Evaluation of Adaptive Planning of Lung Cases based on Cone Beam CT Images

S.T. Tarigan1, A. Nainggolan2, M. Fadli2, S. Liura2 and S.A. Pawiro1*

1 Physics Department of Faculty of Mathematics and Natural Science, University of Indonesia, Depok, West Java, 16424, Indonesia;
2 RS Khusus Kanker MRCCC Siloam Semanggi, Jakarta, 12930, Indonesia

*Corresponding Author E-mail: supriyanto.p@sci.ui.ac.id

Abstract. The purpose of this study was to evaluate the accuracy of dose calculation based on Cone Beam Computed Tomography (CBCT) as adaptive planning for lung cancer. Dose calculation based on CBCT images was compared to Computed Tomography (CT) simulator images as references. Treatment planning was generated for 7 patients of lung using Intensity Modulated Radiotherapy (IMRT) technique and Volumetric Arc Therapy (VMAT) technique. Eclipse v13.6 Treatment Planning System (TPS) with Analytical Anisotropic Algorithm (AAA) and Acuros External Beam (AXB) algorithm were used to calculate the dose. This study was divided into three major parts: (1) Hounsfield Unit (HU) calibration for CBCT images by using CIRS 002LFC phantom; (2) analysis of Dose Volume Histogram (DVH); (3) analysis of Passing Rate Gamma with criteria Dose Difference (DD) 2% / Distance To Agreement (DTA) 2mm and DD 3% / DTA 3mm using Electronic Portal Imaging Device (EPID). The DVH analysis for D98%, D50% and D2% deviation was evaluated and compared to the DVH for CT images with AAA algorithm as reference. The deviation of D98%, D50% and D2% for lung cancer was less than 2%. The range of conformity index based on CBCT images for all planning was 0.923 – 0.999 and the homogeneity index was in the range of 0.042 – 0.197. The gamma criteria (DD/DTA) of dose difference and distance to agreement for 2%/2mm are 87% - 94% and for 3%/3mm were 96% - 98% for IMRT techniques. Passing Rate Gamma for VMAT with 2%/2mm criteria were 87% - 96% and 3%/3mm criteria were 96% - 98%. The results of this study showed that dose calculation based on CBCT image was similar to dose calculation using CT image with discrepancy less than 2%.

1. Introduction

Change of patient anatomy can be caused by weight loss or tumor diminution as a response to radiation. Change of anatomy can occur in body organs undergoing therapy or healthy organs around tumor. Sonke (2019) reports that the Gross Tumour Volume (GTV) of lungs increased between the simulation and planning at about 35% and the lung tumor regression during radiotherapy ranged from 0.6% to 2.4% per day [1]. Barker et al., (2004) reports that radiotherapy in head and neck area reduced the median of tumor volume approximately 1.8% per day and parotid volume also changed 0.19 cm³ per day [2]. Change of anatomy also occurs in patients with lung cancer.

The technique to verify patient position radiotherapy can be performed using Cone Beam Computed Tomography (CBCT) to reduce geometrical error, smaller margin, and adaptive planning radiotherapy. Adaptive Planning Radiotherapy (ART) using CBCT modality is highly potential to be used in improving the quality of radiation therapy because it can see real time volume of tumor, reduces margin, reduce exposure on Organ at Risk (OAR) and also reduce toxicity as a result of radiation effect. However, CBCT image has some weaknesses when it is going to be used as a basis of dose calculation. The quality of CBCT image compared to standard image of CT fan beam planning is lower because of beam hardening effect and the less accuracy of CT number (the value Hounsfield Unit/HU). The lack of accuracy of CBCT image HU is caused by large of the scattering of object volume radiated and many artefacts are produced [3].

In this study, the result of CBCT image dose calculation compared to dose calculation based of CT image as reference. Dose calculation was done using computer TPS Eclipse v13 with capability of Intensity Modulated Radiotherapy (IMRT) and Volumetric Modulated Arc Therapy (VMAT) with...
algorithm variation of Analytical Anisotropic Algorithm (AAA), Acuros XB dose to medium (AXB_m) and Acuros XB dose to water (AXB_w). The conformity index (CI) and homogeneity index (HI) obtained in dose calculation of CBCT image compared to CT simulator image as reference.

