The impact of pitch and modulation factor to Tomotherapy treatment plan optimization for motion target

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Abstract. The influence on target motion resulted from the respiratory process, the pitch and modulation factor presented in Tomotherapy. This study was aimed to investigate the effect of motion management using CT-images obtained from the fusion process between the static and dynamic scanning mode on the CIRS Thorax Phantom. The images were created using axial and helical modes which amplitudes were varied from 10 mm, 15 mm, and 20 mm. Then, the organ structures were planned using TomoPlan TPS with the variation of pitch ranging from 0.25 to 0.5, and the modulation factor (MF) in the range 2 to 3. Furthermore, evaluation of radiotherapy planning was performed using dose parameters on target, the organ at risk, homogeneity index (HI), and mean leaf open time (LOT). Target volume for static mode was 3.53 cc, whereas target volume has changed to 10.9 cc, 10.3 cc, 16.1 cc for axial and 6.6 cc, 8.5 cc, 14.9 cc for helical scanning. The HI value obtained was less than 0.07 and lower HI was resulted for a larger MF. It means that the higher modulation factor values will provide a uniform dose distribution to the target and lower dose to the OAR. The greater value of pitch gave the greater mean LOT. The optimum parameters were at the pitch of 0.5 and MF of 3 based on the evaluation of mean LOT and HI. Axial scanning mode provides a larger target volume compared to a helical scanning mode. Therefore, the increment of the target volume in delineating organ should be considered.

1. Introduction

In the case of lung cancer with treatment using radiotherapy, the movement of intrafraction is an issue with the level of attention that continues to increase along with the development of radiotherapy techniques such as using image-guided radiotherapy techniques [1]. Intrafraction movements occur during treatment sessions caused by movements in the respiratory system, cardiac movements, and digestive or gastrointestinal system movements. An important note in the treatment of lung cancer cases is the presence of movement in the respiratory system which will lead to errors in defining GTV and CTV and errors during patient setup. Therefore, a movement management is needed so that the errors can be minimized. Management of movement caused by breathing does not only affect the accuracy of the target localization, but it can also reduce the dose in normal tissue [2,3].

The lung organ moves in 3-dimensional direction which is superior-inferior, anterior-posterior and in the right-left direction. The movement of the lungs during the breathing process has a different shift. Steven et al. showed that of the 22 patients, 10 patients showed no movement in the superior-inferior direction, and 12 patients showed movement in the superior-inferior direction (SI). The magnitude of lung movement in the SI direction has a range from 3 mm to 22 mm with an average of $8 \pm 4$ mm [4].
The lungs have varying movements depending on the position of each lobe. The lower lungs have a greater movement than the middle lobe, the upper or the middle part (mediastinum). The magnitude of lower lung movement is about 18.5 mm [5]. From the many studies that have been done, it was found that the most dominant movement in the respiratory system is in the superior-inferior direction.

There are several methods [1] that have been developed to reduce the effects of respiratory movements in radiotherapy such as the motion encompassing, respiratory-gating technique, breath-hold technique, forced shallow-breathing technique, and breathing synchronization technique (respiration-synchronized). A shift in the target organ will affect the dose which is given to the target organ. Ehrbar et al., compared dosimetric results for different movement management techniques using free breathing techniques with the concept of the internal target volume (ITV), mid-ventilation (MidV), respiratory gating, and dynamic target tracking using 4D-CT. It showed that by using movement management, the target organ will receive coverage dose more than 99% (A>> D_{min}> 99%). For active movement management techniques such as gating or tracking provides greater dose coverage to the target and smaller doses for organs at risk compared to passive techniques [6]. Besides using 4D-CT, movement management can also be done using slow-CT which is available in almost 3D-CT. One of the solution to get the representation of CT scan for peripheral lung tumors is by using slow-CT. The target volume is covered by 95% doses ranging from 75.8% to 95.4% for PTV with a margin of 1 cm [7].

Along with the need for a high level of accuracy for radiation doses in target organs, radiotherapy techniques are also being developed. Tomotherapy can give more coverage dose to the target organs. In Tomotherapy, besides rotating gantries, the patient's couch also give a movement in the superior-inferior direction. The speed of the movement of the gantry and the patient's couch are affected by pitch and modulation factors. As the influence on movement management techniques and pitch and modulation factors, this research was conducted to investigate the effect of movement management using slow CT techniques and find the optimum parameter for planning for moving target volume.

