Motion effects in stereotactic body radiotherapy (SBRT) dosimetry of bone metastases: case study using homogeneous and inhomogeneous CIRS phantoms

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Abstract. The Stereotactic Body Radiotherapy (SBRT) for bone metastases has been implemented in radiotherapy center in Indonesia. In this study, we simulated and explored the effect of target motion in SBRT on bone metastases using the homogeneous (002 H9K) and inhomogeneous (002 LFC) CIRS phantom to simulate the presence of inhomogeneous medium near the target, with the holder for chamber. Both phantoms have the interchangeable rod for ionisation chamber, while for TLD and gafchromic EBT3, a holder was devised using Teflon material. In order to evaluate the impact of target motion, the measurements were performed in static and superior-inferior motion with the amplitude of 5, 10, and 20 mm. The measurement in the static condition has the standard deviation of <1.5 for gafchromic film EBT3 and <0.2 for PTW N30013. For the measurement of superior-inferior dynamic motion, we obtained a decrease in the dose of the target volume with increasing amplitudes of the movements. In addition, the standard deviation of dynamic measurement results was in the range of 1.13 to 11.7, 9.5 to 28.6, and 0.05 to 7.21 for gafchromic film EBT3, exradin A16 and PTW N30013, respectively.

1. Introduction

Greco et al stated that 13% of deaths were caused by cancer, and bone metastases is a common complication that occurs in more than 40% of oncology patients [1] and approximately 70% will develop spinal metastases [2]. Bone metastases and primary cancer may cause pain and functional disorder of the patient itself [3]. Stereotactic body radiotherapy (SBRT) is a technique deemed appropriate for bone metastases for its ability to deliver a high radiation dose to a small volume with a very tight margin [4]. The advantages of radiotherapy using small field is to improve dose accuracy in target volume and to decrease dose impact in organ at risk (OAR) around the tumor [5].

In terms of Quality Assurance (QA), target motion present specific challenges due to a regular displacement of the target during dose delivery, causing undesired dose differences in the target volume [6]. The motion itself is affected by pressure in the lungs, whose volume can change together with the movement of the diaphragm and ribs [7]. Since the main respiratory system is supported by the diaphragm, the movement was largely on superior-inferior (SI) direction with averaged displacement of the spine in superior direction is around 4.7 to 19.1 mm in normal patients [8]. The commercially available CIRS Dynamic Platform Model PL 008 is able to simulate the specific patient movement in SI direction. The movement of the spine and dose differences owing to it were not well described in

existing literature. In terms of the several types of motion, it is better to know and understand how much the differences of dose between static and moving (dynamic) position. Two CIRS phantom (002 H9K and 002 LFC) were employed in this study to observe dose differences in static and dynamic target under homogeneous and inhomogeneous situations.

2. Methodology

2.1. Target Contouring
Contouring process on both CIRS phantoms was performed to determine the dimension and volume on the target. In treatment planning, the target was simulated by a cylindrical object at the spine point area with volume and dimensions of the target is around 7 cc in both of CIRS phantom. The volume and dimension being determined and adjusted with respect to the clinical references of SBRT techniques.

2.2. Treatment planning and delivery
Treatment plans were generated in Pinnacle^3® (Philips Radiation Oncology Systems, Fitchburg, WI) TPS, by using adaptive cone-convolution algorithm. Treatment was performed using 6 MV photon beam produced by Synergy-S (Elekta AB, Stockholm, Sweden). Prescribed dose and number of fields was determined based on the clinical requirement and thirteen irradiation fields were applied in both of homogeneous and inhomogeneous phantom. The results of optimization from the overall plan was evaluated by observing the Dose Volume Histogram (DVH) to check if the percentage of dose received by the PTV in the SBRT success criteria.
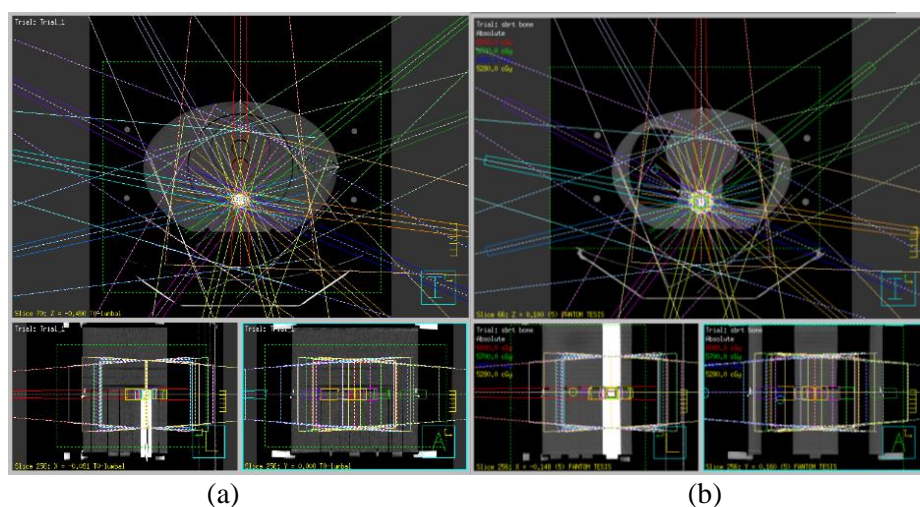

