Original Articles/นิพนธ์ต้นฉบับ

Comparative Dosimetric Analysis of Lung Cancer Treatment Planning for 3D-CRT Using 6 and 10 MV Photon Beams

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Abstract

Purpose: To compare the dosimetric results of planning target volume (PTV) and organs at risk (OAR) and the quantitative analysis of PTV between 6 and 10 MV photon beams for lung cancer patients with 3D-conformal radiotherapy (3D-CRT) treatment technique.

Materials and Methods: Twelve non-small cell lung cancer patients who underwent 4D-CT scan at Division of Radiation Oncology, Siriraj Hospital between March 2009 and August 2011 were retrospectively reviewed. The radiation oncologists delineated target volumes for each patient using Varian Eclipse Treatment Planning System, software version 8.6. The target volume was classified as gross target volume (GTV), clinical target volume (CTV) and planning target volume (PTV). Treatment planning performed in PTV were projected on a free breath CT set. In PTV, the same exact beam arrangement that was used with beam energies was 6 MV and 10 MV photons. The tumor prescription dose was 60 to 66 Gy in 2 Gy per fraction. For overall plan, 95% of PTV should receive at least 60-66 Gy. An accepted maximum dose was 107% of prescribed dose unless a higher maximum dose was located within PTV.

Results: Both energy 6 MV and 10 MV photon beams did not have statistically significant effect on the maximum of radiation. The average maximum radiation doses on both energy 6 MV and 10 MV photon beams were 70.358 and 68.783 Gy. There was no significant difference of average dose of radiation (P = 0.948) of 6 and 10 mv which were 64.667 and 64.542. In addition, the effect of radiation dose for spinal cord, dose for esophagus and dose for lung yielded the similar result. Both 6 MV and 10 MV photon beams did not have any effect on the dose for spinal cord, dose for esophagus and dose for

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lung. Average dose for spinal cord was 42.250 Gy (6 MV) and 42.067 Gy (10 MV), average dose for esophagus was 24.567 Gy (6 MV) and 24.475 Gy (10 MV), and average dose for lung was 15.875 Gy (6 MV) and 15.808 Gy (10 MV).

Conclusion: Use of high-energy 10-MV photon was found to achieve the same tumor control as the 6-MV photon with acceptable complication rate as well as better saving for normal tissue, while generating negligible neutron dose equivalent. It is recommended that the choice to treat at 10 MV be taken as a risk versus benefit since the clinical significance remains to be determined on case by case basis.

Keywords: 3D-conformal radiotherapy, Dose Volume Histogram, Conformity Index, Homogeneity Index, lung cancer,

Introduction

The treatment of lung cancer is composed of surgery, chemotherapy and radiotherapy. The proper treatment depends on many factors such as staging, performance status and histological subtype. Radiotherapy is a main treatment in medical inoperable patients. Moreover, there is also a role of radiotherapy in postoperative and palliative cases.

This study was aimed to compare the dosimetric analysis of tumor and organs at risk among photon energy between 6 and 10 MV photon beams. Dose-volume histogram was used to evaluate. Moreover, we assessed the correlation between tumor location, tumor volume and benefit of using photon energy for 3D-CRT.

Materials and Methods

Materials

I. CT simulator scanner

The 16 slice CT scanner (Brilliance CT big bore, Philips Medical Systems, Madison, WI, USA), which is shown in Figure 1, had the ability to simultaneously collect 16 rows of scan data. The bore size was 850 mm diameter with the focus to detector distance of 1183 mm and focus to isocenter distance of 645 mm.

Figure 1 *The 16 slice CT Simulator*

There were 3 kVp options of 90, 120, and 140 kVp and various mA from 20 to 500 mA with 1 mA increment.

II. Linear accelerator

The 23EX linear accelerator (Varian Oncology Systems, Palo, Alto, CA, USA) (Figure 2) had dual photon beams of 6 MV and 10 MV, and six electron beams energies. Photon fields ranged from 0.5x0.5 cm^2 to 40x40 cm^2 at isocenter with the distance form target to isocenter of 100 cm. The dose rate can be varied from 100 MU/min to 600 MU/min. The Millennium MLC system was mounted at the treatment head as tertiary collimator system.