2. Material and Method

The study was done at Radiotherapy Department of MRCCC Siloam Cancer Hospital of Semanggi. Equipments that we used were: Clinac IX (Varian Medical System) with CBCT (On Board Imaging/OBI) that produces photon 6 MV and 15 MV, CT Simulator Philips Brillance CT Big Bore 16 Slice, CIRS 002LFC phantom, TPS Eclipse v13.6 with IMRT and VMAT technique by Rapid Arc using AAA and Acuros XB algorithm, and Electronic Portal Imaging Device (EPID) used to measure gamma index. Seven (7) patients with diagnose lung cancer were simulated with the total dose of 60 Gray (Gy) in 30 fractions with slice thickness 3 mm. The standard acquisition parameters for CT images were 140 kVp, 275 mAs and for CBCT images were used 110 kV and 20 mA with half-fan bow-tie filter.

2.1 CT and CBCT HU Calibration

The CBCT image was calibrated using CIRS 002LFC phantom. The material objects of CIRS 002LFC phantom were equivalent to the density of organs in ROI (Region of Interest) to find the value of Hounsfield Unit (HU). The value of HU was analyzed using TPS Eclipse v13.6. The calibration curve between HU CBCT and density was then used in dose calculation using CBCT image. The scanning result of CIRS 002LFC phantom is presented in Table 1.

![Figure 1. Calibration Curve of HU CBCT and Density of CIRS 002LFC Phantom in CBCT](image)

| Material  | HU  | Density (g/cm³) |
|-----------|-----|----------------|
| Lungs     | -921.1 | 0.21          |
| Water     | 0    | 1             |
| Bones     | 907.9 | 1.60          |
| Muscles   | 64.6 | 1.06          |
| Fat       | -120.3 | 0.96        |

2.2 Image Registration

The CBCT image was registered to CT simulator image in TPS Eclipse using auto registration feature that adjusted the set images between CBCT and CT. The auto registration in TPS feature still needed manual correction so that the registration of CBCT image really conformed to CT image. In the image registration, the bone area in both images was frequently made as reference because it was assumed that bones is static. The PTV contour of CT simulator was copied on registered CBCT images. The copy of PTV contour was corrected by radiation oncologist to ensure the accuracy of PTV area to be used as
adaptive planning. OAR around PTV was also copied from CT simulator image on registered CBCT images. The copy of OAR was corrected to adjust the change of its volume.

2.3 Treatment Planning Based on CT and CBCT Images

CBCT image was taken from each patient when they underwent radiation therapy treatment. The dose calculation of radiation therapy planning was performed using computer TPS Eclipse v13.6 with IMRT and VMAT by Rapid Arc technique with algorithm variation of AAA and Acuros XB dose to medium (AXBm) and Acuros XB dose to water (AXBw). In each image and therapy planning technique, the parameters were the same which are isocenter, gantry direction, collimator angle, and dose optimization. All patients with lung cancer were simulated using IMRT Technique with 5 beam directions and VMAT technique using 2 (two) partial rotations. The total dose given in lung PTV was 60 Gy in 30 fractions.

2.4 Evaluation of Dose Calculation

The dose calculation of CBCT image was compared to dose calculation based on CT simulator image using the same planning and algorithms. The comporation were performed based on dose delivered to 98% PTV volume (D98%), dose delivered to 50% PTV volume (D50%), and dose delivered to 2% PTV volume (D2%) value between CT and CBCT images and using AAA algorithm CT image as reference. The conformity index (CI) and homogeneity index (HI) of each image were also evaluated. The difference of result of dose calculation between organs were evaluated by comparing D50%, CI, and HI of each organ.

