EVALUATION OF DOSIMETRIC EFFECT OF RESPIRATORY GATING ON LUNG IMRT DELIVERY

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ABSTRACT

Purpose: For treatment of 3 dimensional conformal or intensity modulated radiation therapy (IMRT) of lung cancer, it is essential that respiratory gating is used to reduce the margins of clinical target volume (CTV). In this study, we evaluate the accuracy of dose in gated-IMRT when dynamic multileaf collimator (DMLC) mode was selected.

Materials and Methods: The Real-time Positioning Management (RPM) respiratory gating was installed on General Electric computed tomography (CT) simulator to view the movement of tumor and the other one gating on Varian Clinac 23 EX linear accelerator to deliver the dose at selected phases of breathing. The beam intensities of IMRT are varied by using DMLC which this mode of MLC may be introduced the dose errors from leaf lag and this error may be exacerbated when the gating is used. The 1 cm leaves gap and wedge shape patterns were created by using MLC shaper software to verify the accuracy of dose in gating method. These patterns were compared between gated and nongated delivery at 300 monitor unit/min dose rate and 1.25 cm/s leaves speed. For gated delivery, the mechanical motion device which Varian supplied was placed nearby the solid water phantom to simulate the breathing motion. Kodak X-Omat Verification (XV) film was employed to measure dose distributions of these patterns, while enhance dose range (Kodak EDR2) film and 0.13 cm3 ionization chamber with DOSE1 dosemeter were used for a lung IMRT pre-treatment verification. OmniProTM I'mRT software was the tool to analyze the film, 3% dose difference at low dose gradient region and 3 mm distance of isodose difference at high dose gradient region (3/3) were set in the clinical criteria for quantitative evaluation of dose distributions.

Result: The Kodak X-Omat V films of a 1 cm wide leaf gap sliding across a 10 cm wide field of undergated and nongated showed the uniform dose distribution across the field. The comparison of central axis profile was almost congruent and there are a few area that 3/3 is higher than unity. For 14x14 cm^2 wedge field, no gamma value higher than unity appeared, while the isodose comparison also well result. In case of lung IMRT QA, the ratio of point dose from chamber between gated and nongated was 1.0033 which is so minute discrepancy. EDR2 film confirmed the impression result because it showed small area that $\gamma_{3/3}$ larger than unity and isodose lines of both gated and nongated were nearly congruent too.

CTV = Clinical Target Volume
DMLC = Dynamic Multileaf Collimator
RPM = Real-time Positioning Management
IMRT = Intensity Modulated Radiation Therapy

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Conclusions: For moderate dose rate of 300 MU/min, the dosimetric difference between with and without gated DMLC deliveries was so small. So, the repeat beam-on and beam-off from Real-time positioning management (RPM) gating have insignificant impact on the dosimetry of DMLC-IMRT.

INTRODUCTION

Intensity modulated radiotherapy (IMRT) is a state-of-the-art cancer treatment method that delivers high doses of radiation to cancer cells while sparing the surrounding healthy tissue. The dynamic multileaf collimator (DMLC) is one of the IMRT delivery mode in which the leaves continuously move and shape the beam intensity while the radiation is turned on.

Intrafraction motion is one type of organ motion that is so influential in the treatment technique of IMRT and image guide radiotherapy (IGRT). This type of motion can be caused by three main systems that are the respiratory, skeletal muscular, cardiac and gastrointestinal system but the most significant is the first one because the respiratory motion is one potential source of error in radiotherapy.[1] During normal respiration, internal anatomy motion can be significant in some instances up to several centimeters[2] especially in lung tumor. Bernes et al.[3] found the average motion of tumor in the lower lung lobe to be significantly greater than other lobes (18.5 mm vs 7.5 mm average superior/inferior direction).