Figure 2 *Varian CLINAC 23EX linear accelerator (Varian Oncology Systems, Palo Alto, CA, USA)*

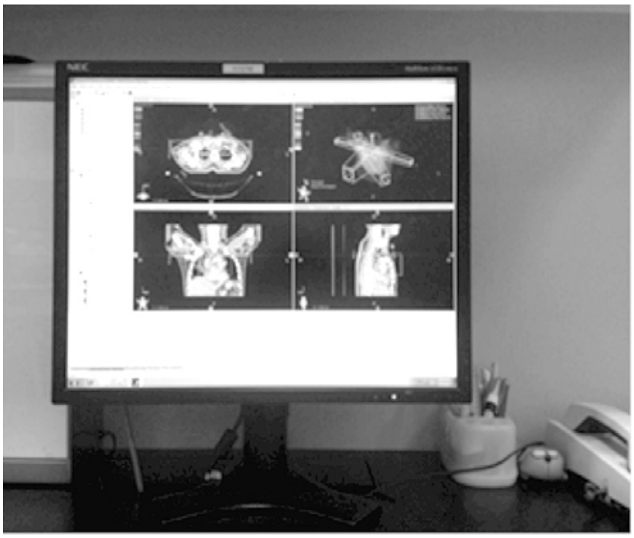

Figure 3 *Eclipse treatment planning*

Treatment planning

The Eclipse planning system Version 8.6 (Varian Medical Systems, Paolo, Alto, CA, USA) shown in Figure 3 was the software used to calculate the radiation dose with AAA algorithm for 2D, 3DCRT, Dynamic Arc, IMRT, and VMAT techniques.

Methods

This study was a retrospective review and re-planning of dosimetric data in non-small cell lung cancer of 12 patients who underwent CT scan at Division of Radiation Oncology, Radiology Department, Siriraj Hospital between March 2009 and August 2011. The 3DCRT Radiotherapy Treatment Planning (RTP) that was performed in PTV were projected on a free breath CT set. Eclipse treatment planning software (Eclipse, Version 8.6 Varian Medical Systems, Palo, Alto, CA, USA) was used in this study (Figure 4). In PTV, the same exact beam arrangement was used with beam energies 6 MV and

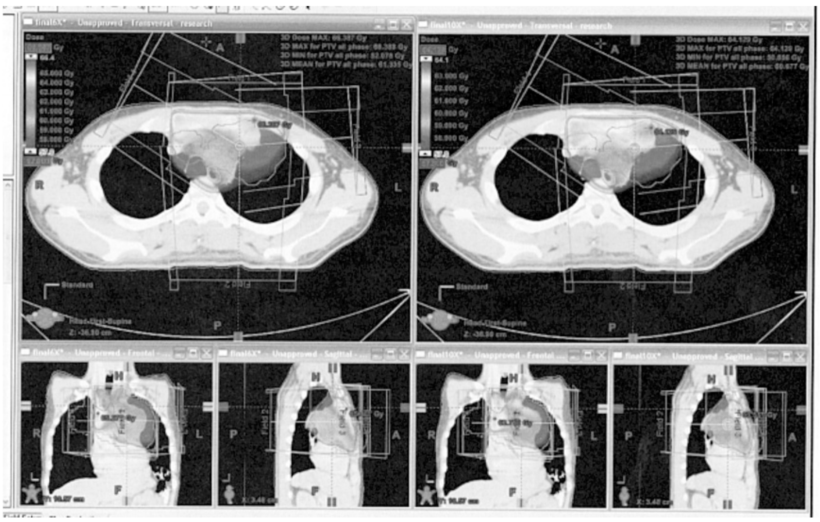

Figure 4 *The sample of treatment planning for the patients in which the left hand side used 6 MV photon beam and the right hand side used 10 MV photon beam. (Eclipse, Version 8.6 Varian Medical Systems, Palo, Alto, CA, USA)*

10 MV photons. The tumor prescription dose was 60 to 66 Gy in 2 Gy per fraction. For overall plan, 95% of PTV should receive at least 60 to 66 Gy. An accepted maximum dose was 107% of prescribed dose unless a higher maximum dose was located within PTV. The RTPs were done firstly by physicist and other types of contouring were performed by resident. Finally, the physicist and radiation oncologist re-checked all of the plans.

