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Performance Evaluation of the Tumor Tracking Method Using Beam on/off Interface for the Treatment of Irregular Breathing

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ABSTRACT

Dose rate regulated tracking is known to be an efficient method which adaptively delivers tracking treatments when patient breathing is irregular. The Motion Management Interface (MMI, Varian Medical System, CA), which provides beam on/off switching during treatment is available for clinic. Study is to test if delivering the adaptive tumor tracking is feasible for irregular breathing using beam switching with MMI. 55 free breathing RPM traces acquired from lung cancer patients are used. The first day RPM traces of the patients are utilized to design preprogrammed tracking MLC patterns, of which periods are intentionally reduced by 20% in order to catch up the variation of patient breathing irregularity in the treatment day. Eligibility criteria for this technique are the variation of amplitude and period less than 20%. An algorithm which determines beam on/off every 100 ms by considering the preprogrammed (MLC) positions and current breathing positions is developed. Tracking error and delivery efficacy are calculated by simulating the beam-switching adaptive tracking from the RPM traces. Breathing patterns of 38 patients (70%) met the eligibility criteria. Tracking errors of all of the cases who meet the criteria are less than 2 mm (average 1.4 mm) and the average delivery efficacy was 71%. Those of rest of the cases are 1.9 mm and 48%. Adaptive tracking with beam switching is feasible if patient selection is based on the eligibility criteria.

Keywords: Motion Management Interface (MMI), Multi-Leaf collimator (MLC), tumor tracking.

Ⅰ. INTRODUCTION

Thoracic and abdominal tumor motions induced by respiration make it hard to deliver precise treatment delivery as planned due to the systematic uncertainty and the respiration abnormality. A variety of motion management technologies have been proposed for the promising solution.[1-5] Respiratory gating methods can deliver radiation treatment as regards to a specific part of the patient's breathing cycle (referred to as gate), where radiation beam is activated only when the respiratory motion is within a predefined amplitude or phase level.[3,6,7] Breath-hold methods, exemplified by the deep inspiration breath hold (DIBH), have been widely used for lung cancer radiotherapy accompanying with spirometer-monitored technique, where the treatment beam will be delivered only if the target breath-hold level is reached; otherwise, the treatment is withheld.[8] Active breath control (ABC), similar to DIBH, use digital spirometer to measure the respiratory trace, where the physician set patient's lung volume and stage of breathing phase to make active the system.[9] Real-time tumor tracking is more advanced where the treatment beam should be adjusted according to current respiration in real time so that it can compensate for the discrepancy between the planning process and the current delivery process through real-time organ motion monitoring.[3,4,10,11] A

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multileaf collimator (MLC) is a sophisticated system to provide conformal shaping of radiotherapy treatment beams.[2,4,5,12] Papiez et al., suggested the formulas of the dynamic multileaf collimator (DMLC) delivery for moving targets and variable beam dose rate[5]. The limitation of Papiez et alapproach is to require extending beam dose rate utilized in commercial DMLC technology. It may not be practical to use for the clinical purpose in the near future. Yi et al., proposed the principle of dose-rate -regulated tracking (DRRT) method, combining a preprogrammed delivery sequence and the dose rate regulation algorithm.[4] DRRT should adjust the dose rate to catch up the newly arrived breathing patterns, where DRRT can be emulated with external system interface by permitting a beam switching signal, i.e., beam hold to pause the beam without causing a beam-off. DRRT has been proved to be suitable to adapt tracking MLC sequences to breathing irregularities in order to achieve dose rate regulation during treatment.[11,13]

This paper is focused on the practical implementation of the adaptive tumor tracking using beam switching. The beam switching can be achieved from gating interface or from the motion management interface (MMI, Varian Medical System, CA). If adaptive tumor tracking is feasible using beam switching, then MMI can be used for the purpose of the adaptive tumor tracking. The previous research showed that DRRT compensates for inter- and intra-fractional period variations of tumor motion. The delivery efficacy defined as the ratio of beam-on time to the total treatment time is often about 30 - 50% for a typical gated 3D CRT treatment, whereas the delivery efficacy in DRRT remains more than 86% for period variations so that the adaptive tracking can be possible if we use beam switching.[1,13]

DRRT is known to be an efficient method which adaptively delivers tracking treatments when patient breathing is irregular.[4,11,13] This study is to test if delivering the adaptive tumor tracking is feasible for irregular breathing using beam switching with MMI.