Respiratory gating is a new technique in radiation therapy (4D radiotherapy; time is the 4th dimension in radiotherapy) where the radiation is selectively at a moving target as a patient breath. The goal of this technique is to reduce the motion by synchronizing the dose delivery from a treatment accelerator with patient breathing so the clinical target volume (CTV) to planning target volume (PTV) margins for treatment planning should be reduced too. Controlling the motion of tumor may improve the precision of the dose delivery, thereby sparing more normal tissue complication probability. Paul JK et al[4] founded that dosimetric reductions for the cord, heart, and lungs were found for 4D planning compared with 3D planning. The principle of respiratory gating technique is to deliver radiation in a small window of each gating cycle at the phases where tumor moves so less. Alternative methods to reduce respiration induced motion include deep inspiration breath hold (DIBH),[5] active breathing control (ABC) with airflow valves,[6] and the use of abdominal pressure.[7] Xia et al[8] studied the communication lag between treatment console and MLC workstation in IMRT technique. They founded that DMLC increases the dose variations at high dose rate and low monitor unit.

The operation of linear accelerators in conjunction with DMLCs has been extensively studied. Jun Duan et al[9] studied about the effect of leaf lag, a delay in the communications between the DMLC and the accelerator, on the accuracy of dose delivered in gated IMRT at various respiratory rate, dose rate, and leaf speed. The results showed that low dose rates, slow leaf speeds and low frequencies of beam interruptions reduce the effect of delay-and-catch-up cycle. The purpose of this study was to investigate the dosimetric effect of DMLC on gated and nongated delivery at 300 MU/min which is the dose rate used to treat all the patients.

MATERIALS and METHODS

A Varian Clinac 23 EX linear accelerator (Varian Medical Systems, Palo Alto, CA) with 120 leaves was employed in this study. The width of leaves is 5 mm at the central 20 cm and 1 cm at the 10 cm outer of each side for the maximum field size of 40x40 cm^2. This machine can use the MLC in both segmented multileaf collimator (SMLC) mode and dynamic multileaf collimator (DMLC) mode but the latter one was chosen for IMRT treatment in our institute and in this study also. The delay between the accelerator and DMLC was reported to be 50 to 80 ms.[10] The limitation of our leaf speed is set at 2.5 cm/

s and the leaf position tolerance at isocenter is set at 0.05 cm following the recommendation of Varian Company.

The Real-Time Position Management (RPM) Respiratory Gating System (Varian Medical Systems, Palo Alto, CA) consists of (a) a wall-mounted infrared illuminator and charge-coupled device camera; (b) a reflective external marker placed on the patient's chest or abdomen; (c) a PC workstation to process the patient breathing signals; and (d) a trigger to the linear accelerator or CT simulator as shown in figure 1.

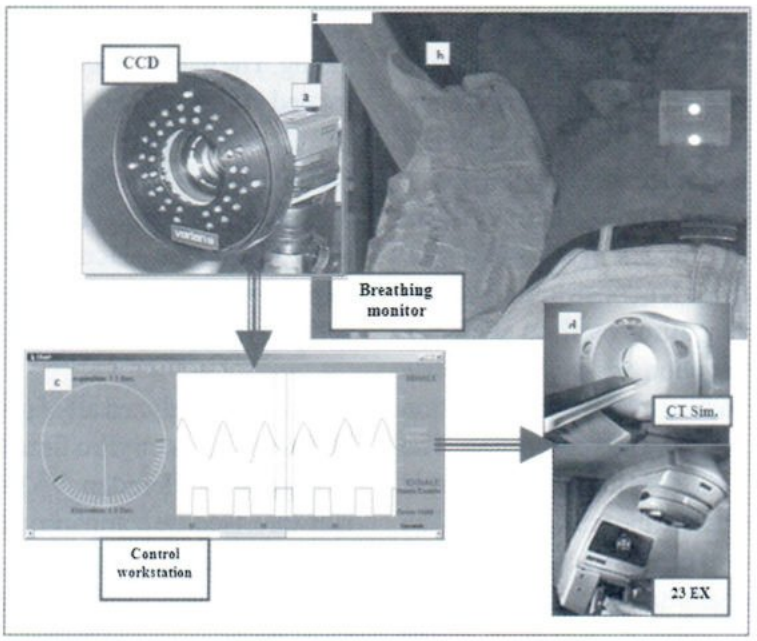


Fig. 1 A pictorial schematic of the functioning of the Varian RPM system.

To evaluate the accuracy of dose of the respiratory gating system, we divided our experimental into to 3 parts.

