

## Dosimetric Analysis of Respiratory-Gated RapidArc with Varying Gating Window Times

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The gated RapidArc may produce a dosimetric error due to the stop-and-go motion of heavy gantry which can misalign the gantry restart position and reduce the accuracy of important factors in RapidArc delivery such as MLC movement and gantry speed. In this study, the effect of stop-and-go motion in gated RapidArc was analyzed with varying gating window time, which determines the total number of stop-and-go motions. Total 10 RapidArc plans for treatment of liver cancer were prepared. The RPM gating system and the moving phantom were used to set up the accurate gating window time. Two different delivery quality assurance (DQA) plans were created for each RapidArc plan. One is the portal dosimetry plan and the other is MapCHECK2 plan. The respiratory cycle was set to 4 sec and DQA plans were delivered with three different gating conditions: no gating, 1-sec gating window, and 2-sec gating window. The error between calculated dose and measured dose was evaluated based on the pass rate calculated using the gamma evaluation method with 3%/3 mm criteria. The average pass rates in the portal dosimetry plans were  $98.72 \pm 0.82\%$ ,  $94.91 \pm 1.64\%$ , and  $98.23 \pm 0.97\%$  for no gating, 1-sec gating, and 2-sec gating, respectively. The average pass rates in MapCHECK2 plans were  $97.80 \pm 0.91\%$ ,  $95.38 \pm 1.31\%$ , and  $97.50 \pm 0.96\%$  for no gating, 1-sec gating, and 2-sec gating, respectively. We verified that the dosimetric accuracy of gated RapidArc increases as gating window time increases and efforts should be made to increase gating window time during the RapidArc treatment process.

**Key Words:** Gated RapidArc, Portal dosimetry, MapCHECK2, Gamma evaluation

### Introduction

Many studies have been performed to minimize respiratory organ motion and consequent dosimetric errors in radiation treatment. The real-time position management (RPM) gating system (Varian Medical Systems, Palo Alto, CA) has been used effectively in many clinical sites. This system only irradiates tumors in a specified respiratory phase region and uses an infrared reflective marker block placed on the patient's abdomen as an indicator of tumor motion. It has also been used in intensity

modulated radiation therapy (IMRT),<sup>1-4)</sup> and many clinics perform the gating method in volumetric modulated arc therapy (VMAT) with RapidArc (Varian Medical Systems, Palo Alto, CA) to reduce the respiratory motion-induced error in the complex treatment process. RapidArc optimizes dose distribution via the combination of gantry rotation speed, dose rate, and the dynamic motion of a multi-leaf collimator (MLC). The gated RapidArc has great potential for dosimetric error than applying the gating method to three-dimensional conformal radiation therapy (3D CRT) and IMRT delivered with fixed gantry fields.<sup>5-9)</sup>

Many studies have been examined the errors that can potentially occur in gated RapidArc process and verified the effective delivery could be performed under a stable respiratory pattern.<sup>10)</sup> The respiratory pattern has many factors to keep a stable condition and a significant factor is gating window time length, which determines the total number of beam-on gates during

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treatment beam delivery. More beam-on gates during heavy gantry rotation can compromise the dosimetric accuracy of gated RapidArc.

In this study, the relationship between dosimetric errors in gated RapidArc and the number of stop-and-go gantry motions, which are inversely proportional to gating window time, was assessed. Errors were analyzed to establish the proper criteria for setting gating window time.

### Materials and Methods

Our study included 10 patients previously treated via gated IMRT for liver cancer. RapidArc plans were created for each patient using the Eclipse treatment planning system (Varian Medical Systems, Palo Alto, CA). Each plan contained two independent delivery quality assurance (DQA) plans for the measurement of integrated dose distribution during delivery. One DQA plan used an electronic portal imaging device (EPID) for portal dosimetry (the portal dosimetry plan) and the other used

a MapCHECK2 two-dimensional diode detector array (SunNuclear, Melbourne, FL) in a water-equivalent MapPHAN phantom (SunNuclear, Melbourne, FL) (the MapCHECK2 plan). After delivery, measured dos distributions were compared with calculated distributions in the two DQA plans. Error evaluation



Fig. 1. System for the DQA process with the MapCHECK2 measurement and the dynamic moving phantom for the accurate control of gating window time.