2. Materials and Methods

The CIRS Model 002 LFC phantom was scanned using a GE High-speed CT-simulator with a CIRS Model 002 LFC phantom placed on the CIRS dynamic platform model PL 008 to simulate lung movement in the superior-inferior direction. The position of the phantom scanning can be seen in Figure 1. The static and dynamic mode of scanning was performed in this research. The amplitude of the dynamic CIRS platform illustrates the different rhythms of breathing for each patient. Based on research conducted by Steven, et al. [4] that the lung movement in the superior-inferior direction varies from 3 mm to 22 mm, then the variations of amplitude are 10 mm, 15 mm, and 20 mm which describes lung movement in patients during breathing. The period applied in the CIRS Thorax phantom is 4 seconds for each amplitude.

![Figure 1. The setting of the thoracic phantom for the scanning process using CT simulator. (a) Thorax CIRS phantom, (b) Dynamic platform.](image-url)
The axial and helical scanning mode were performed using the pitch of 0.75. Images of the phantom were obtained from the static and dynamic phantom. The markers made of lead placed on the target before the scanning process. The markers can be clearly seen when delineated the target volume. The images then transferred to a virtual simulator to delineate the target and the organ at risk. The delineation software used in this study is the Eclipse TPS. Images from the static mode and dynamic mode were fused in order to get accurate target volume. The image fusion process was carried out for axial and helical scanning mode in order to obtain the optimal delineation result due to movement in the superior-inferior direction. The depiction of gross tumor volume (GTV) was performed by looking at the outer boundary of the target organ which can still be seen in a virtual simulator. Then delineated target volume for cylindrical shape.

The margin which is used for CTV and PTV was 3 mm from the GTV which was obtained from the delineation of image fusion for static and dynamic phantoms. The actual volume of the target volume was also calculated. The target was a cylindrical shape made of polymethyl methacrylate (PMMA) material which has an equivalent density of tissue with a diameter of 15 mm and a length of 20 mm. The CIRS Thorax phantom moves in the superior-inferior direction, the target size is added only to the target length dimension, so that the dynamic target length was 40 mm, 50 mm and 60 mm, where the addition is carried out for the superior and inferior directions for amplitude variation of 10 mm, 15 mm and 20 mm respectively.

The organ at risk was also contoured, such as lungs, heart, and spinal cord. After delineation was carried out on all target organ at risk, the structures were then sent to the TomoPlan TPS. The next step was to make a radiotherapy planning calculation using TomoPlan with inverse planning techniques. The prescription dose which was given in this study was 66 Gy given in 33 fractions. The independent variable which is used in this study was the value of pitch and modulation factors and the width of the jaw. The modulation factor value varied of 2 and 3. The variation of pitch values started from 0.2 to 0.5. The width of the jaw which was used in this study was 1 cm, 2.5 cm, and 5 cm. Optimization of pitch and modulation factors was performed in order to get the maximal value for the dynamic phantom.

The quantitative parameters that were used as a reference in defining the optimal pitch and modulation factors were the homogeneity index value and the mean leaf open time (LOT) for coverage dose in the target volume. The planning result then was evaluated by calculating the HI value that is close to the ideal value (zero) [8], and for the dosage on the organ at risk by using the recommendations given in QUANTEC radiation dose constraint.

3. Results and Discussions
The thorax phantom CIRS Model 002LFC was scanned on CT-simulator with static and dynamic positions for axial and helical scanning modes. The images fusion process of the static and dynamic phantom for axial and helical scanning modes gave the actual target volume of 3.53 cm³. The differences between actual target volume and the scanning results using CT-simulator can be seen in Table 1. It can be seen that the addition of lung target volume was affected by the magnitude of the organ movement’s amplitude. The greater the amplitude value was given, the greater the increase in target volume which is caused by the movement. It was found that scanning using axilal mode gave a greater increase in target organ volume compared to the scanning using helical mode. This is due to scanning with axial mode used longer gantry rotation so when scanning is performed, the movement of phantoms can be imaged more accurate. The helical scanning mode gave the movement for gantry and patient tables on CT-simulator so that the phantom was inaccurately imaged because of the phantom changes with the movement of the CT-simulator table.