3. Results

The dose calculation on 7 patients found that the average deviation of D98% based on CT image with AXBm and AXBw algorithm against AAA was insignificant (p = 0.96). Figure 2 showed that the greatest average deviation of D98% of CT (AXBm compared to AAA) was -0.37% and CT (AXBw compared to AAA) was -0.38% in IMRT technique. Furthermore, the average deviation of D50% CT (AXBm compare to AAA) was -0.67% and CT (AXBw compared to AAA) was -0.63%. Generally the dose calculation using Acuros XB showed lower than AAA. The comparison between CT AAA and CBCT image obtained the largest average deviation of D98% for -1.68% for CBCT image using AXBm algorithm with IMRT technique (CBCT AXBm compared to CT AAA). The average of deviation of D50% did not show any significant difference between CT image with AAA algorithm and CT Image using AXBm algorithm and also AXBw (p=0.94). The average deviation obtained was in the range of 0.14% - 0.24%. Figure 3 presented the average deviation of D50% (CBCT AXBm compared to CT AAA) was -0.72% and (CBCT AXBw compared to CT AAA) was -0.70% using VMAT technique. The result of evaluation of average deviation of D2% (CBCT AXBm compared to CT AAA) was 1.85% and (CBCT AXBw compared to CT AAA) was 1.92%.

3.1 Conformity Index and Homogeneity Index

The conformity index (CI) based on CT and CBCT images with IMRT and VMAT technique is presented in Figure 4 and 5. The difference of value of CI in lung PTV between CT and CBCT images in the range of 0.97 - 0.987. The result was similar with the previous study conducted by Sriram et al, (2012) which compared CI between CT and CBCT images as adaptive planning by conducting dose calculation on 10 patients of esophagus cancer using VMAT Technique. The result of CI dosimetry on CT image was 1.01 ± 0.02 and on CBCT image was 1.01 ± 0.03 [4].

The result of homogeneity index (HI) for each patient in the study is presented in Figure 6 and 7. The greatest value of HI was obtained in CBCT image with AXBw algorithm, at about 0.107. Sriram et al, (2012) evaluated HI between planning using CT image and CVCT image as adaptive planning in esophagus cancer cases with result of HI on CT image for 0.13 ± 0.01 and on CBCT image the value of HI was 0.12 ± 0.01 [4].
3.2 Evaluation Dose of Organ at Risk

The total mean dose of planning is presented in Figure 8 and 9 for IMRT and VMAT technique, respectively. The difference of total mean dose of lung on the second patient and the fourth patient was higher than the other five patients between CT and CBCT images. It is caused by the total volume of healthy lung (excluding PTV) got smaller than the total volume of healthy lung in CT simulator images. In other words, the volume of lung PTV increased during radiation therapy. For the second patient, the decrease of volume of healthy lung was 40% on CBCT image compared to CT image and volume of
healthy lung for the fourth patient decreased 62% on CBCT image. The greatest mean dose received by the second patient with ranged (2450 ± 40) cGy based on CBCT image.

The percentage of lung part where PTV existed (Lung PTV V20) was evaluated. It was obtained that the volume of healthy lung receiving dose more than 50 Gy was higher than 20%. The percentage of volume of lung PTV V20 receiving dose more than 20 Gy on the fifth and the sixth patient was around 60%-70%. The volume of lung PTV V20 receiving dose more than 20% is caused by big volume of lung PTV.

3.3 Gamma Index Analysis

The average value of gamma index on 7 lung cancer patients with criteria of 2%/2mm and 3%/3mm with IMRT and VMAT technique is illustrated in Figure 10 and 11. The average passing rate gamma in VMAT and IMRT technique with criteria of 2%/2mm and in criteria on 3%/3mm was greater than 91% and 96% respectively. In criteria of 2%/2mm using IMRT and VMAT technique resulted passing rate gamma within range of 84%-97%. The passing rate gamma using criteria of 3%/3mm was obtained in the range of 94%-100%. Generally, gamma index analysis in this study did not show any differences based on CT image or CBCT image. Furthermore, the algorithm variation is not provide the effect passing rate gamma.