Ⅱ. MATERIAL AND METHODS

1. Tumor motion traces and MLC sequences

Fifty-five free breathing RPM traces acquired from lung cancer patients are used for the feasibility test of MMI to implement DRRT. The first day RPM traces of the patients are utilized to design tracking MLC patterns, of which periods are intentionally reduced by 20% in order to catch up the variation of patient breathing periods in the treatment day. Eligibility criteria for this technique are the variation of amplitude and period less than 20%.

2. Beam Switching Interface System

MMI (Varian Medical System, CA, USA) is a commercially available system to provide a flow of selected treatment data from the linear accelerator (Linac) machine out to an external system, as shown in Fig. 1. The Linac machine can transmit treatment information (e.g. real-time MU, beam status, machine status) to external system using a dedicated serial port at 100 millisecond intervals. In addition, there exists a control path which allows the external system to change the Linac beam generation state, i.e. beam switching (beam hold). This beam switching function provides the external system with temporal capability of beam stop without disturbing the treatment procedure[14].

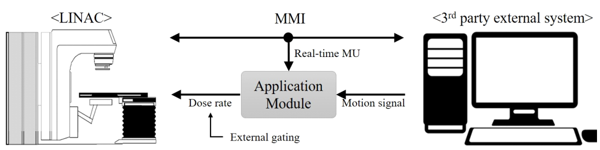


Fig. 1. The overview of beam switching interface system.

The proposed tumor tracking method operate with two folds; 1) received the selected treatment data using the dedicated serial port from Linac machine, and the motion signal from the external system (e.g. RPM, Calypso, or Vision RT), 2) sent out the beam switching signal temporarily to hold the beam for the purpose of controlling the dose rate during treatment.

3. Tumor tracking algorithm

The first day RPM traces of the patients are utilized to design tracking MLC patterns, which periods are intentionally reduced by 20% in order to catch up the variation of patient breathing periods in the treatment day. All the breathing traces are categorized into two groups based on eligibility criteria, i.e., Group A (70%): thirty-eight breathing traces with less than 20% of intra-fractional variation for amplitude/baseline drift and with the baseline drift range being less than amplitude, and Group B (30%): seventeen breathing traces with more than 20% of intra-fractional variation for amplitude/baseline drift or with the baseline drift range being more than amplitude.

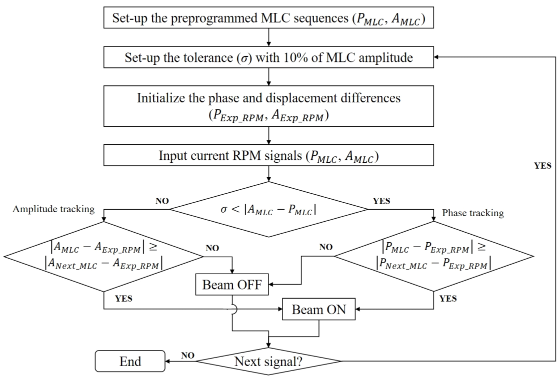


Fig. 2. Flow chart of the tumor tracking algorithm.

We used phase and displacement information for the tumor tracking, as shown in Fig. 2. We set up 10% displacement tolerance of MLC Amplitude to switch from phase tracking mode to displacement tracking mode or vice versa. We set up the expected phase and displacement values (P_{Exp_RPM} and A_{Exp_RPM}) based on the incoming current RPM signals. If the difference between the current RPM displacement and the current MLC displacement is less than the tolerance, the algorithm conducts the adaptive tumor tracking on the phase mode; otherwise it works based on the displacement mode.

In the phase tracking mode, we implemented the algorithm by comparing the phase difference between the expected tumor phase (P_{Exp_RPM}) and the current MLC phase (P_{MLC}) (or the next MLC phase (P_{Next_MLC}) after 100ms). If the phase difference between the expected tumor phase (P_{Exp_RPM}) and the current MLC phase (P_{MLC}) is greater than the phase difference between the expected tumor phase (P_{Exp_RPM}) and the next MLC phase (P_{Next_MLC}), the radiation beam is on and the MLC sequence follows tumor motion as planned.

