The Impact of Corrected-MVCT Images to Dose Distribution on Adaptive Tomotherapy: Hepatocellular Carcinoma Case

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Abstract. Position verification before the treatment is performed to ensure the actual position to the planning position, so the dose distribution received by the tumor target would be in accordance with the planned dose. In Helical Tomotherapy (HT) treatment, the image of Megavoltage CT (MVCT) could be used to verify the patient’s position by registering the image to Kilovoltage CT (KVCT) image. The aim of this study was to evaluate the comparison from the dose distribution resulted from MVCT and KVCT image registration with and without automatic position correction at high doses. The correction in MVCT image registration to KVCT image was performed with adjustment in four HT degrees of freedom (lateral, longitudinal, vertical and rotational direction). Nine MVCT patient images with Hepatocellular Carcinoma were used with high doses therapy in 4-10 fractions using HT at Cipto Mangunkusumo Hospital. Evaluation of the dose distribution in the verification variation (the corrected and uncorrected position) was analyzed with Homogeneity Index (HI), Conformity Index (CI) and Organ at Risk. The results show that HI ranges from 0.06 to 0.3, while CI varies from 0.7 to 1. Based on these results, the position correction may less contribute to the dose distribution to the tumor target.

1. Introduction

The time difference between the fractions allows target’s shape to change volumetrically as well as target to shift geometrically. Adaptive radiotherapy is a radiation treatment process where the subsequent delivery can be modified using a feedback of the geometric and dosimetric information from previously treated fractions [1]. Shifts and changes on target conditions can be identified using adaptive radiotherapy systems with Mega Voltage Computed Tomography (MVCT). In radiotherapy, the use of MVCT is needed to ensure the position of the patient before irradiation [1, 2]. Verification of the patient's position can be performed by registering the planning image (KVCT) with a daily image of MVCT. Registration of the two images is the most important component in the formation of adaptive radiotherapy [3]. MVCT in adaptive planning can be used in evaluating the dose obtained by
the target during several irradiations with the change in the position and shape of the target [4]. Evaluation of the treatment dose is to evaluate the accuracy delivering dose to patient. In the case of HCC, research on the effect of verification position on the distribution of adaptive doses is still difficult to find. Some studies have focused more on the benefits of adaptive planning produced using standard fractions (hyper fraction) range from 25-30 fractions using conventional doses of 2 Gy per fraction. Therefore, research on the influence of position verification on the distribution of doses produced by adaptive therapy using the hypo fraction method on high energy needs to be carried out.

2. Materials and Methods

The tools and materials used in this study consisted of GE Hi Speed CT-simulator, Hi-ART Helical Tomotherapy, TomoHD System, Virtual Water Phantom (Cheese phantom) as well as nine images of patients with indications of Hepatocellular Carcinoma.

2.1. Density Calibration

This study began with scanning the image on a tomotherapy that uses phantom virtual water (phantom cheese). In this study, scans were performed on MVCT. The scan aimed to see the value of the electron density and the value of the Hounsfield Unit (HU) which would be useful in calculating the dose of radiotherapy planning.

2.2. Patient Selection Process

Furthermore, after calibration of MVCT, the study was continued by ascertaining the presence of images of patients registered between KVCT and MVCT as a whole on tumor targets with an indication of Hepatocellular Carcinoma disease contained in the patient database system of the Department of Radiotherapy, Cipto Mangunkusumo Hospital. KVCT images were obtained from GE Hi Speed CT-Simulator devices and MVCT images were obtained from Helical Tomotherapy devices.

![Figure 1. MVCT images of HCC patients (a) do not cover the whole target (b) cover the whole target](image)

2.3. Data Collection Process

The data were obtained based on the Dose Volume Histogram (DVH) generated from the automatic registration of KVCT and MVCT images on the TomoHD system with and without position verification. The position verification applied was a correction of the position of the MVCT image in the lateral, longitudinal, vertical, and rotational directions which was useful to get a match between the
MVCT image and the KVCT image. Data obtained at DVH consists of Homogeneity Index, Conformity Index, and Organ at risk.

