Comparison of radiotherapy dosimetry for 3D-CRT, IMRT, and SBRT based on electron density calibration

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Abstract. Accurate calculation of dose distribution affected by inhomogeneity tissue is required in radiotherapy planning. This study was performed to determine the ratio between radiotherapy planning using 3D-CRT, IMRT, and SBRT based on a calibrated curve of CT-number in the lung for different target’s shape in 3D-CRT, IMRT, and spinal cord for SBRT. Calibration curves of CT-number were generated under measurement basis and introduced into TPS, then planning was performed for 3D-CRT, IMRT, and SBRT with 7, and 15 radiation fields. Afterwards, planning evaluation was performed by comparing the DVH curve, HI, and CI. 3D-CRT and IMRT produced the lowest HI at calibration curve of CIRS 002LFC with the value 0.24 and 0.10. Whereas SBRT produced the lowest HI on a linear calibration curve with a value of 0.361. The highest CI in IMRT and SBRT technique achieved using a linear calibration curve was 0.97 and 1.77 respectively. For 3D-CRT, the highest CI was obtained by using calibration curve of CIRS 062M with the value of 0.45. From the results of CI and HI, it is concluded that the calibration curve of CT-number does not significantly differ with Schneider’s calibrated curve, and inverse planning gives a better result than forward planning.

1. Introduction

The human body is composed of various tissues and cavities with different physical and radiological properties. The most important from the perspective of radiotherapy dosimetry is that there are physical differences between the tissues and cavities found in the body, such as lung, oral cavity, teeth, nose, sinuses and bones. In some cases, in the human body, there are even foreign objects deliberately planted, such as metal prostheses. It becomes important that the absorbed dose is given to the entire irradiated tissues must be corrected using tissues homogeneity as predicted [1].

One of the most important steps in radiotherapy planning process is the acquisition of patient data needed to define the target volume and an accurate calculation of the dose distribution [2, 3]. This data is mostly derived from the patient's radiology images which are usually obtained from a scanning using computed tomography (CT), which contains all the important information, for example in order to see the density distribution of organs and tissues. This information is then used for an accurate dose calculation, especially when the radiation beam passes through non-homogeneous tissues such as lungs and bones where the attenuation coefficient is very different with soft tissue’s attenuation coefficient [3, 4].
Images from computed tomography (CT) have largely become the standard for radiotherapy treatment planning due to its ideal structure (transverse images with high-resolution images and its relation to Hounsfield Units as well as the density of electrons). Inhomogeneity corrections can be made on the basis of pixel based on accurate considerations of the density from different tissues in the body of the patient.

Radiotherapy planning is performed to get the optimal therapeutic ratio that provide sufficient dose distribution in target and minimal dose to normal tissue [5]. CT-simulator can generate 3D images, then the purpose of radiotherapy will be easier to be achieved. In lung cancer, radiotherapy treatment becomes more complicated due to anatomic structures that have different densities between lung, bone and soft tissue. Hounsfield Unit (HU) that were very different between those tissues caused homogeneity of the radiation dose on the medium will be difficult to be achieved.

Research conducted by Klein, et al. showed quite different results between planning using heterogeneity correction and without heterogeneity correction in three-dimensional treatment planning (3DTP). Klein, et al. conducted a study using a homogeneous medium (water) and a heterogeneous medium, and comparing the results. The results showed that 6 to 18% doses on isocenter would be greater in the planning without heterogeneity correction [6]. Because of different results that have been gotten previously, this study was performed to compare radiotherapy planning between 3D-CRT and IMRT for lung and to compare radiotherapy planning using different targets that have different mass density (lung and spinal cord) for SBRT based on calibrated and not calibrated of electron density curve by calculating homogeneity index (HI), conformity index (CI) and also dose volume histogram (DVH).

2. Materials and methods

This study was conducted at the Department of Radiotherapy Cipto Mangunkusumo Hospital. Electron Density Phantom CIRS Model 062M and Thorax Phantom CIRS Model 002LFC was used. CIRS Phantom was scanned on CT-simulator GE Bright Speed. Target volume and normal tissue cross-sections were contoured in Oncentra Masterplan. Radiotherapy planning was conducted in Pinnacle3 Treatment Planning System using energy 6 MV.

Calibrating CT number curves was the early step in this research. Initially, the calibration curve of CT number was obtained by scanning phantom using CT-simulator and then transferred to the virtual simulator. Afterwards, CT density calibration curve were obtained by entering density ($\rho$) of each plug as the y-axis, and the number of CT as the x-axis. This radiotherapy planning used 3 calibration curves of electron density are calibration curve of CT number from Electron Density Phantom CIRS Model 062M, Thorax CIRS Model 002LFC and linear calibration curved which is obtained from research conducted by Uwe Schneider in 1995 [7].