In the amplitude tracking mode, we implemented the algorithm by comparing the displacement difference between the expected tumor displacement (A_{Exp_RPM}) and the current MLC displacement (A_{MLC}) (or the next MLC displacement (A_{Next_MLC}) after 100ms). If the displacement differences satisfy the following condition, i.e. $|A_{MLC}\text{-}AE_{xp\_RPM}| \geq |A_{Next\_MLC}\text{-}A_{Exp\_RPM}|$ the radiation beam is on and the MLC sequence follows tumor motion as planned. If the MLC sequence is located in the maximum position and tumor position is not, the beam will be hold until the tumor position is within the tolerance.

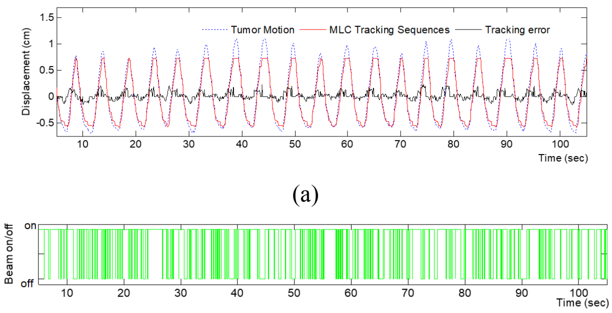
4. Measurements

For the real beam delivery with the proposed tracking method, we implement the breathing sequences into the moving phantom (MotionSim, Sun Nuclear Corp., FL, USA). The phantom consists of the platform table, which motion is designed for the real-time breathing motion of patients, and the gating surrogate, that is designed to control the beam hold signals with breathing surrogate. For the real-time breathing motion of patients, we used three variables, i.e. breathing period, amplitude, baseline drift, by changing these variables within 10% of standard breathing pattern. The standard breathing pattern has the following characteristic, breathing period 13.5 sec, amplitude 5 cm, no baseline drift. The breathing period varied from 12 to 15 seconds. The amplitude varied from 4.5 cm to 5.5 cm. The baseline drift is changed within ± 5 mm that is in 10% range of breathing amplitude.

Ⅲ. RESULT AND DISCUSSION

70% of patients (Eligible group) get 71% average delivery efficacy and 1.4 mm average displacement error. Fig. 3 shows a typical tracking result with beam switching method signals. The preprogrammed MLC sequences are adjusted based on the phase and amplitude information of the lung cancer patient. The delivery efficacy and the mean of tracking error are 68.75% and 0.7 mm, respectively.

Table. 1 shows the average results of the patient groups including 'Eligible group' and 'Ineligible group' about three variables which are period, amplitude and baseline drift. Let us assume that there exist some patients with average tracking error 2 mm and average delivery efficacy 60%. The null hypothesis is accepted when the p-value is greater than 0.05. As shown in Table. 1, p-value of mean error and delivery efficacy are less than 0.05 in the eligible group. This value is considered to be extremely statistically significant. That means we can deliver treatment beam with satisfying the tracking error less than 2 mm and the delivery efficacy more than 60% if the breathing irregularity of the patient is less than 20% of intra-fractional variation for amplitude/baseline drift.



(b)

Fig. 3. Result of irregular motion adaptive tumor tracking with Beam Switching: (a) Tumor motion (blue dotted), MLC tracking signal (red solid) and tracking error (black solid) (b) Pattern of beam on/off for adaptive tracking with switching.

Table 1. Average results of eligible and ineligible groups about three variables

	Period (sec)	Period Variation (%)	Amplitude (mm)	Amplitude Variation (%)	Baseline drift (mm)	Mean Error (mm)	Delivery Efficacy (%)
Eligible Group	4.9	4.2	6.6	14.7	3.5	1.4	71.7
Two-tailed p-value						0.0001	0.0001
Ineligible Group	4.5	19.1	6.8	22.7	7.0	1.9	48.6
Two-tailed p-value						0.7106	0.0001

Fig. 4 shows the delivery efficacy and the mean of tracking error for all the breathing traces using a beam switching interface. Here, we define the ratio as the baseline drift range over amplitude. Note that all the cases of Eligible group are with less than 2 mm tracking error and more than 60% duty cycle. On the other hand, ineligible group shows the much lower duty cycle with various tracking errors which between about 0.5 mm and 4.5 mm. It means that the patients with satisfying the eligible criteria which are the variation of amplitude and period less than 20%, can achieve decent treatment efficiency as well as considerable accuracy. The average delivery efficacy defined as the ratio of beam-on time to the total treatment time was 64 % and the maximum delivery efficacy was 86 %, regardless of the group.

