Translation and rotational target motion effect in NSCLC case with 3D-CRT, IMRT, and VMAT techniques using in-house dynamic thorax phantom.

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Abstract. This study aimed to make in-house dynamic thorax phantom that simulate translational and rotational direction mimicking NSCLC target movement. In addition, this study also investigate dosimetric effect of target movement for several translational amplitude. This work used in-house dynamic thorax phantom based on CIRS Dynamic Thorax Phantom model 008A. This phantom simulated translation in superior-inferior direction, rotational in the anterior-posterior and left-right lateral plane to mimic human respiratory motion. It was designed and controlled by linear actuator motor, servo motor, Adafruit motor shield L293D and Arduino UNO R3. It was implemented to evaluate point dose of 3D-CRT, IMRT, VMAT technique and for 5 mm; 10 mm; 15 mm translational motion amplitude 90° rotational target motion amplitude.

The GafChromic EBT 3 film was used as a dosimeter for point dose measurement. This in-house dynamic thorax phantom can mimicking NSCLC target movement for translational amplitude 5±1 mm; 10±1 mm; 15±1 mm and rotational amplitude 90°±3°. The average dose deviation of target dose (centre and peripheral) of TPS dose planning and target motion measurement on 3D-CRT with 5 mm, 10 mm and 15 mm were 3.2%, 3.1%, and 1.8% respectively, and dose deviation on IMRT were 3.9%, 2.5%, and 2.8%, while dose deviation on VMAT treatment were 4.2%, 4.6%, and 6.1% respectively. The preliminary result supported the previous work by Mukhlisin. Furthermore, rotational movement of phantom contributed in average of 1.5% compare to translational movement only.

1. Introduction

According to the American Cancer Society (ACS) the most common types of lung cancer are Non-small cell lung cancer (NSCLC). Some modalities that used to treat NSCLC are surgery, chemotherapy, and radiotherapy, and a combination of these three modalities can be performed [2]. Radiotherapy with 3D-CRT techniques was the lowest standard in handling NSCLC cases in Indonesia [3]. However, conventional radiotherapy techniques provide respective 5-year survivals were 5% for standard radiation therapy in advance stages [4]. It was necessary to improve the effectiveness of radiotherapy for NSCLC cases using intensity modulation radiotherapy (IMRT), and volumetric modulated arc therapy (VMAT) [5]. Complexity of IMRT and VMAT technique can caused several uncertainties [6]. Each cases of tumors in the thorax and abdomen such as the lung including NSCLC, breast, and liver have organ movements due to the respiration process [7]. Those can lead to inaccuracy of given dose and have implication in tumor control, morbidity and toxicity treatment [8].
Mukhlisin, et al., and Arif, et al. (2015) had created an in-house dynamic thorax phantom which can describe and examine the effect of NSCLC case, target movement on the superior-inferior (SI) direction [9] [10]. This study adding rotational movement in anterior posterior (AP) and Left right lateral (RL) field, to find the contribution of rotational movement for dose deviation in center and peripheral target tumor.

2. Material and Method

In order to get dose distribution for static and dynamic target this study made a new motion system for in-house dynamic thorax phantom as shown in Figure 1 (a). It was designed and controlled by linear actuator motor, servo motor, Adafruit motor shield L293D and Arduino UNO R3. It enable to move in translational amplitude 5±1 mm; 10±1 mm; 15±1 mm and rotational amplitude 90°±3° that give 5 mm amplitude for AP and RL movement. This phantom can simulate translational and rotational direction mimicking NSCLC target movement. Gafchromic EBT3 film inserted in the target to get the dose as shown in Figure 1 (b). Phantom was irradiated with 6 MV photon produce by Clinac iX™ linear accelerator (Varian Medical System, Palo Alto, CA, USA) equipped with 120 leaf MLC at MRCCC Siloam Hospital. Eclipse v 13.6 was utilize to create 3D-CRT, IMRT, and VMAT plan for the phantom.