Figure 2 showed that the dynamic phantom with the greater amplitude value for axial and helical scanning gave the volume of the target was closer to the actual volume of the calculation. This study used a constant period of the movement. To change the amplitude value with a constant period value, the speed of the dynamic phantom will increase, resulting in the image captured by the CT-simulator will have a value close to the actual volume value for axial scanning and helical scanning mode.
Table 1. Target volume for static and dynamic phantom with axial and helical scanning

| Amplitude (mm) | GTV (cc) Actual | Axial Difference (%) | Helical Difference (%) | PTV (cc) Axial | Helical | Target volume without motion (cc) |
|----------------|----------------|----------------------|-----------------------|----------------|---------|----------------------------------|
| 10             | 7.06           | 6.8                  | 3.75                  | 3.6            | 49.04   | 11.8                             |
| 15             | 8.83           | 8.1                  | 8.28                  | 5              | 43.38   | 13                               |
| 20             | 10.59          | 10.3                 | 2.81                  | 9.5            | 10.36   | 16.1                             |

Figure 2. The volume differences of the target for the variations of the phantom scanning modes

Homogeneity index was used as a parameter to determine the uniformity of the dose on the target. It was obtained that the homogeneity index from the planning using Tomotherapy was close to the ideal value of 0. The homogeneity index which is obtained in this study was ranged between 0.03-0.07. This low homogeneity index showed that the distribution of near maximum (D$_{95}$) and near minimum (D$_{2}$) doses is quite uniform. The homogeneity index value obtained in this study had a lower value compared to the homogeneity index value which is obtained by Xu, Yujin, et al. which is 0.1 [9]. This is because the target volume which was used in this study had a simple shape which was a cylindrical shape, so it will get a more homogeneous dose distribution compared to the homogeneity index which was obtained by Xu, Yujin who used the target organ of patients which had a more irregular in shape.

Determination of optimal modulation factor in the radiotherapy planning using Tomotherapy can be done by looking at the homogeneity index values which is produced in the planning. In this study, two modulation factor values are used which were 2, and 3. The results showed that the homogeneity index was lower for the larger modulation factors as shown in Figure 3. The modulation factor is a parameter which is used in adjusting the modulation level of IMRT planning in Tomotherapy.

Figure 3. The graph of the relationship of modulation factors and homogeneity index for varying amplitude
The lower homogeneity index value which is given by the planning with the higher modulation factors was due to the increase of the complexity of the TPS calculations. The high modulation factor is related to the level of complexity of the target and organ at risk which is more critical, so with the higher modulation factor, the homogeneity index value was close to the ideal value. This was in line with the research conducted by Geert De Kerf who found that the high modulation factor would provide a uniform dose distribution and would provide lower doses in healthy tissues [10].

Radiotherapy planning evaluation can be done by looking at the mean leaf open time (LOT) value which was generated after the planning calculation was performed using the TomoPlan TPS. The mean leaf open time (LOT) calculation was performed for the varying pitch value. The results of the mean leaf open time for different pitch values were shown in Figure 4. The graph of the mean leaf open time with the varying pitch value indicated that the greater pitch value gave the greater mean leaf open time. This is consistent with the research obtained by Westerly, et al. which showed that the greater changes of mean leaf open time were generated with the higher pitch values [11].

Figure 4. The graph of the relationship of pitch value and mean leaf open time (LOT) for the variation of the jaw width.

4. Conclusion
The axial scanning mode was suitable for the treatment of the moving target. As evidenced by the target volume for the axial scanning mode was closer to the actual target volume compared to the helical scanning mode with the difference of 3.75%, 8.28%, and 2.81% for the axial scanning mode and 49.04%, 43.38%, and 10.36% for the helical scanning for the variation of the amplitude of 10 mm, 15 mm, and 20 mm. Therefore, the increment of the target volume in delineating organ should be considered. The best modulation factor and pitch value in this study are 3 and 0.5 based on the homogeneity and mean leaf open time.