The 3D-CRT treatment plan evaluation

A 3D treatment plan consists of dose distribution information over a 3D matrix of points over the patient's anatomy. DVHs summarize the information contained in the 3D dose distribution and are extremely powerful tools for quantitative evaluation of the treatment plans.

In its simplest form a DVH (Dose Volume Histogram) represents a frequency distribution of dose values within a defined volume that may be the PTV itself or a specific organ in the vicinity of the PTV. Rather than displaying the frequency, DVHs are ordinate against the dose on the abscissa.

Qualitative evaluation

Qualitative evaluation of three-dimensional (3D) dose distribution represented in DVHs was used to define the maximum, minimum and goal dose delivered to each volume of interest, as well as the dose delivered per unit or percentage volume for all structures as shown in Figure 5.

The purpose of the DVHs was to summarize 3D dose distributions in a graphical 2D format that could be analyzed in terms of:

1) Goal dose or Dgoal which was dose to 95% of PTV volume as displayed on DVHs, they should be received at prescription dose.

2) Minimum dose or Dmin which was dose to 99% of PTV volume as displayed on DVHs.

3) Maximum dose or Dmax which was dose to 1% of PTV volume as displayed on DVH.

4) The prescribed isodose line should be covered slice-by-slice at least 95% of PTV and hot spot should not be over 110% or prescription dose, and the cold spot is 93% of prescription dose that should not be over 1% of PTV volume. Organs at risk (OARs) are the critical organs near tumor or PTV.

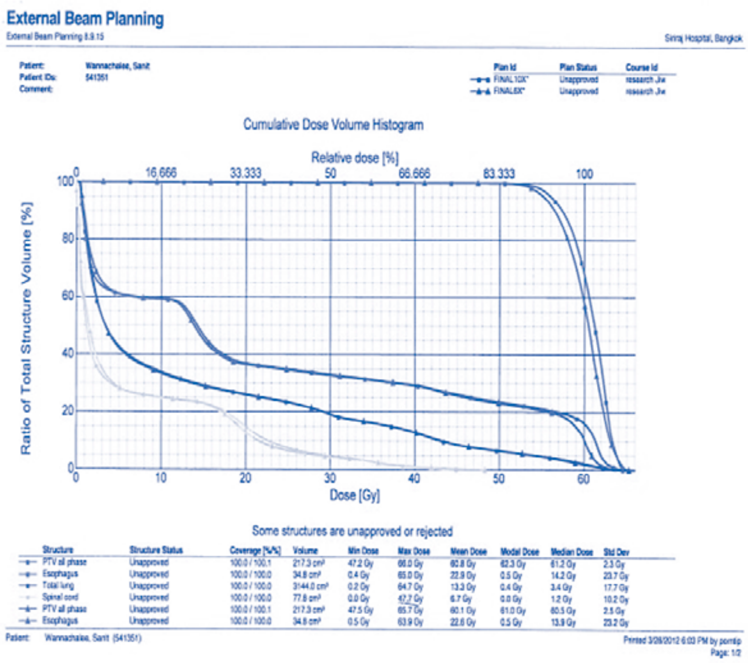

Figure 5 *The sample of dose volume histogram (DVH)*

Quantitative evaluation

(a) Target coverage (TC)

Target coverage was evaluated accordingly to compare maximum and mean doses to PTV that is defined as the ratio of VT, Pi and VT). The aim of coverage at least 90% was an acceptable criterion for lung plan.

