Original Article

Investigation of the Effect of Calibration Curves Obtained from Different Computed Tomography Devices on the Dose Distribution of Tomotherapy Plans

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Abstract

Purpose: This study investigated the effect of Hounsfield units (HU)-relative electron density (RED) calibration curves obtained with devices from three different Computed Tomography (CT) manufacturers on dose distribution in Accuray Precision planning of patients with lung cancer. **Methods:** All CT data required for treatment planning system (TPS) were obtained using the Tomotherapy "cheese" phantom. HU RED calibration curves were created with images obtained from Siemens Somatom, GE Optima, and Toshiba Aquilion devices. The obtained calibration curve was extrapolated. CT images of lung cancer patients were acquired on a single device and treatment plans were created. The existing plans were recalculated using three calibration curves and the effect of the HU RED calibration curve on dose distribution was analyzed. **Results:** The results showed that different CTs did not produce significant dose differences in organ doses and PTV for Accuray TPS. **Conclusions:** Based on clinical judgment, images from different CT devices can be used in treatment planning.

Keywords: Calibration curve, computed tomography, Hounsfield unit, tomotherapy

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Introduction

Cancer is an important health problem in many countries. Many reasons, including genetic reasons, can cause cancer. The aging of the world's population and environmental factors such as carcinogenic elements are also among the factors that affect cancer.[1] Radiotherapy has an important role in cancer treatment.[2-5] Technological advances in radiotherapy have contributed significantly to survival. Radiotherapy plays an important role in the treatment of locally advanced lung cancer.[1,2,6] In radiotherapy, beam plans are made using computed tomography (CT) images through the treatment planning system (TPS).[7] TPSs used in radiotherapy also transform data obtained from CT to generate dose distributions in the patient.[8]

The calculation accuracy of TPSs depends on the correct definition of Hounsfield units (HU) and relative electron density (RED) derived from CT images. HU numbers provide information about the X-ray attenuation of a given volume of an element in the patient's body relative to water.[9] TPSs are important component of radiotherapy centers. Before TPSs are used for dose calculation in radiotherapy, the calibration curve including the relationship between HU numbers and RED must be obtained and this calibration curve must be defined to the TPS.[1,10,11] The calibration curve is usually obtained with a tube voltage of 120 kV, and the application of different tube voltages, such as in pediatric patients, can be ignored.[12] HU numbers vary depending on scan parameters and HU values may also vary according to different CT manufacturers.[13,14]

The HU-RED calibration curve is among the most important combinations of the TPS. The correct definition of the calibration curve is especially important for dose distribution in heterogeneous media.[15] TPSs perform dose calculations

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using different algorithms. As treatment techniques improve, the importance of dose calculation algorithms increases. Studies have shown that CT number data may differ between scanners with different energy levels.[16-19] Manufacturers usually provide phantoms for CT performance measurements and calibration. The monthly CT calibration tolerance is ±5 HU. Monthly maintenance involves the use of materials with different densities in the phantom.[20-22]

One of the best ways to measure the accuracy of CT numbers used in TPS is to verify data conversion from the CT scanner to the TPS or to convert CT numbers to relative electron densities. A commonly used data verification method is the CT number calibration technique using tissue-equivalent materials. However, the elemental content of the measured substances may differ from actual tissues. Therefore, the electron density calibration curves of the CT number can differ significantly.[23] HU values obtained from CT mostly depend on the design of the CT, scanning parameters and the form, content and position of the phantom used.[24,25] Some TPSs allow the use of more than one calibration curve.[15] HU changes according to the reconstruction kernels of different brands of CT scanners have not been adequately interpreted in the literature.[26,27] In addition to LINAC-based devices, modern radiation devices with helical treatment features such as tomotherapy are also used in lung radiotherapy.[28-30] The HU-RED calibration curve for TPSs is important for all radiotherapy devices. In the literature, there are studies investigating the effect of HU-RED calibration curves obtained according to different tube voltage values on dose distribution in linear accelerators. However, there are limited studies in the literature on the effect of HU-RED calibration curves obtained from CT images of three different companies on dose distribution in tomotherapy.