First, the DMLC pattern was made by the 1 cm wide leaf gap sliding across a 10 cm wide field. This DMLC file was generated by MLC shaper software that supplied from Varian. Fifty-six monitor unit (MU) was exposed at 300 MU/min, this dose rate corresponds to 1.25 cm/s DMLC leaf speeds.

Second, the pattern was made by the 14 cm wide wedge field shaped by opening leaf gap in DMLC mode. Forty MU was delivered to our detector in order to get the leaf speed at 1.25 cm/s also. Kodak X-Omat V (XV), Eastman Kodak Company, Rochester, NY, was used as a film dosimetry to measure the dose distributions in planar plane for both 1 cm wide leaf gap and wedge field shaped. Dose delivered to the rectangular solid water phantom at 5 cm depth with source-to-axis -distance technique between gated and nongated were compared. For gated delivery, however, we do not have a moving phantom to simulate the patient breathing. So, we applied a mechanical motion device with the infrared reflective marker box which Varian supplied as part of its' RPM system to use in this experimental. This device was placed near the stationary solid water phantom and moves sinusoidally in cranio-caudal direction.

Finally, we used the IMRT plan of lung cancer patient to verify the accuracy of dose distribution for gating method. A patient in this study is a 61-year-old male with the diagnosis of stage I T2N2M1 non-small lung cancer thigh metastasis. At the time of simulation, patient was immobilized in the supine position on a Vac-Loc (Med Tech Inc., Orange City, IA) with his

arm raised over his head. The video camera tracks respiratory motion by monitoring the markers that were attached halfway between the xiphoid tip and the umbilicus of patient. The corners of the block were then drawn by permanent ink on the skin to ensure reproducible positioning of the block during the remainder of the simulation during all treatments. A GE LightSpeed RT CT simulator (GE Medical Systems, Milwaukee, WI) was used to scan in cine mode with retrospective gating. The gating system sends the patient breathing signal to Advantage 4D software in order to synchronize this signal with CT images. Advantage 4D software showed the movement of tumor volume on CT images in all directions. Figure 2 shows the scan and reconstruction of this patient in retrospective gating method with CT simulator machine. The duration of x-ray in ON mode is equal to the average breathing cycle plus the duration of data acquisition for an image reconstruction. The duration of x-ray in OFF mode is the period for table translation from one position to the next position. The gating system provides two modes of operation, base either on the phase of breathing cycle or on the trace amplitude. Phase-based gating was chosen and we divided the images to 10 phases (peak inhale = 0% phase, peak exhale = 50% phase). Maximum intensity projection (MIP) images were created from Advantage 4D software then these MIP images were exported to Eclipse planning software to be used for IMRT planning. At the linear accelerator machine, the gating system sends the gating signal to the machine to trigger beam hold-off when the target volume moves beyond the preset limits. The treatment phases were selected by the radiation oncologist. For this case, the 30%-80% phases were selected because the end-expiration is more reproducible than inspiration. Pre-treatment IMRT verification plans were performed by using extended dose range 2 (EDR) film and ion chamber in solid water phantom both with and without gating. The gantry, collimator, and couch angles were rotated to zero degree. A 0.13 cm^3 ionization chamber (IC 13, Scanditronix Wellhofer, Schwarzenbruck, Germany) was placed at 10 cm depth for point dose measurement using with DOSE1 dosemeter while a EDR2 film was placed at isocenter point of 5 cm depth for planar dose measurement as shown the setup in figure 3.

We analyzed all of our films by using a Vidar VXR-16 DosimetryPro film digitizer (Vidar Systems Corporations, Herndon, VA) and OmniProTM I'mRT software. Isodose comparison for the dose distributions between gated and nongated was evaluated. Moreover, gamma (γ) was used for quantitative comparison. Gamma is an index proposed by Low et al.[11] for quantitative evaluation of dose distributions. $\gamma_{3/3}$ (3% dose difference at low dose gradient region and 3 mm distance of isodose difference at high dose gradient region) was set in the clinical criteria. The area that γ value was higher than unity means that the dose different between gated and nongated is out of the criteria.