(b) Conformity Index (CI)

Conformity index was performed to define how prescribed dose close to the PTV that can be defined as the ratio of VT, pi and VPi. The acceptable CI value is 0.6 or higher.

(c) Conformation Number (CN)

Conformation number was the proportion of TC and CI. The lower the score plan gets, the lesser conformal the plan you receive.

(d) Homogeneity Index (HI)

HI value was defined as the highest dose delivered to 2% of the target volume (D2%) minus the dose delivered to 98% of the target volume (D98%) divided by median dose (Dmedian) of the target volume. A value of 0 corresponded to absolute homogeneity of dose within the target.

The results were analyzed by: average, standard deviation (SD), percentage. To analyze the difference between 6 MV and 10 MV photon beams, this study implemented the paired sample t-test with the significant level of 0.05.

Results and Discussion

There were 12 subjects involved in this study whose primary GTV volume ranges from 16.0 cm^3 to 218.7 cm^3 and 3 out of 12 were post-surgery subjects. Three patients underwent surgical resection, therefore, they had only GTV lymph nodes. For other 9 patients, 8 patients had primary tumor located in upper lung and only one patient had lower lung tumor.

Treatment planning

Treatment plan was performed to the total dose 60-66 Gy. The number of beam directions ranged from 4 to 6 beams. Most of patients received 66 Gy (9 patients) and only 2 patients had a dose of 60 Gy. One patient could not undergo to 60 Gy due to limitation of normal tissue toxicity parameter.

The dose differences between measurement by ionization chamber and calculation by AAA algorithm were less than recommended criteria in both photon energies. The maximum dose deviation of 3.44% was found in case number 7 at location number 5 at 90° gantry angle of 6 MV beams.

Monitor Unit of 6MV and 10 MV

The treatment machine monitor (MU) generated by using the 3D-CRT planning system must be independently checked prior to the patient's first treatment(1,2). The average MU for 6 MV and 10MV was 464.75 and 398.17 MU, respectively. Figure 6 describes the monitor unit from the treatment plan. We found that the MU of photons-beams 10 MV was less than that from 6 MV for all of the patients. It means that we used less time to treat the patient by using 10 MV than 6 MV. The less monitor unit for the treatment is better. Increase in the number of MUs will increase out-of-field radiation dose(3). Hall and Wuu(4) pointed out that if the number of MUs in IMRT is increased with a factor of 2-3 compared with 3D-CRT, the 3D-CRT will be preferable compared to intensity-modulated radiation therapy (IMRT).

Conformity Index (CI) and Homogeneity Index (HI) of the subject

The CI = (TV/PTV), which is the quotient of the treated volume (TV) and the PTV. Conformity indices may be affected by both planning variables and tumor factors. From Figure 7, it shows that for both