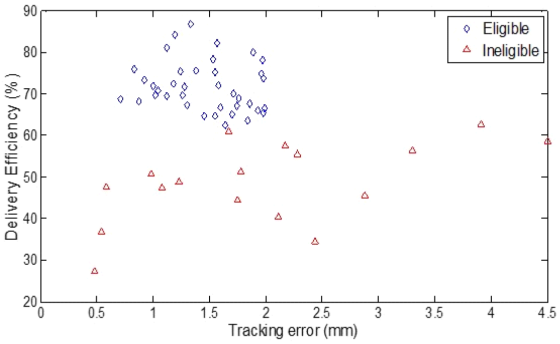


Fig. 4. Delivery efficacy and mean of tracking error of all the breathing traces using a beam switching interface. Here the blue diamond and the red triangle are for the cases eligible and ineligible, respectively.

Ⅳ. CONCLUSION

In this paper, we presented the practical imple mentation of the adaptive tumor tracking using beam switching interface used for DRRT to compensate for the breathing irregularities. The results showed that the patients with satisfying the eligible criteria can get 71% average delivery efficacy and 1.4 mm average displacement error.

The study revealed that the adaptive tumor tracking was feasible using beam switching interface. The average delivery efficacy defined as the ratio of beam-on time to the total treatment time was 64% and the maximum delivery efficacy was 86%. This tracking technique using beam switching interface potentially offers an effective and sophisticated method to minimize the total treatment time and the irradiation of healthy tissues in contrast to the typical gated 3D CRT treatment system.

Reference

[1] S. B. Jiang, “Technical aspects of image-guided respi ration-gated radiation therapy,” Medical dosimetry, Vo l. 31, No. 2, pp. 141-151, 2006.

[2] P. J. Keall , H. Cattell, D. Pokhrel, S. Dieterich, K. H. Wong, M. J. Murphy, S. S. Vedam, K. Wijesoori ya, R. Mohan, “Geometric accuracy of a real-time tar get tracking system with dynamic multileaf collimator tracking system,” International Journal of Radiation O ncology Biology Physics, Vol. 65, No. 5, pp. 1579-1 584, 2006.

[3] C. Shi, N. Papanikolaou, “Tracking versus Gating in the Treatment of Moving Targets,” European Oncolog ical Disease, No. 1, pp. 83-86, 2007.

[4] B. Yi, S. Oh, B. Berman, F. Lerma, C. Yu, “Real-ti me tumor tracking with preprogrammed dynamic mult ileaf collimator motion and adaptive dose-rate regulati on”, Medical Physics, Vol. 35, No. 9, pp. 3955-4017, 2008.

[5] L. Papiez, R. Abolfath, “Variable beam dose rate and DMLC IMRT to moving body anatomy”, Medical Ph ysics, Vol. 35, No. 11, pp. 4837-4885, 2008.

[6] P. J. Keall, G. S. Mageras, J. M. Balter, R. S. Emer y, K. M. Forster, S. B. Jiang, J. M. Kapatoes, D. A. Low, M. J. Murphy, B. R. Murray, C. R. Ramsey, M. Herk, S. Vedam, J. Wong, E. Yorke, “The manag ement of respiratory motion in radiation oncology rep ort of AAPM Task Group 76,” Medical Physics, Vol. 33, No. 10, pp. 3874-4774, 2006.

[7] H. Kubo, B. C. Hill, “Respiration gated radiotherapy treatment: a technical study,” Physics in Medicine an d Biology, Vol. 41, No. 1, pp. 83-91, 1996.