2.4. Planning Evaluation
Data of planning analysis was obtained and then evaluated to compare the resulting dose distribution between MVCT and KVCT images registered with or without position verification. The evaluation used several parameters including the homogeneity and conformity index evaluation used in the study, based on ICRU NO.83 of 2010 [5], with the following formulation:

\[ HI = \frac{D_{2\%} - D_{98\%}}{D_{50\%}} \]  \hspace{1cm} (1)

And the conformity index is defined as:

\[ CI = \frac{V_{95\%}}{V_{PTV}} \]  \hspace{1cm} (2)

Furthermore, the calculation of the value of Organ at Risk was obtained based on the Radiation Therapy Oncology Group (RTOG) protocol No. 1112 regarding Hepatocelullar Carcinoma [6].

3. Result and discussion

3.1. Density Callibration
Evaluation of adaptive planning requires the CT-number linearity as the basis for calculation in calculating the radiation dose received by the body. The results of the CT-number linearity evaluation in this study are the results of the linearity test conducted on the tomotherapy based on KVCT and MVCT images. The regression results show good value because it has approached a reference value [7]. The blur images of MVCT are caused by the high energy MVCT that causes the dominant Compton scattering effect on attenuation of the beam [8]. When KVCT and MVCT only depend on electron density, the KVCT image displays high contrast, so the quality of the resulting image is clearer [9]. The results of the CT-number linearity can be seen in Figure 2.

![Figure 2. Comparison of HU values and material density in KVCT and MVCT images in Tomotherapy](image-url)
3.2. Homogenity Index Analysis

Homogenity index values obtained in this study ranged from 0.065 to 0.295 (HI = 0.17 ± 0.0892) for corrected MVCT images and ranged from 0.063 to 0.301 (HI = 0.171 ± 0.0899) for MVCT images without position correction. Homogenity index results for each patient's MVCT image as illustrated in Figure 3. In general, the homogenity index values obtained for the two MVCT images in each patient did not have any significant difference with the discrepancy generated in the homogeneity index ranged from 0.15% to 2.82% and an average discrepancy of 0.27%.

3.3. Conformity Index Analysis

Conformity index values obtained in this study range from 0.771 to 1 (CI = 0.911 ± 0.085) for MVCT images that have been corrected with KVCT and range from 0.773 to 1 (CI = 0.915 ± 0.082) for MVCT images without correction. Conformity index values that are not in accordance with the reference cannot be used as a failure parameter for a planning treatment. That is because the discrepancy between the CI value and the reference value can be due to differences in the position of the patient that is not in accordance with the planning using KVCT and therapy treatment using MVCT. Discrepancy of the resulting conformity values range from 0.06% to 4.13% with an average of 0.39%. The highest value of discrepancy was found in the 6th patient at 4.13%. Based on the study, the 6th patient had a higher value on the x-axis and roll than the other patients, which were 8.31 mm for the x-axis and 3.74 mm for the roll. The position shift shows that the patient's position during planning and the patient's position when the treatment has a difference that affects the value of the discrepancy between the corrected MVCT image and the MVCT image without correction. The results of the conformity index produced by the two images can be seen in Figure 4.
3.4. Organ at Risk Analysis

In the case of HCC, the liver becomes the main organ at risk of exposure to high doses due to radiation. RTOG No.1112 concerning Hepatocellular Carcinoma regulates the various safe threshold values of an organ [6]. Healthy liver has a safe threshold provided that the volume of healthy liver that receives a dose limit exceeds 700 cc. The results of the evaluation of healthy liver volume are shown in Figure 5. Overall, almost all patients had healthy livers that met RTOG No.1112. But there is one patient, the 9th patient who has a volume value that is very far from the RTOG requirements. That is because the patient only has a total liver volume of 513,377 cc. Nevertheless, the planning of the performed treatment therapy has been declared feasible by doctors for treatment as needed.
Not too significant difference between the volume values was obtained from the two images in each patient, resulting in a fairly low discrepancy of 0.141%. The difference in healthy liver volume values between the two images was highest produced by the second patient with a discrepancy of 1.65% in the volume range of 784.94 cc for the corrected MVCT image and 772,036 cc for the MVCT image without correction. The discrepancy generated between the corrected image and without correction shows that the verification of the patient’s position prior to the therapy treatment can affect the target volume of the tumor that has absorbed the treatment dose so that it affects the healthy liver volume value that the patient has.

4. Conclusion
From this study, we have discovered that position correction may have less contribution to the dose distribution of the tumor target - as we perceive the HI discrepancy of 0.27% and CI of 0.39%. Despite of the OAR evaluation, verification of the patient’s position will affect the dose distribution for the applied parameter has excessive number of errors.

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