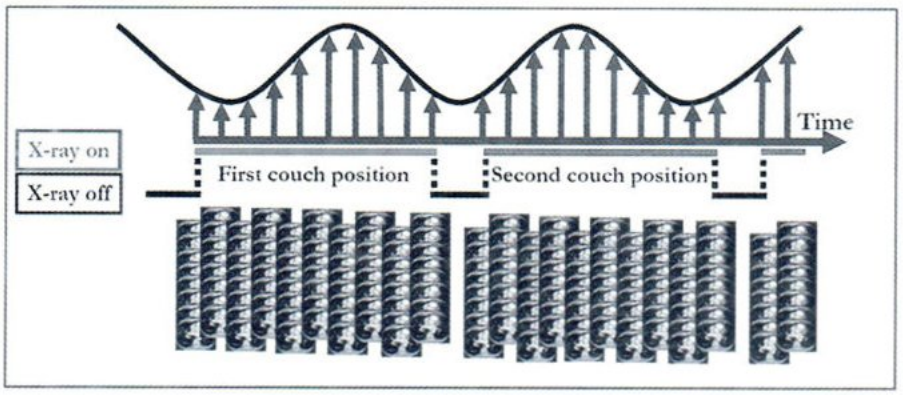


Fig.2 The scanning and image reconstruction of 4D CT in retrospective method.

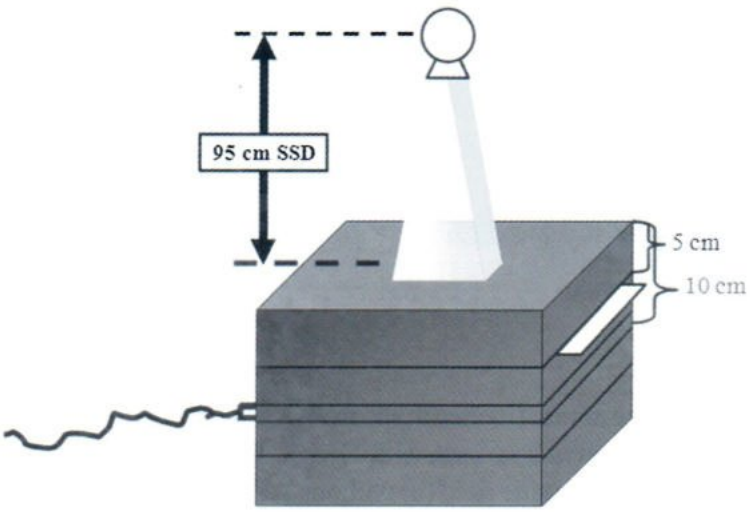


Fig.3 The phantom setup for pre-treatment IMRT verification.

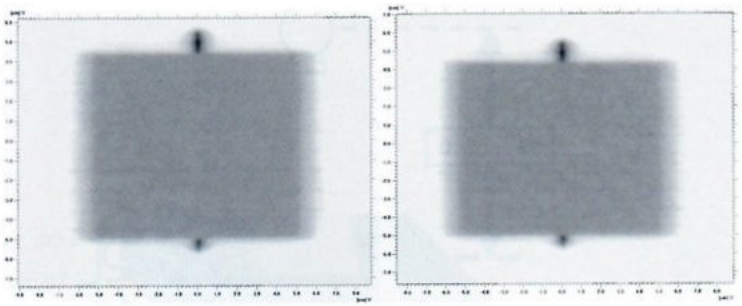
RESULTS AND DICUSSION

The dose error by respiratory gating depends on several factors such as the respiratory rate, dose rate, or leaf speed but in this experiment we studied at only dose rate of 300 MU/min. For the DMLC mode, when the beam is turn on, the leaves are not move immediately but their remains stationary and then moving accelerate to their leaves speed. While the beam off trigger by gating, the leaves do not stop instantly but they also moving forward decelerate to stop. When the beam is on again, the leaves starting from the position where they are overdue.

The dose distributions in this experiment are shown in figure 4. Its comprise of a) 1 cm gap sliding across a 10 cm wide, b) 14x14 cm^2 opening wedge, and c) lung IMRT plan.

a b c

Fig.4 a,b,c Fluence maps from treatment planning of a) 1 cm wide DMLC leaf gap sliding across a 10 cm wide field, b) 14 cm wide opening wedge field, and c) lung IMRT field.



a b

Fig.5 The actual fluence maps from Kodak X-Omat V films delivered by a 1 cm wide DMLC leaf gap sliding across a 10 cm wide field (a) without and (b) with gating of 30 -80% phases.