This study aims to investigate the effect of HU-RED calibration curves obtained with the devices of three different CT manufacturers on dose distribution in the tomotherapy planning of lung cancer patients.

Materials and Methods

Phantom

The Tomotherapy cheese phantom (Gammex RMI, Middleton, WI), which serves as a calibration phantom, possesses a cylinder shape with a diameter of 30 cm and a length of 18 cm. This phantom can be conveniently divided into two equal parts, allowing for easy placement of the film between them. Furthermore, to conduct point dose measurements, ion chamber slots are strategically positioned on the axis perpendicular to the film plane. These slots are situated at intervals of 1 cm and its multiples on one semicircle side, and at intervals of 0.5 cm and then +1 cm multiples on the other half. A visual representation of the cheese phantom can be observed in Figure 1. The phantom contains compartments for materials of different densities. Tomograms were taken for each CT scan with these materials attached to the phantom.

Figure 1: Tomotherapy "cheese" phantom

Acquisition of calibration curve for different computed tomography devices

Images of the calibration phantom were scanned from a 16-slice Siemens Somatom Emotion Duo (Siemens Healthcare Global, Somatom Emotion Duo Eco), GE Optima (GE Healthcare, UK), and Toshiba Aquilion (Toshiba Medical Systems, Japan) CT scanner with 1 mm slices. The tube voltage was 120 kV for all three devices. Care was taken to ensure that the materials in the phantom reached the same point in each CT device. Then, HU values corresponding to the inserts corresponding to each density were read from the CT images by creating 3 mm rings. These values were transferred to the tables in the CT calibration tablet of the Accuray Precision TPS. The curve created after the transferred data was interpolated.

Contouring of patients

A total of 16 patients with Stage IIB-IIIB non-small cell lung cancer aged between 42 and 73 years who previously treated at the Radiation Oncology Department of Necmettin Erbakan University Medicine Hospital (The Ethics Institutional Review Board of this retrospective study was approved by the Ethics Committee of Necmettin Erbakan University Medicine School with approval number 2023/4643) between January 2010 and December 2022 were selected for the retrospective study. Patients were placed supine with a wing board in our clinic and a slice spacing of 3 mm was used in the CT simulator. The resulting CT images were sent to Precision TPS, where a radiation oncologist contoured the target tissue (PTV) and organs at risk (OARs). Left lung, right lung, total lung, heart, esophagus, and spinal cord were defined as OARs.

Treatment planning

In Accuray TPS, medical physicists created helical plans to deliver 60 Gy dose in 30 fractions to the patient's PTV. During helical planning for tomotherapy, field width 2.5 mm, pitch 0.2, and 3 modulator factor were selected for all three HU-RED calibration curves. Plans were made so that 95% of the PTV received at least 5700 cGy and critical organ dose constraints must not exceeded. It was also ensured that the maximum dose did not exceed 110%. Plans were made to reduce the dose to the lungs as much as possible by ensuring that the dose to the spinal cord did not exceed 4600 cGy in terms of critical organs and that the mean dose to the esophagus was below 3400 cGy. For each patient, three different CT calibration curves were used and optimization and calculation were performed at the same time under the same conditions. The final dose calculation was performed at the same resolution for each plan.

Statistical analysis

Descriptive statistics for the continuous variables were presented as mean and standard deviation, while counts and percentages were used for categorical variables. One-way analysis of variance was performed to compare group means for quantitative variables. The statistical significance level was set at 5%. The Statistical Package for Social Sciences (SPSS) v.25.0 was used for statistics (IBM Corp. Armonk, NY: USA) was used for all statistical computations.

Results

HU-RED calibration curves extrapolated and without extrapolated from Siemens Somatom, GE Optima and Toshiba Aquilion CT scanners are shown in Figures 2 and 3 respectively. The graphs show the differences in these curves due to data differences in the CT scanners. A tomotherapy plan was made for each patient and the treatment plan was recalculated for calibration curves obtained from different CTs without changing the optimization parameters. The PTV and OAR values in the treatment plan according to different HU-RED calibration curves are shown in Table 1.