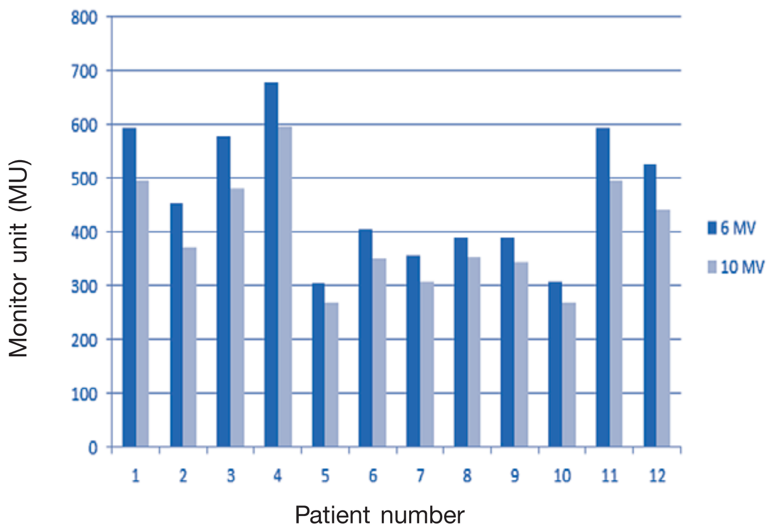

Figure 6 *Monitor unit result*

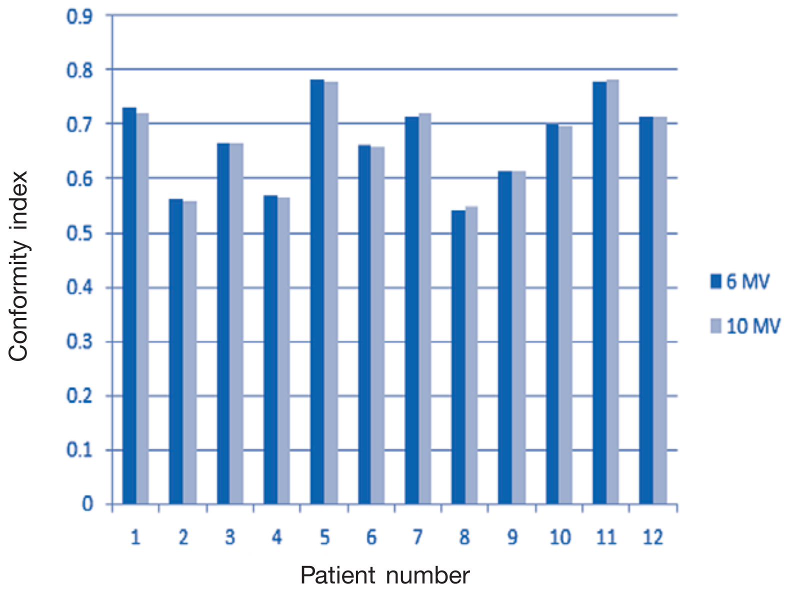

Figure 7 *Conformity index for both 6 and 10 MV plans for 12 patients*

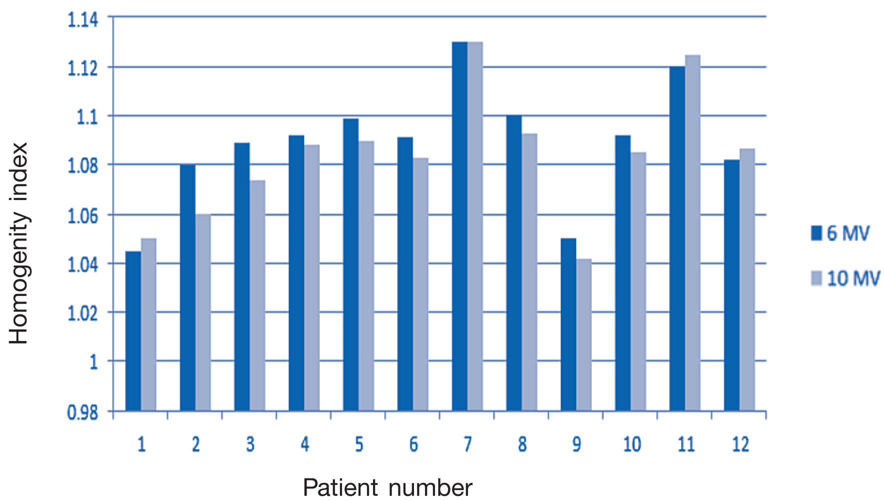

Figure 8 *Homogeneity index 6 and 10 MV plans for 12 patients*

6 and 10 MV plan are closed to 1. The conformity of 10 MV plan is better than 6 MV plan in general. The closer the CI value is to 1, the better the dose conformity[5]. Another study confirmed that increasing the photon energy improves the dosimetric parameters of bladder, femoral heads and PTV, but no statistically significant differences for radiation dose to the rectum were observed. By increasing the number of beams, one can compensate for the low energy defect[6].

A study on the non-small cell lung cancer found that on univariate analysis, PTV, number of beams, medial vs. lateral tumor location, and increasing tumor stage were associated with improved conformity. On multiple regression analysis, factors found to be associated with CI included central vs. peripheral tumor location (P = 0.041) and PTV size (P = 0.058)[7].