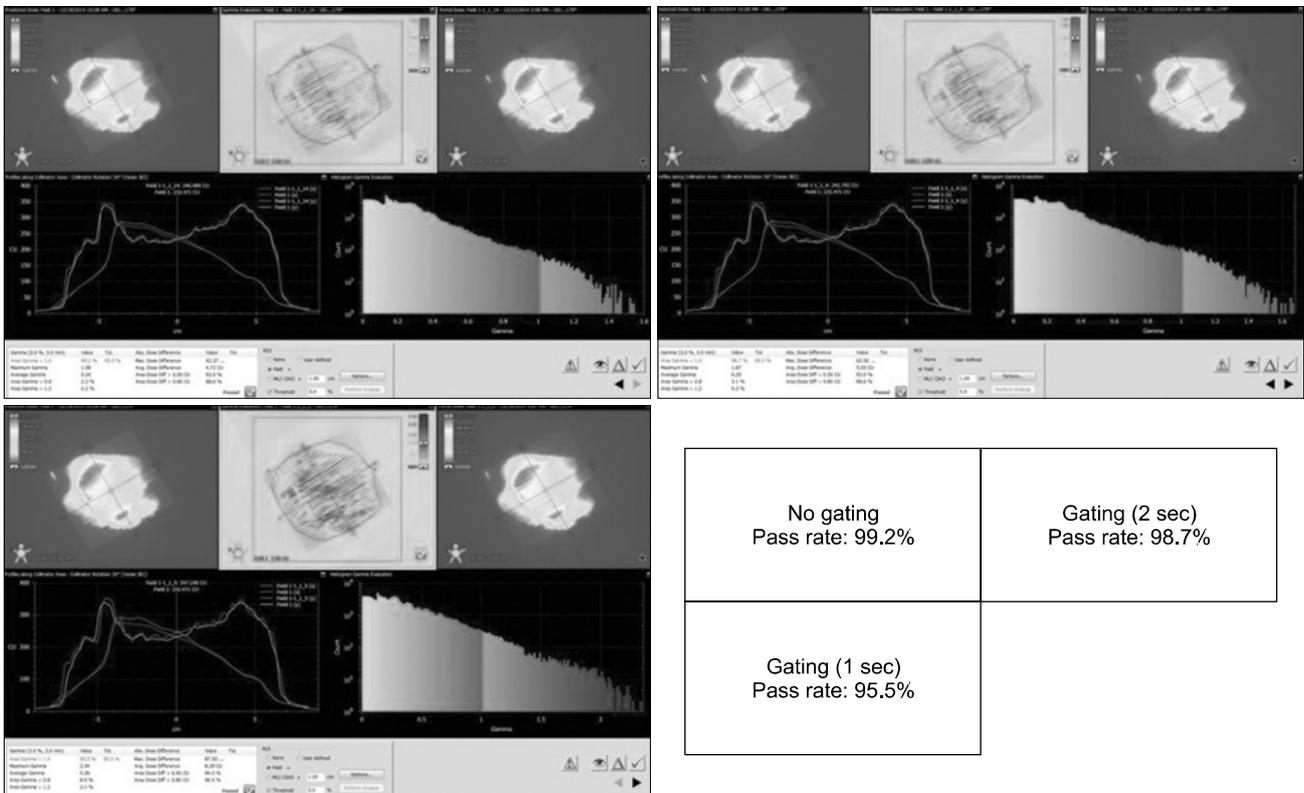


Fig. 2. Example of the DQA analysis with portal dosimetry plan in three different gating cases.

was based on the pass rate calculated using the gamma evaluation method with a 3% dose difference, and a 3-mm distance to agreement criteria.

The Dynamic Platform Model 008PL system (CIRS Inc., Norfolk, VA), which can simulate respiratory motion, was used to set up accurate gating window times. The simulated respiratory cycle in this study was 4 sec, and beams were delivered and measured in three different conditions: no gating, a 1-sec gating window, and a 2-sec gating window. Our study used the Novalis Tx linear accelerator (Varian Medical Systems, Palo Alto, CA) and, for gating, the Varian RPM system. The overall setup for measurements using the MapCHECK2 plan is shown in Fig. 1.

### Results

Example of the results obtained using the portal dosimetry

plan and the MapCHECK2 plan are shown in Fig. 2 and Fig. 3, respectively.

The dosimetric accuracy of RapidArc with no gating and 1-sec and 2-sec gating windows are shown in Table 1. The pass rate worsened as gating window time decreased.

Fig. 4 shows the results of the portal dosimetry plan. No gating produced the highest average pass rate; pass rates were  $98.72 \pm 0.82\%$ ,  $94.91 \pm 1.64\%$ , and  $98.23 \pm 0.97\%$  for no gating, 1-sec gating, and 2-sec gating, respectively.

Fig. 5 shows the results of the MapCHECK2 plan. No gating again produced the highest average pass rate; pass rates were  $97.80 \pm 0.91\%$ ,  $95.38 \pm 1.31\%$ , and  $97.50 \pm 0.96\%$  for no gating, 1-sec gating, and 2-sec gating, respectively. The mismatch between the measurement data and the planning data was lower when gating window time was longer in both DQA plans.