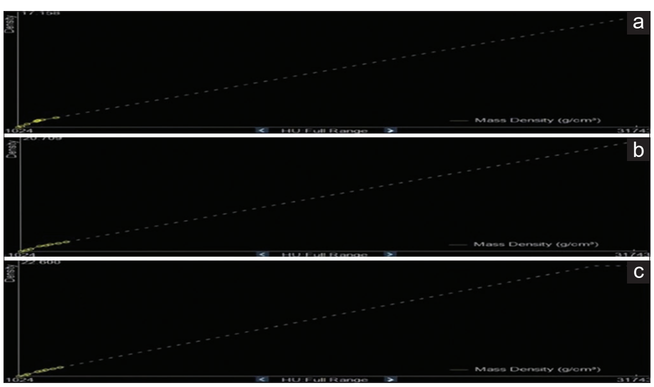

Figure 2: Variation of the extrapolated Hounsfield units-relative electron density calibration curve for Siemens, GE and Toshiba computed tomographies. (a) Siemens Somatom, (b) GE Optima, (c) Toshiba Aquilion

The mean dose values for PTV were 4728.50, 4734.94, and 4752.06 cGy for Siemens, Toshiba, and GE, respectively, in the TPS dose calculation for each calibration of the CT devices. The difference between the maximum, minimum, and mean values of the PTV is <1%. According to the calibration curve, a change of up to 23% in the maximum MS dose was observed. The highest dose for MS was obtained from plans calculated using the HU-RED calibration curve obtained from GE CT. For the heart, the highest dose in dose plans using calibration curves obtained from Siemens, Toshiba, and GE devices was obtained from the treatment plan interpolated according to the Siemens CT device. This value was 1062 cGy. The dose difference between the calibration curves for Siemens and GE devices was 0.95%. This value was 0.28% for Siemens and GE devices. In addition, the dose difference between the calibration curves of Toshiba and GE devices on the heart dose was 0.67%. In the helical treatment of lung cancer with tomotherapy, the effect of the calibration curve of Siemens, Toshiba, and GE devices on dose calculation was approximately 1%.

The effect of the calibration curves obtained from Siemens and GE devices on the dose distribution was 0.06% for the right lung in the plans made through the TPS. This value was approximately 1.24% for Siemens and Toshiba CT devices. It was also 1.18% for Toshiba and GE devices. For the dose distribution of the left lung, the lowest dose was obtained in plans using the calibration curve obtained from the GE CT device. The largest difference in dose distribution was observed in the HU-RED calibration curve obtained from Siemens and GE devices.

The comparison of statistical significance for PTV according to the HU-RED calibration curve obtained from three different CTs is shown in Table 2. The statistical significance analysis of the calibration curve for OARs is shown in Table 3. In addition, Figure 4 shows the 95% dose distribution of our plan in the transverse and sagittal planes for the three cases. As shown in the figures, no significant dose difference was observed.

Table 1: Dose distributions for PTV and organs at risks according to the hounsfield units - relative electron density calibration curve obtained from three different computed tomographies

Structure	Dose	Siemens	Toshiba	GE	Siemens and Toshiba (%)	Siemens and GE (%)	Toshiba and GE (%)
PTV	D_{min}	4728.50	4734.94	4752.06	0.13	0.49	0.036
	D_{mean}	6094.94	6090.63	6094.91	0.07	0.00	0.07
	D_{max}	6482.88	6483.13	6511.13	0.00	0.043	0.043
MS	D_{max}	3232.06	3228.88	4216.56	0.09	23.34	23.42
Heart	D_{mean}	1062.00	1051.88	1059.00	0.95	0.28	0.67
Right lung	D_{mean}	1911.40	1887.60	1910.20	1.24	0.06	1.18
Left lung	D_{mean}	1413.06	1407.13	1396.56	0.41	1.16	0.75