The Organs at Risk (OAR)

Figure 8 presents the Homogeneity Index (HI) by which is an objective tool to analyze the uniformity of dose distribution in the target volume. Histogram of PTV in all 12 cases in both 6 and 10 MV photon beams. The results of all cases were nearly

Figure 9 *Dose distribution of PTV which is displayed dose at 50 Gy.*

ideal value of 1.00. A HI value approaching zero indicates a more homogenous dose distribution within the PTV[8]. The 10 MV beams exhibited better in homogeneous view compared with the plan from 6 MV beams. This study was different from a study on the pelvis area. It was found that the HI indexes did not diverge in both 6 MV and 15 MV[9].

Lung: The V20 of all cases passed criteria of 35% lung volume and the mean lung doses were also less than 20 Gy except case number 11. The MLD dose of 6 and 10 MV plans were not significantly different. It was found that the average dose for 6 MV was 15.8±4.2 Gy and for 10 MV was 15.8±4.3 Gy.

Esophagus: The similar results were observed; V50 and mean esophageal dose of 6 MV plans were not significantly different from 10 MV plans. It was found that the average dose for 6 MV was 24.567 ±6.227 Gy, and for 10 MV it was 24.475±6.173 Gy.

Spinal cord: It was found that the average dose for 6 MV was 42.2±5.5 Gy, and for 10 MV it was 42.1±5.3 Gy. Figure 9 shows that spinal cord received radiation dose more than limit dose (< 45 Gy).

The statistical analysis showed that the energy 6 MV and 10 MV photon beams did not have significantly different effect on the dose for spinal cord, esophageal and lung with the P-value equal to 0.934, 0.971 and 0. 970, respectively. The current study shows similar finding to the research on effect of photon energy for prostate cancer by using intensity-modulated radiation therapy in Korea; there was no significant impact on the OARs for 6 MV and 15 MV[10]. However, this current study gave different results from a study on the treatment for esophageal and rectal cancer. It articulates the difference between doses received by OARs, namely spinal cord, bladder and head of femurs. It was found that using low energy photons (6 MV) in lower esophageal treatment and high energy photons in the rectal treatment provides a better dose coverage[9]. We can learn that the impact of photon will be different by the OAR and by the method of therapy (IMRT or 3D CRT).

In addition, the paired t-test results that 6 MV and 10 MV photon beams do not show statistically significantly different effect on the maximum of radiation dose at significant level 05 ($P = 0.300$), whereas the average radiation dose does not show significant difference in average dose of radiation ($P = 0.948$).

Conclusions

This study yields an important finding on the implementation of 3D CRT for 6 MV and 10 MV. The photon beam of 10 MV gave lower MU than 6 MV. The 6 MV and 10 MV do not show different effect toward the OARs. Using of high-energy 10-MV photon achieves the same tumor control as the 6-MV photon with acceptable complication rate as well as better saving normal tissue, while generating negligible neutron dose equivalent.

Acknowledgments

We would like to express profound gratitude to Porntip Iampongpaiboon, the radiation physicist, for her contribution in all treatment planning and kind supports. We acknowledge Assist. Prof. Chumpot Kakanaporn for her kind support and grateful suggestion about statistical analysis. We are extremely grateful to all medical staffs, radiation physicists, radiation therapists and medical record officers in the Division of Radiation and Oncology, Siriraj Hospital for their knowledge, helps and supports. Finally, we wish to thank all of patients who provided valuable information which is the most important thing in this work.