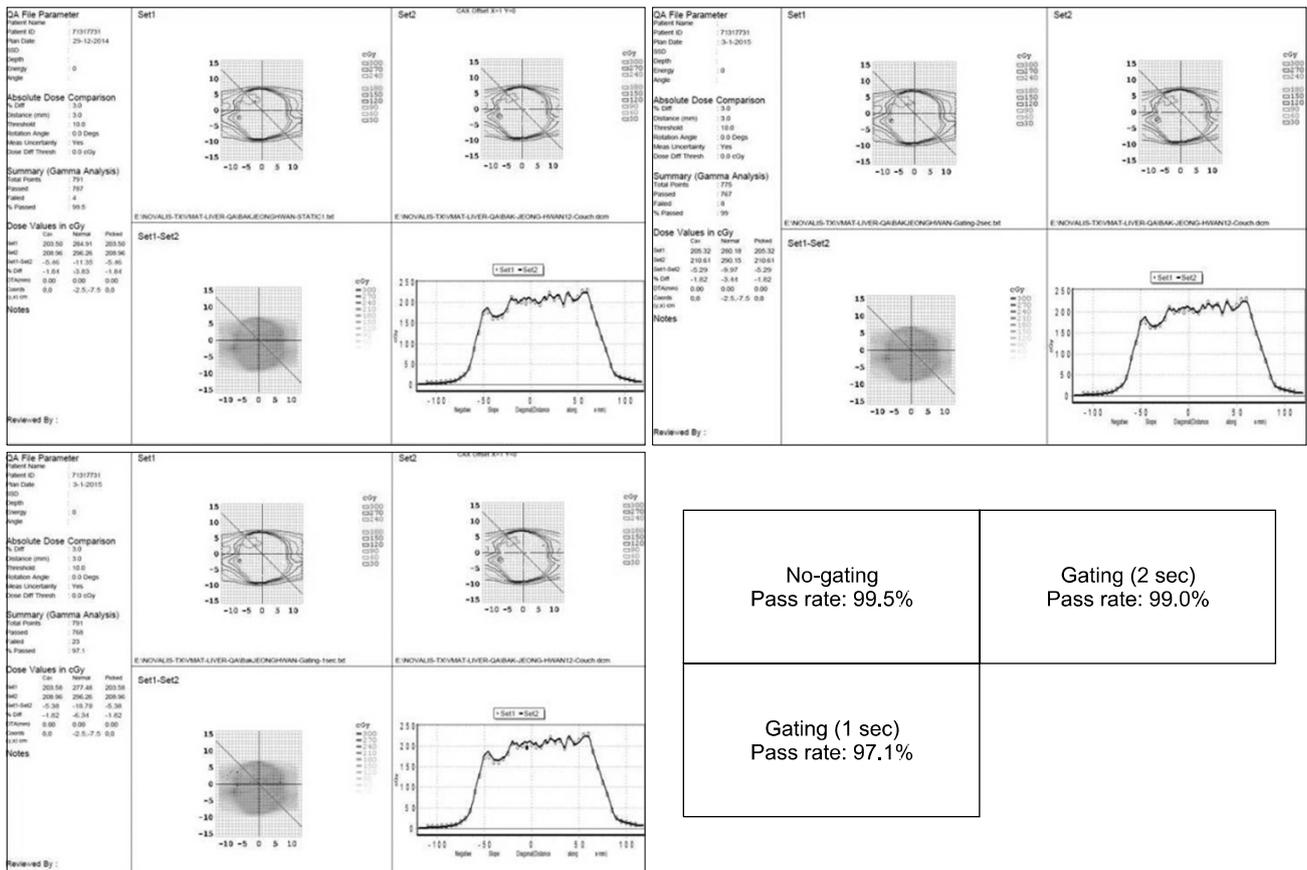
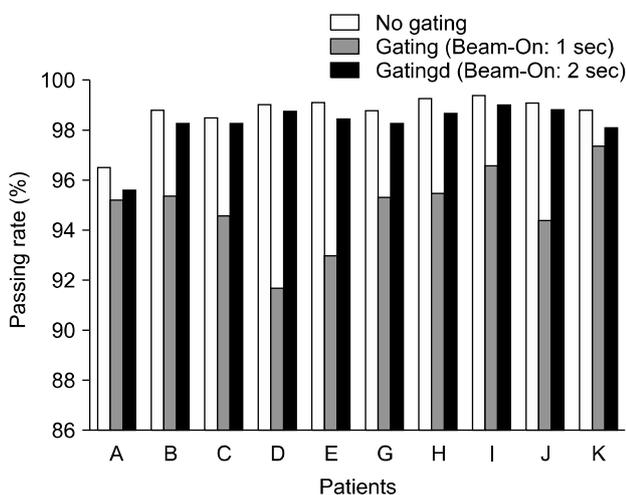