<div align="center">(a)   (b)</div>

Figure 1. Treatment Plans on (a) Homogeneous (002 H9K)
and (b) Inhomogeneous (002 LFC) CIRS Phantoms

2.3. Dosimeter preparation
Calibration was performed on TLD and gafchromic EBT3 film dosimeters. Gafchromic EBT3 film was cut into a small square with a size of 2 x 2 cm^2 and 6 x 1 x 1 mm^3 sized of TLD were also prepared accordingly. Both dosimeters were calibrated using high range dose (500 to 1800 cGy), with 10 x 10 cm^2 field size at 5 cm depth in solid water phantom.

2.4. Measurements
In order to evaluate the impact of target motion, the measurements were carried out in static and SI movement with the amplitude of 5, 10, and 20 mm. In target dose measurement, there were four dosimeters employed: PTW N30013, Exradin A16, TLD, and gafchromic EBT3 film. Dose measurements using TLD and film were performed using holders which have made from teflon. Holders were designed resembling the original interchangeable rod from the CIRS phantom.

2.5. Result Analysis

The evaluation was performed by calculating the magnitude of dose differences (discrepancy) between the value of measured dose ($D_{measured}$) with a value of TPS calculated dose ($D_{planned}$) using the following equation:

$$\text{Discrepancy } (\Delta\%) = \left(\frac{D_{measured} - D_{planned}}{D_{planned}}\right) x\ 100$$

3. Result and Discussion

3.1. Static and Dynamic Measurements

In static measurement, four dosimeters were employed: PTW N30013, Exradin A16, TLD, and gafchromic EBT3 film. Figure 2 shown the results of static measurements where all measured dose were lower than planned dose (underestimate) except for gafchromic EBT3 film. The gafchromic EBT3 film was characterised by high spatial resolution, linear response to a given dose and not being affected by the effects of volume averaging. PTW N30013 and TLD showed the lowest accuracy. PTW ionisation chamber with 0.6 cm^3 active volume is not suitable to be used in small field measurements because it indicates volume averaging effect occured, and TLD is a detector with uncertainty measurement up to 15% [9]. The results obtained by Exradin A16 is also sufficient to prove the ability of Exradin A16 in high-dose measurement on small field, being a type of microchamber with an active volume of 0.007 cm^3. Moreover, the standard deviations on both phantoms were less than 1.5 for gafchromic EBT3 film and less than 0.2 for PTW N30013.

In dynamic measurement, we used three dosimeters employed: PTW N30013, Exradin A16, and gafchromic EBT3 film. Measurement on both phantoms was performed with the phantom moving 5, 10, and 20 mm in SI direction. The dynamic situation generated significant difference and being unsynchronized between the 5, 10 and 20 mm motion. An increase in amplitude of the phantom movement generated a drastic dose reduction from the average doses received by target bone.

3.2. Dosimetric Comparison

Figure 3 shown the results of all measurements in static and dynamic conditions. Measured dose decreased with the increase of movement amplitude. This dose reduction is due to the fact that the objects are regularly moving away from the field during the irradiation. PTW N30013 and TLD is the most perturbative dosimeter in 5, 10, and 20 mm motion. This is due to the volume averaging effect, in which the area of the target radiation has a nearly equal size to the size of the cavity of a PTW N30013.

On measuring targets in motion, Exradin A16 has a slightly different pattern with other dosimeters, with the measured dose being greater than the dose of static target. This is because of the increase in the attenuation of the primary beam radiation affecting the distribution of the scattering. Moreover, relatively rapid movement hinders the electrometer from recombining of ion since the measurement points are away from the radiation field, resulting in high fluctuation with the value being not stable at electrometer readings.

In addition, the standard deviation of dynamic measurement results was in the range of 1.13 to 11.7, 9.5 to 28.6, and 0.05 to 7.21 for gafchromic EBT3 film, Exradin A16 and PTW N30013, respectively. Dose target evaluation of homogeneous and inhomogeneous phantom between static and dynamic, yielded differences in doses with a dose range of 0.62 to 347.44 cGy. The dose profile measurements result obtained proved that an increased amplitude of phantom movement from 5 mm, 10 mm and 20 mm resulted in significant decrease in the dose on target volume. This finding is in line with the finding of Seco *et al.* [10] and Siebenthal [7] that motion effect correlate with decreasing dose on target volume.

3.3. Dose Profil of Measurements

Dose profile of each motion in a homogeneous and inhomogeneous phantom was analyzed to observe reduced dose on movements. Figure 4 shown the normalized graph of homogeneous and inhomogeneous phantom, showing that the position of 90% to 100% dose being away from the point of measurement.