![Image](a)

![Image](b)

Figure 1 (a). Motion system for in-house dynamic thorax phantom, translational motion using linear actuator and rotational motion using servo motor. (b) phantom design (Mukhlisin, et al., 2015)

The treatment planning was created based on ICRU report 62 (1999), the clinical target volume (CTV) determined from static image phantom with additional Internal Margin (IM) 5 mm to compensate target movement and make Internal Target Volume (ITV). For Patient Target Volume (PTV), the additional margin also applied 5 mm from ITV.

The EBT3 films were scanned using an Epson Perfection V700 Photo flatbed scanner (Seiko Epson Corp., Nagano, Japan) operating in transmission mode and analyzed in the red-channel. A set of small (2×3 cm²) pieces of film were irradiated to calibrate the doses between 0 and 400 cGy, the resulting pixel value data were plotted against delivered dose which fitted with 3rd degree polynomial. The pixel value determined in each film image obtained during the moving target study were then converted into measurements of dose using the pixel value versus dose curve, producing two-dimensional dose maps of each radiation treatment examined.

The percentage difference between dose treatment planning and measurement for several points in target was quantitatively measured using equation (1) from AAPM TG 119 (2009).

\[
\Delta\% = \frac{D_{\text{measurement}} - D_{\text{plan}}}{D_{\text{prescription}}}
\]
For image calculation, Matlab 2014a (version 8.3.0.532, The MathWorks, Natick, MA, USA) and ImageJ (Version 1.48v, Rasband, W.S., ImageJ, U. S. National Institutes of Health, Bethesda, Maryland, USA) were used.

3. Result and discussion

The dose at peripheral region of the target volume were decreasing when the motion amplitude increased from 5 mm to 15 mm, as shown in Figure 2 till Figure 4. The peripheral dose range relatively higher than previous work by Arif et al. The increase doses received by the target volume may be due to the mutual interaction between the movement of the target and the movement of the MLC aperture (interplay effect), where there is a possibility that a small portion of PTV receives a radiation dose that match with TPS only for certain time.

![Figure 2](image)

**Figure 2.** (a) Dose distribution in cGy from treatment planning system using 3D-CRT technique. (b)-(d) in sequence dose distribution for translational movement 5 mm, 10 mm, 15mm amplitude. It shows some under-dosage in peripheral region of target, that increasing accordingly to movement amplitude.

This may cause by the absence of synchronization target motion with MLC, which means that the correlation of target motion due to patient breathing and MLC motion is independent. This phenomenon of interplay can cause undesirable dosimetry effects such as under-dosage [13]. For IMRT and VMAT technique, it not only shown under-dosage, but also over-dosage in the central region. It may cause by target translational movement that accidentally move in same direction with MLC so the large part of PTV always received the beam and target rotational movement that always ignored. The rotational movement made detector not always perpendicular with the beam and change the target depth during the treatment. The change of target depth made unpredicted photon interaction that can caused over-dosage in both peripheral and central region of target as shown in Table 1. In central region of target both IMRT and VMAT confirm that rotational movement give over-dosage in central region. It disagree with previous study of Sause et al (2000), Mukhisin et al., (2015), and Larsson T et al.,(2010) about dose blurring and interplay effect which use translational movement only, always shown under-dosage in centre region of target [4][9][13].
Table 1. Dose deviation between measured and planning dose for 3D-CRT, IMRT and VMAT technique.