Furthermore, Thorax CIRS Model 002LFC was scanned and then transferred to the virtual simulator. The image was contoured to determine the target organs and organ at risk. Afterwards, target organ were formed in three shapes in order to make it as the real target in the patient for instance cylinder, half cylinder and concave. Details of the target volume in different shapes were shown in table 1. Then the contour was transferred to TPS Pinnacle3. Radiotherapy planning technique performed in this study was forward planning for 3D-CRT and SBRT, whereas inverse planning was for IMRT.

Seven radiation fields which were 0° (AP), 51.4°, 113°, 164.4°, 215.8°, 275°, and 331° were used for 3D-CRT and IMRT technique. Although 5 radiation fields were used clinically, but 7 radiation fields gave optimal result according to Arianty. [8] On the other hand 15 radiation fields which were 0° (AP), 51.4°, 113°, 164.4°, 215.8°, 275°, 331°, 98°, 70°, 60°, 257°, 195°, 130°, non-coplanar 30°, and non-coplanar 330° were used for SBRT technique. Radiation field used in SBRT technique was much more than 3D-CRT and IMRT in order to achieve isodose line that can cover small target volume.

In order to evaluate the planning, the calculation of homogeneity index (HI) [9] and conformity index (CI) [10] can be done follow equation (1)-(2). The evaluation of radiotherapy planning was also performed at the organ at risk by referring to the Quantitative Analysis of Normal Tissue Effects in the Clinic (Quantec). Afterwards, the comparison of radiotherapy planning could be made.

$$HI = \frac{(D_{2\%} - D_{98\%})}{D_{50\%}} \quad (1)$$
\[ CI = \frac{V_{OS}}{V_{PTV}} \]  

(2)

**Table 1.** Target volume in different shapes; cylinder, half-cylinder, concave.

| Organ   | Cylindrical target |   | SBRT |   | Half-cylindrical target |   | Concave target |   |
|---------|-------------------|---|------|---|-------------------------|---|----------------|---|
|         | Diameter target (cm) | Volume (cm³) | Diameter target (cm) | Volume (cm³) | Volume (cm³) | Volume (cm³) |
| GTV     | 4.6               | 37.37         | 2.1            | 8.43        | 18.68       | 14.97        |
| CTV     | 5.72              | 59.72         | 2.1            | 8.43        | 27.74       | 28.02        |
| PTV     | 7.34              | 117.39        | 2.1            | 8.43        | 56.45       | 69.55        |

**3. Results and discussions**

The comparison between 3D-CRT and IMRT technique can be seen in Table 2. IMRT technique formed higher coverage isodose line on GTV and PTV compared to 3D-CRT. The higher coverage isodose line was on PTV, it means doses could cover target organ and the more cancer cell would be killed. Both in 3D-CRT and IMRT, the organ at risk received doses that can be tolerated according to QUANTEC, for example, 20 Gy dose received by lung was still below 30% total volume of the lung, 30 Gy dose received by heart was still below 46% total volume of the heart, and \( D_{max} \) of the spinal cord was less than 46 Gy.

Homogeneity index (HI) differences from 3D-CRT and IMRT could be seen distinctly in figure 1(a). HI obtained from 3D-CRT and IMRT using calibration curve of Phantom CIRS Model 062M, Thorax Phantom CIRS Model 002LFC, and Schneider’s calibration curve (linear) were 0.25, 0.243, 0.248, and 0.103, 0.101, 0.102 respectively. The HI of IMRT planning was closer to ideal value 0 according to ICRU No. 83. IMRT result was more homogeneous because optimization was performed in TPS. Different calibration of electron density curves would make the different planning results because electron density curve affected dose calculation. A phantom that had more mass density would deliver dose calculation accurately than phantom that had less mass density.

**Table 2.** Comparison of radiotherapy planning result between 3D-CRT and IMRT

| Parameter                  | 3D-CRT | IMRT |
|----------------------------|--------|------|
| Coverage isodose line      | 86%    | 95%  |
| MLD (Mean Lung Dose)       | 7.23 Gy| 8.47 Gy|
| \( V_{20} \) (Lung)        | 25%    | 28%  |
| \( V_{30} \) (Heart)       | 10%    | 5%   |
| \( D_{max} \) (Spinal cord)| 31.67 Gy| 32.27 Gy|