References
[1] Keall P.J., G.S. Mageras, J.M. Balter, R.S. Emery, K.M. Forster, S.B. Jiang, J.M. Kapatoes, D.A. Low, M.J. Murphy, B.R. Murray, C.R. Ramsey, M.B. Van Herk, S.S. Vedam, J.W. Wong, E. Yorke. (2006). "The management of respiratory motion in radiation oncology report of AAPM Task Group 76," Medical Physics 33, 3874-3900.
[2] Hanley, J., M. M. Debois, D. Mah, G. S. Mageras, A. Raben, K. Rosenzweig, B. Mychalczak, L. H. Schwartz, P. J. Gloegger, W. Lutz, C. C. Ling, S. A. Leibel, Z. Fuks, and G. J. Kutcher. (1999). “Deep inspiration breath-hold technique for lung tumors: The potential value of target immobilization and reduced lung density in dose escalation.” Int J Radiat Oncol Biol Phys 45(3):603–611.
[3] Yorke, E. D., L. Wang, K. E. Rosenzweig, D. Mah, J. B. Paoli, and C. S. Chui. (2002). “Evaluation of deep inspiration breath-hold lung treatment plans with Monte Carlo dose calculation.” Int J Radiat Oncol Biol Phys 53(4):1058–1070.

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[4] Stevens, C. W., R. F. Munden, K. M. Forster, J. F. Kelly, Z. Liao, G. Starkschall, S. Tucker, and R. Komaki. (2001). “Respiratory-driven lung tumor motion is independent of tumor size, tumor location, and pulmonary function.” Int J Radiat Oncol Biol Phys 51(1):62–68.

[5] Barnes, E. A., B. R. Murray, D. M. Robinson, L. J. Underwood, J. Hanson, and W. H. Roa. (2001). “Dosimetric evaluation of lung tumor immobilization using breath hold at deep inspiration.” Int J Radiat Oncol Biol Phys 50(4):1091–1098.

[6] Ehrbar S., Perrin., Peroni M., bernatowicz K., parkel T., Pytko I., Klock S., Guckenberger M., Tanadini-Lang S., Weber D. C., Lomax A. (2016). Respiratory motion-management in stereotactic body radiation therapy for lung cancer – A dosimetric comparison in anthropomorphic lung phantom (LuCa). Radiotherapy and Oncology. Nov; 121 (2): 328-334.

[7] De Koste J. R. V. S., Lagerwaard F.J., Scuchhard-Schipper R. H., Nijssen-Visser M. R.J., Voet P. W. J., Oei S. S., Senan S. (2001). Dosimetric consequences of tumor mobility in radiotherapy of stage I non-small cell lung cancer – an analysis of data generated using ‘slow’ CT scans. Radiotherapy and Oncology 61: 93-99.

[8] International Comission on Radiation Units and Measurements. (2010). ICRU Reposrt 83: Prescribing, Recording and Reporting Photon-Beam Intensity-Modulated Radiation Therapy (IMRT). Journal of the ICRU Volume 10 No 1

[9] Xu.Y., Den. W., Yang. S., Li. P., Kong. Y., Tian. Y., Liao. Z., Chen. M. (2017). Dosimetric Comparison of The Helical Tomotherapy, Volumetric-Modulated Arc Therapy and Fixed-Field Intensity-Modulated Radioterapy for Stage IIB-IIIB Non-small Cell Lung Cancer. Sci Rep; 7: 14863.

[10] Kerf. G.D., Gestel D.K., Mommaerts. L., Daneielle. V.W., Verellen. D. (2015). Evaluation of The Optimal Combinations of Modulation Factor and Pitch for Helical Tomotherapy Plans Made with TomoEdge Using Pareto Optimal Fronts. Radiation Oncology 10:191.

[11] Westerly. D.C., Emilie. S., Katherine. W., Leah. S., Gustavo. O., Thomas. R.M. (2009). Treatment Planning to Improve Delivery Accuracy and Patient Throughput in Helical Tomotherapy. Int. J. Radiation Oncology Biol Phys., Vol. 74, No. 4, pp. 1290-1297.

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