4. Discussion

In this study we have evaluated the dose calculation based on fan beam CT images with CBCT images for lung cases. The result showed that dose calculation between CT images with CBCT images almost similar with descrepancy less than 2%. Dose calculation between CT and CBCT images on lungs was also compared to the other organs such as larynx and prostate by evaluating the dose that received by 50% volume of PTV (D 50%), 98% volume of PTV (D 98%), and 2% volume of PTV (D 2%). The greatest deviation of D 50% on lung PTV with average deviation (CBCT AXBm compared to CT AAA) was -0.72% ± 1.16 and (CBCT AXBw compared to CT AAA) was -0.70% ± 1.19 in VMAT technique. More
over, the largest deviation of $D_{50\%}$ on larynx PTV (CBCT AXB\textsubscript{m} compared to CT AAA) was at about 0.74\% ± 0.37. The difference of dose calculation using Acuros XB dose to medium and Acuros XB dose to water in inhomogeneous organs such as lungs and larynx was greater than the organ that tend to be homogeneous (prostate). It occurred because the dose calculation using AXB\textsubscript{m} and AXB\textsubscript{w} required medium density and tissue atom composition to evaluate macroscopic interactions of each voxel. It was different from the dose calculation in AAA algorithm which is only requires relative electron density [5]. The result of the study was in line with the previous studies conducted by M. Fadli, et al. (2017) that reported the algorithm of AXB dose to medium in inhomogeneous organs compared to homogeneous organs resulted greater deviation compared to AAA algorithm [6].

The conformity index obtained in lung PTV was also compared to CI for larynx PTV and prostate. The CI value on prostate more stable with greater value (close to 1) than the CI value on lungs and larynx as well as nasopharynx. The average value of CI was obtained in the range of 0.94-1. However, the same pattern of calculation using AXB\textsubscript{m} algorithm showed lower CI than calculation based on AAA algorithm. The difference of CT image and CBCT image and algorithm variation did not show any significant results in calculation of CI value. The average value of HI ranged from 0.04-0.16. Overall it was found that the value of HI using AXB\textsubscript{m} algorithm both on CT image and CBCT image showed greater value. It means that the dose uniformity distributed on target was more homogeneous using AAA algorithm compared to AXB\textsubscript{m} on the two organs. It occurred because AXB\textsubscript{m} had correction on inhomogeneous medium so the result of calculation using AXB\textsubscript{m} was more accurate.

5. Conclusion

The study showed that the dose calculation using CT image was almost the same as the dose calculation based on CBCT image. Dose calculation based on CBCT image compared to CT image resulted descrepancy less than 2\%. The range of CI based on CBCT images for all planning was 0.923 – 0.999 and HI at about 0.042 – 0.197. Gamma criteria (DD/DTA) for 2%/2mm were 87\% - 94\% and for 3%/3mm were 96\% - 98\% for IMRT techniques. Furthermore, Passing Rate Gamma for VMAT with 2%/2mm criteria were 87\% - 96\% and 3%/3mm criteria were 96\% - 98\%. Therefore, CBCT image could be said feasible as Adaptive Planning Radiotherapy.

Acknowledgment

This work is supported by Universitas Indonesia PIT-9 with contract number NKB-0034/UN2.R3.1/HKP.05.00/2019.

References

[1] Sonke, J, Aznar, M and Rasch, C 2019 Adaptive Radiotherapy for Anatomical Changes Seminars in Radiation Oncology 29(3) 245–257
[2] Barker, JL, Garden, AS, Ang, K K, O’Daniel, JE, Wang, HE, Court, LE, Morrison, WH, Rosenthal, DI, Chao, KSF, Tucker, SL, Mohan, R, Dong, L, 2004 Head and Neck Quantification of Volumetric and Geometric Changes Occurring During Fractionated Radiotherapy for Head and Neck Cancer Using an Integrated CT/Linear Accelerator System Patient Eligibility Int. J. Radiation Oncology Biol. Phys. Vol.59(4), 960–970
[3] de Smet Mariska, Danny, S, Sebastiaan, N, and Frank, V 2016 Accuracy of Dose Calculations on kV Cone Beam CT Images of Lung Cancer Patients Medical Physics, 43(11), 5934–41
[4] Sririm, P, Svanikumar, SA, Deva, JS, Prabakar, S, Dhanabalan, R, and Vivekanandan, N 2012 Adaptive Volumetric Modulated Arc Treatment Planning for Esophageal Cancers Using Cone Beam Computed Tomography Physica Medica 28(4), 327–332
[5] Vangvichith, M, Autret, D, Tiplica, T, Barreau, M, and Dufreneix, S 2019 Comparison of Five Dose Calculation Algorithms in a Heterogeneous Media Using Design of Experiment Physica Medica, 61, 103–111
[6] Fadli M 2017 Verifikasi Dosis pada Kasus Nasofaring Menggunakan Algoritma AAA dan AXB dengan Teknik IMRT dan VMAT, Universitas Indonesia