Figure 5 shows the actual fluence maps of a 1 cm wide DMLC leaf gap sliding across a 10 cm wide field on Kodak X-Omat V films by (a) nongated and (b) gated deliveries at a dose rate of 300 MU/ min and a leaf speed of 1.25 cm/s after 40 MU exposed. Both films show the uniform dose distribution across the field. Dose profiles along the midline across these two plans are shown in figure 6. The red line represents of without gate delivery while green one means gate delivery. The doses without gated were normalized to central axis. The profiles are nearly congruent while the $\gamma_{3/3}$ shows so less gamma value higher than unity.

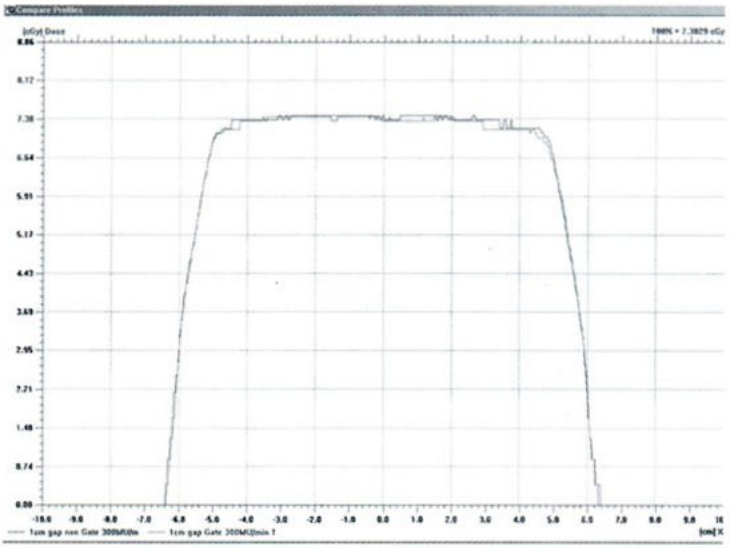


Fig.6 Dose profile comparison between gated and nongated at the center of field across the beams in Fig. 5.

The results of 14x14 cm^2 single wedge shapes between gated and nongated delivery are shown in figure 7. Left upper quadrant is the fluence from XV film of 14x14 cm^2 wedge fields for nongated delivery, left lower quadrant is under gated delivery, right upper quadrant shows isodose comparison between these fluences, and the last quadrant shows the gamma value with the limit of 3% dose difference and 3 mm

distance. It will appear as a dot if gamma value is not in a limit (the value greater than1). Fifty-six MU was delivered at 300 MU/min which this dose rate is correspond to 1.25 cm/s DMLC leaf speeds. A 15 cycles/min respiratory rate and 1.0 sec gating window that center at the end of expiration were used in gated delivery. Isodose distributions of gated beam are overlain on those with nongated beam to check the dose differences. The dose discrepancy between them is very small as shown in isodose comparison and no $\gamma_{3/3}$ values higher than unity.

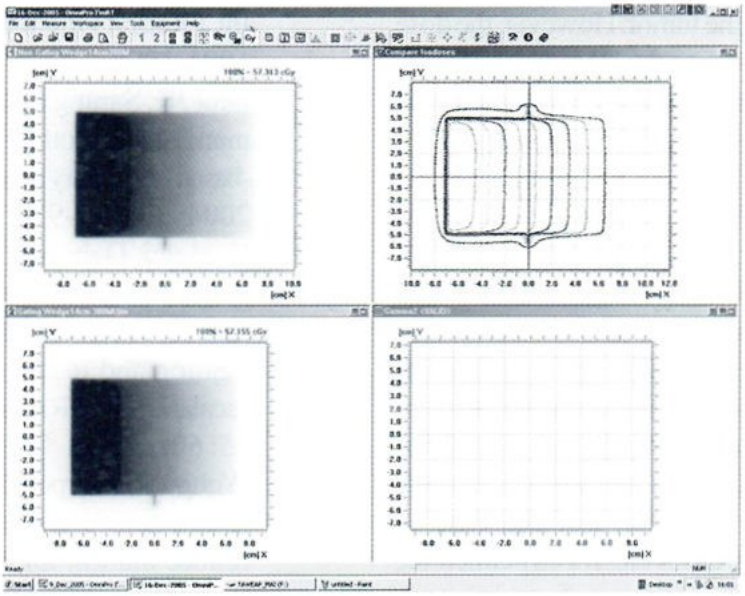


Fig.7 OmniProTM I'mRT software for film analysis and comparisons.