Moreover, conformity index (CI) using 3D-CRT technique was far below CI using IMRT that was shown in figure 1(b). CI obtained from 3D-CRT and IMRT using calibration curve of Phantom CIRS Model 062M, Thorax Phantom CIRS Model 002LFC, and Schneider’s calibration curve (linear) were 0.45, 0.43, 0.41, and 0.97, 0.91, 0.97 respectively. The CI of IMRT was closer to ideal value 1 which means that prescription isodose line was overlapping with PTV. High conformity on IMRT was occurred because there were dose constraints that had been given in the planning so that PTV would receive dose according to the prescription. IMRT also delivered non-uniform dose so that radiation beam would be modulated. The weighting of each segment would be different so that prescription isodose line would follow the form of planned targets. Both HI and CI using 3D-CRT and IMRT had a quite different results from Ganesh [11]. The differences might be caused of different target volume used because the HI was extremely effected by target volume [8].
The comparison of target organs which were lung and spinal cord was only performed in SBRT. The HI value for lung and spinal cord using calibration curve Phantom Model 062M CIRS, CIRS Model 002LFC, and Schneider’s were respectively 0.366, 0.365, 0.361 and 0.173, 0.174, 0.158. Spinal cord had better HI than lung shown in figure 2(a) because it has a greater density ($\rho$) so that particle fluence in spinal cord would be greater. The dose would also spread evenly through PTV, and gave HI closer to the ideal. CI of the spinal cord was closer to ideal than lung shown in figure 2(b). Both lung and the spinal cord had The CI slightly different from ideal because target volume used was very small which is about 8 cc, and the prescription dose was not 100% on isocenter for SBRT. According to the RTOG protocol 0813, the prescription dose in SBRT is conducted by calculating the dose that covers 95% PTV then divided by the total dose. With this calculation, the goal of radiotherapy planning in SBRT can be achieved that deliver the high dose in a small fraction, but isodose line of PTV will be slightly widened.

The isodose line of different target shapes for 3D-CRT and IMRT were shown in figure 3.a and 3.b. All radiotherapy planning with different shapes had a high dose in the boundary area between the lung and soft tissue which is caused by the algorithm in TPS. It used adaptive convolution algorithm which required only a short time in dose calculation. Adaptive convolution algorithm did not take into account the presence of inhomogeneity tissue according to Todd McNut. It gave the high dose in the boundary of lung and soft tissue because lung has a mass density ($\rho$) which is smaller than the soft tissue. Hotspot area in the boundary could be happened because there was a re-built-up PDD from the lung to soft tissue.

The HI obtained using different electron density curves from different shapes of target gave the same trend which produced lowest HI for the cylindrical target, concave, and half-cylindrical target respectively. Cylindrical target had a regular shape so that dose uniformity could be easily achieved. Half-cylinder and concave had more complex shape than cylinder so that uniformity dose was more difficult to be achieved using same weighting and beam angle. The HI in IMRT was better than 3D-CRT.

**Figure 1.** Comparison of (a) HI and (b) CI from radiotherapy planning result using different calibration curve of CT number between 3D-CRT and IMRT.

**Figure 2.** Comparison of (a) HI and (b) CI from radiotherapy planning result using different target organ; lung and spinal cord for SBRT.
CRT for all different target. It did not have the same trend for the different calibration curve. The HI from calibration curve of Phantom CIRS Thorax Model 002LFC gave best result because it was phantom that was used at irradiation so that this calibration curve gave dose distribution more uniform compared with calibration curve of Phantom CIRS Model 062M and Schneider’s calibration curve (linear).

Ideal CI was difficult to be achieved using 3D-CRT especially for targets that have more complex shapes such as a concave. Half-cylindrical target had a better CI compared to cylindrical target and concave because it had smaller volume so that 95% of prescription dose would be more evenly distributed. Concave target had a lower CI because of its irregular shape so that prescription isodose line could not follow target shape easily. More beams were given from above to avoid OAR such as the spinal cord. It would cause dose distribution did not evenly distributed and the isodose line would not overlap with target volume. More complex target shape such as concave could be covered using IMRT because it delivered non-uniform dose distribution. It means that each radiation beam angle had different weighting depending on the target shape so that isodose line would overlap with target planned. The CI in IMRT planning was higher than 3D-CRT even for the concave target. The average conformity index for different target shape was 1,033. This value was ideal according to the RTOG 0813.

![Comparison of radiotherapy planning result from different target shapes; cylinder (left), half-cylinder (center), concave (right) using (a) 3D-CRT and (b) IMRT.](image)

**Figure 3.** Comparison of radiotherapy planning result from different target shapes; cylinder (left), half-cylinder (center), concave (right) using (a) 3D-CRT and (b) IMRT.

4. Conclusion

Homogeneity index and conformity index obtained from planning of radiotherapy using calibration curve of Phantom CIRS Model 062M, and CIRS Model 002LFC did not significantly differ with available literature (Schneider’s calibrated curve). IMRT could cover dose was around 95%, while 3D-CRT only 88%. The results obtained could support IMRT as a standard technique used for radiotherapy treatment today. Spinal cord’s radiotherapy planning gave better DVH, HI, and CI than lung. Radiotherapy planning using cylindrical target gave a better HI than half-cylindrical and concave, and better CI was obtained using half-cylindrical target for 3D-CRT and IMRT.

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