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Original Articles/นิพนธ์ต้นฉบับ

เปรียบเทียบวิเคราะห์การวางแผนการรักษาแบบสามมิติทั่วไป ในผู้ป่วยมะเร็งปอดโดยใช้โฟตอนพลังงานสูง 6 และ 10 MV

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บทคัดย่อ

บทนำและวัตถุประสงค์: เพื่อเปรียบเทียบผลการวัดปริมาณรังสีของขอบเขตที่ครอบคลุม (PTV) และอวัยวะที่มีความเสี่ยง (OAR) และเพื่อศึกษาเชิงปริมาณขอบเขตที่ครอบคลุมในการฉายรังสีสามมิติ ระหว่างระดับรังสีโฟตอนพลังงาน 6 และพลังงาน 10 เมกกะโวลต์ สำหรับการวิเคราะห์ผู้ป่วยโรคมะเร็งปอด

วิธีการศึกษา: การศึกษาครั้งนี้ใช้ข้อมูลจากการเก็บข้อมูลผู้ป่วยโรคมะเร็งปอด 12 คน ที่ไม่ใช่เซลล์ขนาดเล็ก และได้รับ 4D-CT สแกนที่หน่วยรังสีรักษาและมะเร็งวิทยาโรงพยาบาลศิริราชระหว่างเดือนมีนาคม 2552 และสิงหาคม 2554 ผู้เชี่ยวชาญด้านเนื้องอกวิทยารังสีใช้เครื่องของ Varian Eclipse V. 8.6 ในการวัดปริมาณรังสีของก้อนมะเร็ง (CTV) ปริมาณรังสีของก้อนมะเร็งรวมกับบริเวณต่อมน้ำเหลืองข้างเคียง (GTV) และปริมาณรังสีบริเวณที่ฉายรังสี (PTV) หลักการทำงานของการฉายรังสีแบบสามมิติ ที่ระดับรังสีโฟตอนพลังงาน 6 และพลังงาน 10 เมกกะโวลต์ โดยก้อนมะเร็งจะได้รับปริมาณรังสีร้อยละ 95 ของการวางแผนทั้งหมด ควรจะได้รับอย่างน้อย 60-66 Gy และปริมาณสูงสุดสำหรับการทดลองเท่ากับร้อยละ 107 ของปริมาณรังสีที่กำหนด

ผลการศึกษา: กลุ่มตัวอย่างรวมทั้งหมด 12 คน ซึ่งเป็นผู้ป่วยที่มีคุณสมบัติเหมาะสมสำหรับการวิเคราะห์ พบว่าการฉายแสง ที่ระดับพลังงาน 6 และ 10 เมกะวัตต์ ในการรักษามีปริมาณรังสีสูงสุดไม่แตกต่างกันอย่างมีนัยสำคัญทางสถิติ โดยมีค่าเฉลี่ย 70.358 และ 68.783 Gy สำหรับค่าเฉลี่ยของปริมาณรังสี พบว่าไม่มีความแตกต่างกันอย่างมีนัยสำคัญทางสถิติ (P = 0.948) โดยมีค่าเฉลี่ยของปริมาณรังสี ที่ระดับพลังงาน 6 และ 10 เมกะวัตต์ ที่ 64.667 และ 64.542 Gy นอกจากนี้ผลการวิเคราะห์การฉายแสง ที่ระดับพลังงาน 6 และ 10 เมกะวัตต์ที่แตกต่างกันไม่ได้ส่งผลต่อ dose for spinal cord, dose for esophagus และ dose for lung (P = 0.934, 0.971 และ 0.970 ตามลำดับ) dose for spinal cord มีค่าเฉลี่ย 42.250 และ 42.067 Gy ส่วน dose for esophagus มีค่าเฉลี่ย 24.567 และ 24.475 Gy และ dose for lung มีค่าเฉลี่ย 15.875 และ 15.808 Gy

สรุป: การใช้โฟตอนพลังงานสูง 10 เมกกะโวลต์ ประสบความสำเร็จในการควบคุมเนื้องอก เช่นเดียวกับการใช้โฟตอนพลังงานสูง 6 เมกกะโวลต์ โดยภาวะแทรกซ้อนที่เกิดขึ้นมีผลไม่แตกต่างกันมากนัก เช่นเดียวกับการประหยัดการสูญเสียเนื้อเยื่อปกติ

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