GE: General electric, PTV: Planning target volume, MS: Spinal cord

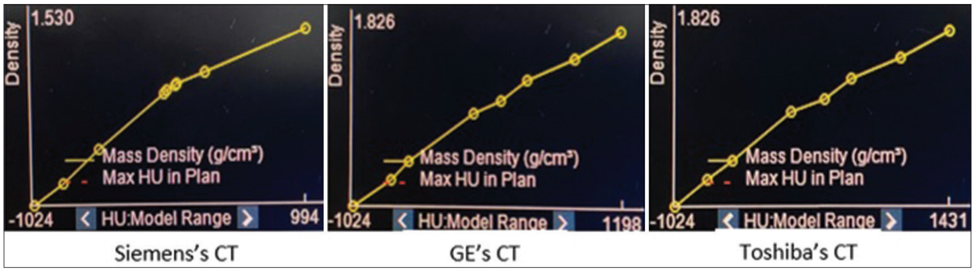

Figure 3: Variation of the Hounsfield units relative electron density calibration curve for Siemens, GE and Toshiba computed tomographies

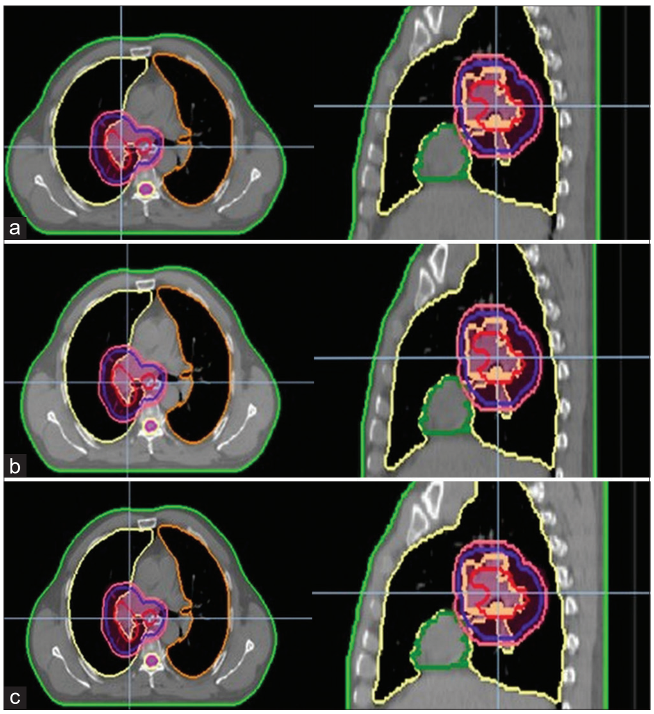

Figure 4: Representation of the 95% dose distribution obtained with plans based on the extrapolated Hounsfield units-relative electron density calibration curve for Siemens, GE and Toshiba computed tomographies in transverse and coronal slices. (a) Siemens Somatom, (b) GE Optima, (c) Toshiba Aquilion

Discussion

The objective of this study was to investigate the impact of data transfer from CTs used for radiotherapy in clinics to TPSs for use in linacs on treatment plans. The study aims to determine whether various tomography devices in the hospital can be utilized for treatment purposes for patients awaiting emergency treatment in the event of long-term malfunctions caused by CTs in clinics. Furthermore, the study compared the results of lung patient plans created under identical conditions using Accuray TPS, which employs the superposition/convolution dose calculation algorithm with tomography data calibrated with different curves.

Mahur *et al*. calculated the RED for four different TPS against HU at various CT kilovoltage values. They found that the dose differences obtained at certain points of the plans created with MV photons on the phantom varied between 0.1% and 0.82%. They also found no significant variation between HU for different kV CT values.[31] In the current study, CT measurements were taken for a single kilovolt (kV) value. Still, the HU-RED calibration curve for three different CT devices was extrapolated and its effect on the dose distribution in a plan for the treatment of lung cancer with a tomotherapy device was examined. The dose difference obtained was approximately 1% and the results were in line with Mahur *et al*.