| Direction | Translational Amplitude | 3D-CRT | 3D-CRT Δ% | IMRT | IMRT Δ% | VMAT | VMAT Δ% |
|-----------|-------------------------|--------|-----------|------|---------|------|---------|
| Superior  | TPS                     | 204.74 | 209.00    | 202.09 | 202.09 |
|           | 0.5                     | 197.40 | -3.7      | 208.03 | -0.5   | 173.89 | -14.1  |
|           | 1                       | 192.11 | -6.3      | 208.55 | -0.2   | 179.30 | -11.4  |
|           | 1.5                     | 202.06 | -1.3      | 214.28 | 2.6    | 190.83 | -5.6   |
| Left      | TPS                     | 209.19 | 209.24    | 202.65 | 202.65 |
| Lateral   | 0.5                     | 210.79 | 0.8       | 220.50 | 5.6    | 203.12 | 0.2    |
|           | 1                       | 201.00 | -4.1      | 205.81 | -1.7   | 204.39 | 0.9    |
|           | 1.5                     | 207.85 | -0.7      | 213.77 | 2.3    | 209.02 | 3.2    |
| Inferior  | TPS                     | 202.89 | 207.39    | 197.62 |        |
|           | 0.5                     | 186.68 | -8.1      | 206.74 | -0.3   | 190.39 | -3.6   |
|           | 1                       | 194.96 | -4.0      | 202.20 | -2.6   | 186.81 | -5.4   |
|           | 1.5                     | 198.63 | -2.1      | 206.77 | -0.3   | 169.96 | -13.8  |
| Right     | TPS                     | 205.72 | 209.95    | 202.56 |        |
| Lateral   | 0.5                     | 208.35 | 1.3       | 223.59 | 6.8    | 204.97 | 1.2    |
|           | 1                       | 205.88 | 0.1       | 211.95 | 1.0    | 196.53 | -3.0   |
|           | 1.5                     | 208.54 | 1.4       | 219.43 | 4.7    | 204.80 | 1.1    |
| center    | TPS                     | 209.01 | 209.26    | 201.82 |        |
|           | 0.5                     | 213.62 | 2.3       | 221.96 | 6.3    | 205.15 | 1.7    |
|           | 1                       | 206.56 | -1.2      | 223.01 | 6.9    | 206.94 | 2.6    |
|           | 1.5                     | 216.09 | 3.5       | 217.44 | 4.1    | 215.04 | 6.6    |

Table 2. Average dose deviation between measured and planning dose for 3D-CRT, IMRT and VMAT technique.

| Translational Amplitude | 3D-CRT Δ% (%) | STDv | IMRT Δ% (%) | STDv | VMAT Δ% (%) | STDv |
|-------------------------|--------------|------|-------------|------|-------------|------|
| Average                 | 0.5          | 3    | 2.6         | 4    | 2.9         | 4    |
|                         | 1            | 3    | 2.2         | 2    | 2.3         | 5    |
|                         | 1.5          | 2    | 1.0         | 3    | 1.5         | 6    |
Figure 3. (a) Dose distribution in cGy from treatment planning system using IMRT technique. (b)-(d) in sequence dose distribution for translational movement 5 mm, 10 mm, 15mm amplitude. It shows some under-dosage in peripheral region of target, and over-dosage in center region of target.

Figure 4. (a) Dose distribution in cGy from treatment planning system using VMAT technique. (b)-(d) in sequence dose distribution for translational movement 5 mm, 10 mm, 15mm amplitude. It shows some under-dosage in peripheral region of target, that increasing accordingly to movement amplitude.

This in-house dynamic thorax phantom can mimicking NSCLC target movement for translational amplitude 5±1 mm; 10±1 mm; 15±1 mm and rotational amplitude 90°±3°. Average dose deviation of target dose (centre and peripheral) between TPS dose planning and target motion measurement on 3D-CRT with 5 mm, 10 mm and 15 mm were 3.2%, 3.1%, and 1.8% respectively, and dose deviation on
IMRT were 3.9%, 2.5%, and 2.8%, while dose deviation on VMAT treatment were 4.2%, 4.6%, and 6.1% respectively as shown in table 2.

4. Conclusion
This study has investigated the interplay effect for 3D-CRT, IMRT, and VMAT technique in NSCLC case. Dose deviation for central region of target shown translational and rotational target motion can cause over-dosage. It disagree with previous study that always show that under-dosage at central region of target as repercussion of interplay effect, but the preliminary result supported the previous work by Mukhlisin that target movement may cause dose deviation between planning and measured. Furthermore, rotational movement of phantom contributed in average of 1.5% compared to translational movement only.

5. References
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