was designed in TPS (Figure 2a). In TPS software, the designed phantom was irradiated with three types of radiation field (two

fields, four fields, and a single field using a 15 degree wedge), a 10 x 10 cm² field size, the SID technique, and 6 MV and 15 MV photon energies. In TPS, the Monitor Unit (MU) for the transfer of 200 cGy doses to the center of the designed phantom was calculated and defined as the standard value for comparison and statistical analysis. Then, the CT image of phantom (Dicom data), which was obtained with multiple protocols, was uploaded to the TPS, and was irradiated to the same conditions as designed phantoms (Figure 2b).

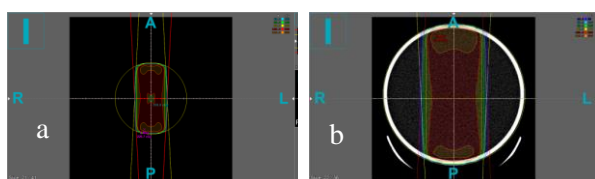


Figure 2. (a) Irradiation to the designed cylindrical phantom as standard object in TPS with 2 fields, and (b) irradiation with similar conditions to the CT image of a cylindrical water phantom transferred to the TPS

The mean MU for three radiation fields was calculated separately for two energies (6 and 15 MV). The mean differences non-parametric Wilcoxon rank-sum statistical test was used to compare the mean MU values obtained for two methods.

3. Results

Table 1 shows the MU values for delivering 200 cGy dose to the center of the designed phantom in TPS for 6 MV and 15 MV photon energies.

In Table 2, the calculated MU values for two energies in TPS for delivery of 200 cGy doses to the center of the CT image of phantom uploaded to the software which were obtained using multiple imaging protocols are shown.

In Figure 3, the mean difference in MU values for all imaging protocols and the standard values is shown for two energies 6 MV and 15 MV.

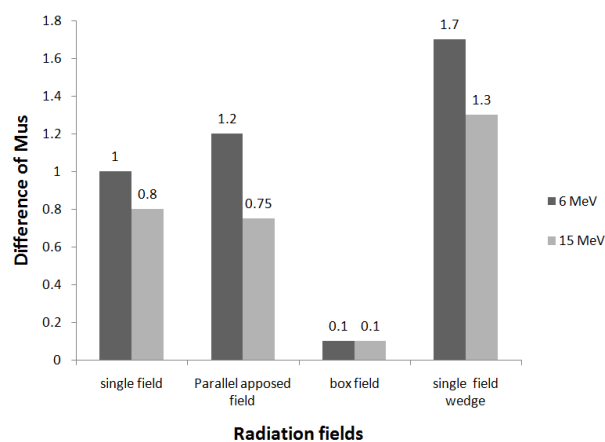


Figure 3. Mean MUs calculated the difference for 200 cGy Radiation doses delivering to the center of water phantom for two calculation methods in TPS (CT image based and virtual designed phantom)

In this study, Wilcoxon ranked sum nonparametric test for independent samples with P < 0.05 was used to compare the two groups and to analyze the hypothesis test. In this statistical test, T value was smaller than 2.056 (comparison criteria) for all ordinal ranks and the values of Table 1 and Table 2 did not show a significant difference.

4. Discussion

In this study, the effects of CT scan imaging protocols from three different CT scan systems on the calculation of point doses in the treatment planning system were investigated. The findings of this study indicate that the variations of CT scan imaging protocols have not significantly affected the dose calculation in water phantom compared to the standard value in TPS (< 1.5 %).

Table 1. Comparison of the Clinicopathological factors of CKD patients and control (N= 77)

Photon Energy	Single Field	Parallel Apposed Field		Box Field				Single Field with 15 Degree Wedge
		Anterior	Posterior	Anterior	Posterior	Left Lateral	Right Lateral	
6 MV	258.6	129.3	123.9	64.6	61.9	63.2	63.7	380.6
15 MV	213.5	106.8	103.1	53.4	51.5	52.6	52.9	286.8

Table 2. Calculated MUs for delivering of 200 cGy doses to center of CT image of water phantom in TPS using two X-ray photon energies and multiple fields. Images were obtained with three CT scan systems and multiple imaging protocols