Cozzi *et al*. performed a comparison between the calibration values provided by the manufacturer for a TPS and the clinical data used in the TPS. They found that the calculated monitor units (MUs) per Gy were 2% lower, on average <1%.[32] In our

Table 2: Comparison of statistical significance for PTV according to Hounsfield units - relative electron density calibration curve obtained from three different computed tomographies

Target volume	Siemens and GE (*P*)	Siemens and Toshiba (*P*)	Toshiba and GE (*P*)
D_{max}	0.997	1.000	0.998
D_{min}	0.925	0.991	0.953
D_{mean}	0.997	0.993	0.993
HI	0.919	0.813	0.811
CI	0.937	0.950	0.979

GE: General Electric, HI: Homogeneity Index, CI: Conformity Index, PTV: Planning Target Volume

Table 3: Comparison of statistical significance for organs at risks according to the Hounsfield units - relative electron density calibration curve obtained from three different computed tomographies

Structure	Dose	Siemens and GE (*P*)	Siemens and Toshiba (*P*)	Toshiba and GE (*P*)
Right lung	D_{min}	0.997	1.000	0.996
	D_{max}	1.000	1.000	1.000
	D_{mean}	1.000	0.997	1.000
Left lung	D_{min}	1.000	1.000	1.000
	D_{max}	1.000	1.000	1.000
	D_{mean}	0.999	0.781	0.780
Heart	D_{mean}	1.000	1.000	1.000
Esophagus	D_{max}	0.963	0.708	0.758
	D_{mean}	0.999	1.000	1.000
Spinal cord	D_{max}	0.465	1.000	0.469

GE: General Electric

study, we found that the maximum difference in MUs for the three CT curves was 2.1%. The percentage differences between Siemens and Toshiba, Siemens and GE, and Toshiba and GE CT were approximately 1%. Our results are consistent with those of Cozzi *et al*.

Cheng *et al*. investigated the minimum, maximum and average dose parameters for the treatment plan of a prostate patient. They compared HU-relative stopping power curves obtained from tissue-equivalent materials and found that the differences in these parameters were <1%. They also observed a 4% difference in these parameters for the nasopharyngeal patient.[33] In our study, the difference between the calibration curve obtained from Siemens-Toshiba CTs for the minimum dose value of PTV was 0.13%, 0.49% for Siemens and GE, and 0.36% for Toshiba and GE. The mean values of PTV were 0.07% for the three different calibration curves. These values are in agreement with and lower than those found by Cheng *et al*. for the prostate.

In their study, Witold Skrzynski *et al*. compared the values of two commercial TPSs using curves between HU values and electron densities extracted from images obtained with single-slice, multi-slice, kV cone-beam computed tomography (CBCT), and MV CBCT systems at 120 kV. They found that the HU and electron density relationship for all CT scanners was very similar. The authors concluded that the HU-electron density relationships predefined in TPS can be used for general-purpose CT systems operating at a voltage close to 120 kV. Furthermore, it is recommended to verify the accuracy of the electron density calculated by TPS. In addition, for nontypical imaging systems, the HU-electron density relationship may differ significantly from the predefined values and must be measured before being used in TPS.[34] Our study found no significant differences in PTV and critical organs for all plans with three CT values.

Conclusions

The study compared target and critical organ doses in lung patient treatment plans obtained with Accuray Precision TPS under the same conditions using HU-RED calibration curves from three different CTs used for various imaging purposes. The results showed that different CTs planning data curves did not produce significant dose differences in organ doses and PTV for Accuray TPS. We believe that these results will contribute to the radiation oncologist's decision to perform simulation with a different CT device and treat the patient in cases where the CT device malfunctions and urgent patient treatment is required. However, further studies are needed to ensure treatment efficacy in areas with higher electron density.

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Nil.

Conflicts of interest

There are no conflicts of interest.