The lung IMRT field presented in figure 8 demonstrates the difference between IMRT dose distributions delivered at 300 MU/min to a solid water phantom on gated and non gated. Isodose distributions delivered on gated and nongated were overlain for comparison. Solid lines represent isodose lines for nongated delivery and dashed ones for gated delivery. These data were measured by using the EDR film for planar dose verification and the ion chamber for point dose verification. For planar dose measurement, the $\gamma_{3/3}$ showed very minute value higher than unity that is congruent of these isodose lines. For point dose measurement, the dose from chamber of gated and nongated are 171.87 and 171.31 cGy, respectively, while from planning is 175.8 cGy.

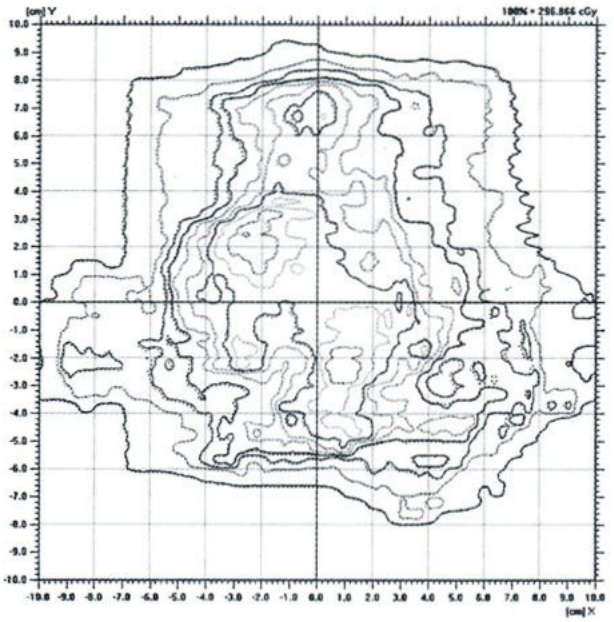


Fig.8 Isodose overlaying of a lung IMRT field delivered to a solid water phantom between under respiratory gating (solid lines) and no respiration gating (dashed lines).

For lung tumor patient, the respiration during radiation treatment may be induced tumor movement. Adequate margins must be established around the CTV to account for tumor motion but the normal surrounding tissues are increasing irradiated. The use of the RPM gating system significantly reduced the size of the margins by turning the beam on and off based on the motion of the tumor. However, the dose errors may be occurred when the DMLC is used and these errors may be exacerbated when the gating is used due to delay-and-catch up phenomenon.

CONCLUSION

The fluence of 1 cm leaf gap across 10 cm on film should be shown the pattern of cold strips in every step that the beam is on. Figure 5 And figure 6, however, show the smoothing fluence across the film and congruence of beam profiles, it can be noted that error of dose at 300 MU/min dose rate at 1.25 cm/s leave speed is insignificantly. For the case of wedge-shaped, this pattern is clearer explained the delay-and-catch-up phenomenon because each position has the difference dose. Anyway, in this study, the data shows satisfied result as presented in figure 7. Therefore, the dose distribution in gated delivery agrees with a reference dose distribution in nongated delivery within the clinical criteria. The results are confirmed again by clinical IMRT results as shown in planar and point dose measurements. Lung IMRT fields are generated by sweeping leaf gaps across the field, requiring both banks to move. The ratio of dose from ionization chamber between gated to nongated deliveries is 1.0033 that is very small dose discrepancies due to lags of the leaves.

In summary, the dose rate of 300 MU/min that we used seems to be a good compromise so that the leaf lag has no effect to the isodose distribution.

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