CT scanner model and protocols for imaging of water phantom (these images imported to TPS for MUs calculation)	Photon Energy (MV)	Radiation Fields in TPS							
		Single Field	Parallel Apposed Field		Box Field				Single Field using 15 Degree Wedge
			Ant.	Post.	Ant.	Post.	RR	LL	
CT scan system 1 (GE OPTIMA 32 slice) Imaging protocols: kVp =80, 120, 140 mA =80, 215, 350 slice thickness(mm) =1.25, 5 Kerenel = smooth, sharp Pitch =1.375	6	259.2±0.5	129.6±0.2	124.2±0.2	64.8±0.1	62.1±0.2	63.4 ± 0.5	63.7±0.5	381.1±0.7
	15	214.1±0.3	107.1±0.1	103.5±0.1	53.5±0.1	51.7±0.1	52.7±0.3	52.9±0.3	287.3±0.4
CT scan system 2 (Siemens Emotion 16 slice) Imaging protocols: kVp =80, 130 mA =80, 240, 400 slice thickness(mm) =2, 5, 10, Kerenel = smooth, sharp Pitch =1.0, 2.0	6	259.8±0.8	129.9±0.4	128.6±0.2	61.8±0.6	63.7±0.6	64.9±0.2	64.3±0.3	382.5±1.1
	15	213.7±0.8	106.9±0.4	106.1±0.2	51.3±0.6	52.8±0.2	53.4±0.2	52.9±0.4	287.1±1.1
CT scan system 3 (GE Bright speed 16 slice) Imaging protocols: kVp =80, 120 mA =80, 250, 380 slice thickness(mm) =1.25, 5 Kerenel = smooth, sharp Pitch = 1.375	6	253.8±0.5	126.9±0.2	127.3±0.5	61.7±0.9	62.8±0.9	63.5±0.1	63.7±0.3	373.3±0.7
	15	210.2±0.4	105.1±0.2	105.7±0.2	50.8±0.1	52.5±0.1	52.6±0.1	52.7±0.2	282.2±0.5

The CT images obtained with multiple X-Ray tube currents (mA) from 80 to 400 have a very small effect on dose calculation in radiotherapy. Ebert *et al.* [9] showed that, in the CT scan imaging protocols, the mA variations either manually or automatically (AEC) causes very little change on the CT number (HU)

calculation. To make a 1% change in the dose calculation in TPS resulting from the change in imaging protocols, it is necessary to change 20 HU in soft tissue and 50 HU in the bone [10].

The difference of the point doses calculated in the center of the phantom based on CT images, which

were obtained with smooth kernels (soft reconstruction filter) and a high slice thickness (10 mm) compared with sharp kernels and low slice thicknesses (2 and 5 mm) was less than the MU obtained by the standard phantom based dose calculated in TPS. CT images with the sharp kernel and lower slice thicknesses are associated with higher noise levels, and therefore it is expected to have less dose calculation accuracy in TPS than images with low noise levels.

According to the Zurl *et al.*'s study, increasing the slice thickness from 3 to 7 cm, the difference in dose calculation was in the range of 0.3% to 1.5% [11]. In Rutonjski *et al.*'s study, a change in the reconstruction of CT images and the use of different kernels, the error in the dose calculation of the TPS for photons with energy of 6 MV would be less than 2% [12]. In our study in 6 MV photon energy, the error in the calculation of doses in TPS based on CT images with sharp kernel and 80 kVp was 2.7% compared to the standard phantom. In CT imaging technique reducing kVp from 130 to 80 kVp increases the difference in calculated MU value in two calculation methods in TPS. Several studies have shown that the X-Ray tube voltage is one of the most important sources of variation in the calculation of HU.

In a study by Mahur *et al.* [13] the effect of kV on the CT number was investigated. In this study, most changes were reported at low kV, but this change had less than a 1% effect on dose calculation in radiotherapy. In our study, the difference in the calculated MU value based on the CT image of the phantom, when the voltage was 80 kVp, was the highest [7, 4], compared with the standard phantom with single radiation field, and the energy of photon 6 MV, however, the error was calculated to be 1.9%.

Our study based on data from Table 2 shows that changing the technical parameters of CT imaging in the TPS with the wedge applied in the radiation field has a greater effect on the dose calculations. The pitch of the CT scan system is defined as how much the CT scan table is displaced in one X-Ray tube rotation in the gantry. The effect of the CT scan pitch between 1 and 2 on dose calculation is negligible (< 1.1 %).

The standard deviation of MU value, according to multiple CT imaging protocols in all scanners at 15 MV, was equal to or less than that of in 6MV energy

with similar imaging protocols. This suggests that variations of the CT scan image protocols are less effective in calculating the dose in TPS when high energy X-Ray photon is applied. By performing the Wilcoxon Ranking Test with a 95% confidence interval and a mean calculated T of 0.27 for all MUs calculated based on different CT scan imaging protocols, the assumption of equalization of the calculated dose with different protocols is confirmed

5. Conclusion

The findings of this study indicated that the calculated point dose for delivering the 200 cGy in the center of water phantom based on CT scan image obtained with multiple imaging protocols and virtual phantom designed in TPS had no significant difference (<2%). The highest calculations errors were related to when 80kV was used in CT scan imaging protocols as X-Ray photon energy and 6MV was applied to phantom irradiations and a wedge was placed in the radiation field in TPS. Selection of different imaging protocols such as convolution kernel, slice thickness and pitch of the CT scan system had slight changes in the calculation of MU values, which were less than 2%. Our study showed that, CT images obtained with multiple protocols can be used without having a significant effect on the calculations of point dose in the treatment planning system.

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