References

1. Mahmoudi R, Jabbari N, Aghdasi M, Khalkhali HR. Energy dependence of measured CT numbers on substituted materials used for CT number calibration of radiotherapy treatment planning systems. PLoS One 2016;11:e0158828.
2. Begg AC, Stewart FA, Vens C. Strategies to improve radiotherapy with targeted drugs. Nat Rev Cancer 2011;11:239-53.
3. Chen HH, Kuo MT. Improving radiotherapy in cancer treatment: Promises and challenges. Oncotarget 2017;8:62742-58.
4. Gul OV. Experimental evaluation of out-of-field dose for different high-energy electron beams and applicators used in external beam radiotherapy. Radiation Physics and Chemistry 2024;215:111345.
5. Gül OV, Başaran H, Duzova M, İnan G. Dosimetric Comparison of Inverse Planning Simulated Annealing and Manual Optimization for Intracavitary Cervix Brachytherapy. Genel Tıp Dergisi 2024;34:109-13.
6. Aktan M, Kanyilmaz G, Koc M, Aras S. Thoracic re-irradiation for locally recurrent lung cancer. Asian Pac J Cancer Prev 2016;17:5041-5.
7. Das IJ, Cheng CW, Cao M, Johnstone PA. Computed tomography imaging parameters for inhomogeneity correction in radiation treatment planning. J Med Phys 2016;41:3-11.
8. Nakao M, Ozawa S, Yogo K, Miura H, Yamada K, Hosono F, *et al.* Tolerance levels of mass density for CT number calibration in photon radiation therapy. J Appl Clin Med Phys 2019;20:45-52.
9. Kruszyna-Mochalska M, Skrobala A, Romanski P, Ryczkowski A, Suchorska W, Kulcenty K, *et al.* Development of a quasi-humanoid phantom to perform dosimetric and radiobiological measurements for out-of-field doses from external beam radiation therapy. J Appl Clin Med Phys 2022;23:e13514.
10. Nhila O, Talbi M, El Mansouri Mh, El Katib M, Chakir EM. Evaluation of CT acquisition protocols effect on Hounsfield units and optimization of CT-RED calibration curve selection in radiotherapy treatment planning systems. Moscow University Physics Bulletin 2022;77:661-71.
11. Chung H, Mossahebi S, Gopal A, Lasio G, Xu H, Polf J. Evaluation of computed tomography scanners for feasibility of using averaged Hounsfield unit-to-stopping power ratio calibration curve. Int J Part Ther 2018;5:28-37.
12. Constantinou C, Harrington JC, DeWerd LA. An electron density calibration phantom for CT-based treatment planning computers. Med Phys 1992;19:325-7.
13. Nobah A, Moftah B, Tomic N, Devic S. Influence of electron density spatial distribution and X-ray beam quality during CT simulation on dose calculation accuracy. J Appl Clin Med Phys 2011;12:3432.
14. Ebert MA, Lambert J, Greer PB. CT-ED conversion on a GE lightspeed-RT scanner: Influence of scanner settings. Australas Phys Eng Sci Med 2008;31:154-9.
15. Davis AT. Radiation dosimetry changes in radiotherapy treatment plans for adult patients arising from the selection of the CT image reconstruction kernel. BJR| Open 2020;1:20190023.
16. Schneider U, Pedroni E, Lomax A. The calibration of CT Hounsfield units for radiotherapy treatment planning. Phys Med Biol 1996;41:111-24.
17. Ramos-Garcia LI, Pérez-Azorin JF, Almansa JF. Reply to comment on 'A new method to measure electron density and effective atomic number using dual-energy CT images'. Phys Med Biol 2016;61:6266-8.
18. Lamba R, McGahan JP, Corwin MT, Li CS, Tran T, Seibert JA, *et al.* CT Hounsfield numbers of soft tissues on unenhanced abdominal CT scans: Variability between two different manufacturers' MDCT scanners. AJR Am J Roentgenol 2014;203:1013-20.
19. Sahmaran T, Atılgan HI, Nur S, Sahutoğlu G, Yalcın H. An evaluation of the occupational external radiation exposure of personnel in nuclear medicine practices (2010-2020). Radiat Prot Dosimetry 2022;198:274-80.
20. Yang K, Li X, George Xu X, Liu B. Direct and fast measurement of CT beam filter profiles with simultaneous geometrical calibration. Med Phys 2017;44:57-70.
21. Avila RS, Krishnan K, Obuchowski N, Jirapatnakul A, Subramaniam R, Yankelevitz D. Calibration phantom-based prediction of CT lung nodule volume measurement performance. Quant Imaging Med Surg 2023;13:6193-204.
22. Mutic S, Palta JR, Butker EK, Das IJ, Huq MS, Loo LN, *et al.* Quality assurance for computed-tomography simulators and