[8] D. Mah, J. Hanley, K. E. Rosenzweig, E. Yorke, L. Braban, C. C. Ling, S. A. Leibel, G. Mageras, “Tech nical aspects of the deep inspiration breath-hold techn ique in the treatment of thoracic cancer,” Internationa l Journal of Radiation Oncology Biology Physics, Vo l. 48, No. 4, pp. 1175–1185, 2000.

[9] V. M. Remouchamps, F. A. Vicini, M. B. Sharpe, L. L. Kestin, A. A. Martinez, J. W. Wong, “Significant reductions in heart and lung doses using deep inspira tion breath hold with active breathing control and int ensity-modulated radiation therapy for patients treated with locoregional breast irradiation,” International Jour nal of Radiation Oncology Biology Physics. Vol. 55,

No. 2, pp. 392–406, 2003.

[10] I. Buzurovic, K. Huang, Y. Yu, T. K. Podder, “A robotic approach to 4D real-time tumor tracking for radiotherapy,” Physics in Medicine and Biology, Vol. 56, pp.1299–1318, 2011.

[11] S. Oh, B. Yi, F. Lerma, B. Berman, M. Gui, C. Yu, “Verification of MLC based real-time tumor tracking using an electronic portal imaging device,” Medical Physics, Vol. 37, No. 6, pp. 2435-2440, 2010.

[12] A. Sawant, R. L. Smith, R. B. Venkat, L. Santanam, B. Cho, P. Poulsen, H. Cattell, L. J. Newell, P. Parikh and P. J. Keall, “Toward submillimeter accuracy in the management of intrafraction motion: the integration of real-time internal position monitoring and multileaf collimator target tracking,” International Journal of Radiation Oncology*Biology*Physics, Vol. 74, No. 2, pp. 575-582, 2009.

[13] S. Oh, B. Yi, B. L. Berman, F. Lerma, C, Yu, “Accuracy of dose-rate-regulated tracking: a parametric study,” Physics in Medicine and Biology, Vol. 55, pp. 1–13, 2010.

[14] Varian Medical Systems, Clinac 3rd Party External System Interface: Version 2, December 2005.

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호흡이 불규칙한 환자의 치료를 위한 Beam on/off Interface를 이용한 종양 추적 치료 방법의 성능 평가

이민식

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요 약

선량률을 조절하면서 종양을 추적하는 방법은 호흡이 불규칙한 환자를 치료할 때 방사선을 적응적으로 전달하는 효율적인 방법으로 알려져 있다. 이 연구에서는 빔 켜기/끄기 스위칭을 제공하는 모션 관리 인터페이스 (MMI, Varian Medical System, CA)를 이용한 불규칙 호흡에 대해 적응성 종양 추적을 시행 할 수 있는지 확인하였다. 폐암 환자로부터 획득한 55개의 호흡 정보를 사용하였다. 첫날 환자의 RPM 흔적을 사용하여 사전 프로그래밍 된 추적 MLC 패턴을 디자인하는데, 치료 기간 중 환자의 호흡 불규칙성의 변화를 따라 잡기 위해 기간을 의도적으로 20% 줄였다. 이 기술의 적정성 기준은 진폭 및 주기의 20 % 미만의 표준편차이다. 사전 프로그래밍 된 MLC 위치와 현재 호흡 위치를 고려하여 100 ms마다 빔 켜기 / 끄기를 결정하는 알고리즘이 개발되었다. 추적 오류 및 전달 효율성은 RPM 추적에서 빔 스위칭 적응형 추적을 시뮬레이션하여 계산되었다. 38 명의 환자(70%)의 호흡 양상이 적합 기준을 충족 시켰습니다. 기준을 충족하는 모든 사례의 추적 오류는 2 mm 미만 (평균 1.4 mm)이며 평균 전달 효능은 71 % 였다. 기준을 충족하지 못한, 나머지 경우의 추적오류와 전달 효율은 1.9 mm와 48% 였다. 본 연구를 통해, 환자 선택이 적격 기준을 기반으로 하는 경우 빔 스위칭을 통한 적응형 추적 치료가 가능한 것을 확인하였다.

중심단어: 움직임 관리 인터페이스 (MMI), 다엽 시준기 (MLC), 종양 추적