Whereas the dose was decreased at the point of measurement, the highest dose point is obtained during movement in superior direction (i.e. cranially).
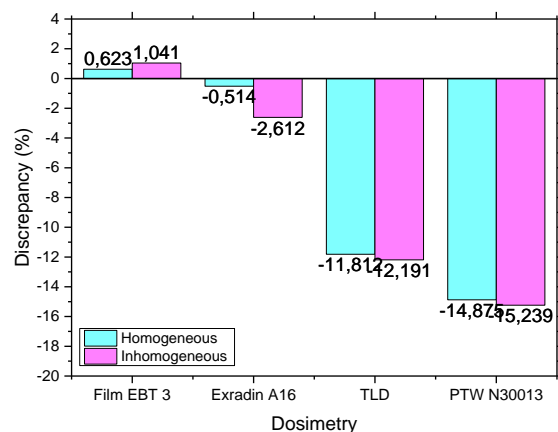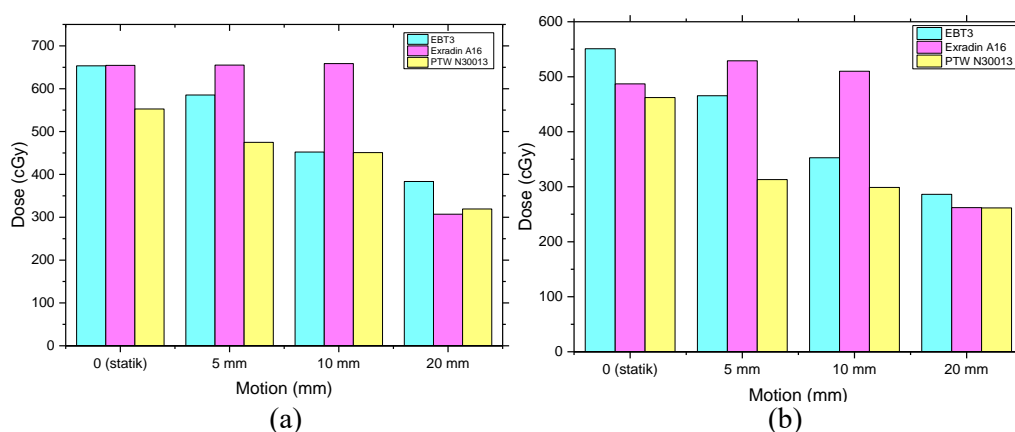

Figure 2. Illustration of Static Measurements

Figure 3. Illustration of dose differences between (a) Homogeneous (b) Inhomogeneous CIRS Phantom
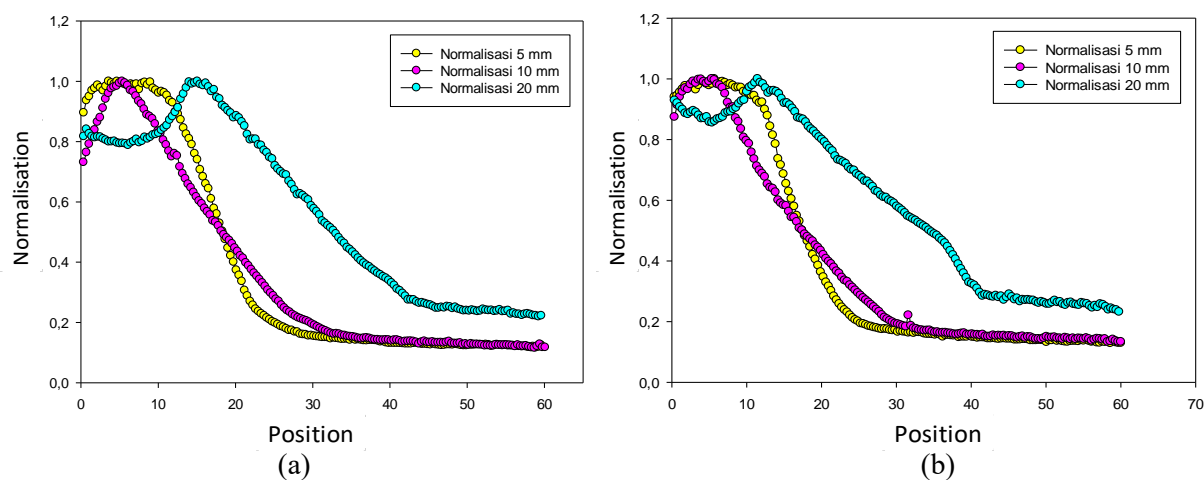

Figure 4. Dose Normalization in (a) Homogeneous (b) Inhomogeneous CIRS Phantom

4. Conclusion

In general, gafchromic EBT3 film shown the best performance for measurement of static target. However, the dose profile measurements result obtained proved that an increase of motion amplitude from 5 mm, 10 mm and 20 mm resulted drastic decrease in the dose on the target volume in phantom motion.

5. References

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