the computed-tomography-simulation process: Report of the AAPM radiation therapy committee task group No. 66. Med Phys 2003;30:2762-92.
23. Yohannes I, Kolditz D, Langner O, Kalender WA. A formulation of tissue- and water-equivalent materials using the stoichiometric analysis method for CT-number calibration in radiotherapy treatment planning. Phys Med Biol 2012;57:1173-90.
24. Brunckhorst E. Commissioning of Radiotherapy Treatment Planning Systems. Testing for Typical External Beam Treatment Techniques. Vienne: International Atomic Energy Agency (IAEA); 2008.
25. Inness EK, Moutrie V, Charles PH. The dependence of computed tomography number to relative electron density conversion on phantom geometry and its impact on planned dose. Australas Phys Eng Sci Med 2014;37:385-91.
26. Zurl B, Tiefling R, Winkler P, Kindl P, Kapp KS. Hounsfield units variations: Impact on CT-density based conversion tables and their effects on dose distribution. Strahlenther Onkol 2014;190:88-93.
27. Kirwin S, Langmack K, Nightingale A. Effect of CT reconstruction kernel and post-processing filter on Hounsfield number constancy in radiotherapy treatment planning. Inst Phys Eng Med SCOPE 2004. Available from: https://ctug.org.uk/meet04-10-14/recon_paramters_ct_number.pdf. The 6th meeting of the CT Users Group was held in Bristol on 14/10/2004
28. Xu Y, Deng W, Yang S, Li P, Kong Y, Tian Y, *et al.* Dosimetric comparison of the helical tomotherapy, volumetric-modulated arc therapy and fixed-field intensity-modulated radiotherapy for stage IIB-IIIB non-small cell lung cancer. Sci Rep 2017;7:14863.
29. Nagai A, Shibamoto Y, Yoshida M, Inoda K, Kikuchi Y. Safety and efficacy of intensity-modulated stereotactic body radiotherapy using helical tomotherapy for lung cancer and lung metastasis. Biomed Res Int 2014;2014:473173.
30. Chi A, Jang SY, Welsh JS, Nguyen NP, Ong E, Gobar L, *et al.* Feasibility of helical tomotherapy in stereotactic body radiation therapy for centrally located early stage non–small-cell lung cancer or lung metastases. Int J Radiat Oncol Biol Phys 2011;81:856-62.
31. Mahur M, Gurjar OP, Grover R, Negi P, Sharma R, Singh A, *et al*. Evaluation of effect of different computed tomography scanning protocols on Hounsfield unit and its impact on dose calculation by treatment planning system. Iranian Journal of Medical Physics. 2017;14:149-54.
32. Cozzi L, Fogliata A, Buffa F, Bieri S. Dosimetric impact of computed tomography calibration on a commercial treatment planning system for external radiation therapy. Radiother Oncol 1998;48:335-8.
33. Cheng C-W, Zhao L, Wolanski M, Zhao Q, James J, Dikeman K, et al. Comparison of tissue characterization curves for different CT scanners: implication in proton therapy treatment planning. Translational Cancer Research 2012;1:236-246.
34. Skrzyński W, Zielińska-Dabrowska S, Wachowicz M, Slusarczyk-Kacprzyk W, Kukołowicz PF, Bulski W. Computed tomography as a source of electron density information for radiation treatment planning. Strahlenther Onkol 2010;186:327-33.