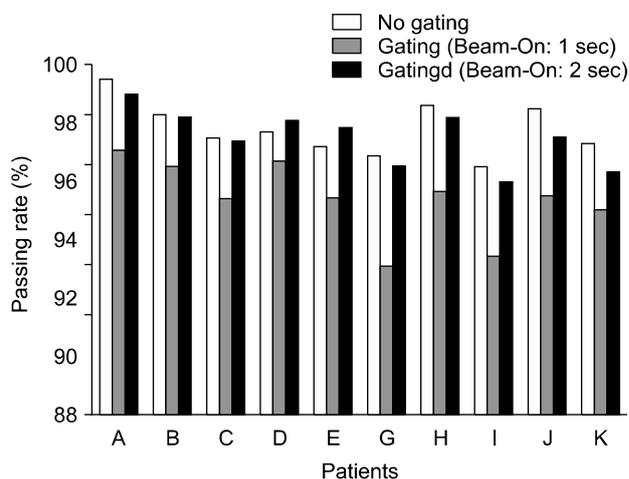
Fig. 3. Example of the DQA analysis with MapCHECK2 plan in three different gating cases.

**Table 1.** The pass rates calculated using the gamma evaluation in the DQA process of gated RapidArc plans with a portal dosimetry and a MapCHECK2 measurement.

Patient	Portal dosimetry			MapCHECK2 with MapPHAN		
	No gating	Gating (1 sec)	Gating (2 sec)	No gating	Gating (1 sec)	Gating (2 sec)
A	96.5%	95.2%	95.6%	99.5%	97.1%	99.0%
B	98.8%	95.4%	98.2%	98.3%	96.5%	98.2%
C	98.5%	94.6%	98.3%	97.5%	95.4%	97.4%
D	99.0%	91.7%	98.8%	97.7%	96.7%	98.1%
E	99.1%	93.0%	98.5%	97.2%	95.4%	97.8%
F	98.8%	95.3%	98.3%	96.9%	93.1%	96.5%
G	99.2%	95.5%	98.7%	98.6%	95.7%	98.2%
H	99.4%	96.6%	99.0%	96.5%	93.4%	96.0%
I	99.1%	94.4%	98.8%	98.5%	95.5%	97.5%
J	98.8%	97.4%	98.1%	97.3%	95.0%	96.3%



**Fig. 4.** The comparison of DQA analysis results with portal dosimetry plan in three different gating cases.



**Fig. 5.** The comparison of DQA analysis results with MapCHECK2 plan in three different gating cases.

### Discussion

Gated RapidArc delivers VMAT beams only when the respiration phase is within a specified gating window and stops the gantry rotation when the respiration phase leaves the gating window. The stop-and-go motion of heavy gantry can offset the gantry restart position owing to momentum effects, which can also reduce the accuracy of MLC position, dose rate, and other important factors in RapidArc delivery. Our data support this premise: dosimetric error was greater in gated RapidArc delivery than continuous RapidArc delivery (no gating).

Analysis of how the number of stop-and-go motions during

RapidArc affects dosimetric error showed that the errors increased as the number of motion increased (i.e., as gating window time decreased). The average pass rate calculated using the gamma evaluation method was significantly lower ( $P < 10^{-4}$ ) for gated compared with continuous beam delivery without gating in both the portal dosimetry and MapCHECK2 plans.

In the MapCHECK2 plan, 2-sec gating had a lower average pass rate than no gating, but the difference was not significant ( $P=0.052$ ). The average pass rate for 1-sec gating, however, was significantly lower than that of no gating ( $P < 10^{-5}$ ), as well as that of 2-sec gating ( $P < 10^{-5}$ ).

In the portal dosimetry plan, the average pass rates of both

1-sec and 2-sec gating were significantly lower than no gating ( $P < 10^{-4}$ ). The low pass rate in the 2-sec gating window may reflect the inevitable effects of stop-and-go motions on the EPID-attached gantry structure. Unlike the MapCHECK2 device, which is static, the EPID may introduce detector position errors. The average pass rate for 1-sec gating was significantly lower than that for 2-sec gating ( $P < 10^{-3}$ ) in the portal dosimetry plan as in the MapCHECK2 plan. Our results confirm that dosimetric accuracy in gated RapidArc increases as gating window (beam-on) time increases and thus suggest more stop-and-go motions result in more dosimetric errors.

The difference between the dose calculated in a plan and the dose delivered to the patient via a gated RapidArc is mainly due to the interplay effects of organ motion during treatment.<sup>11,12</sup> Court et al.<sup>13</sup> suggest that errors based on interplay effects cancel each other out when doses are delivered in many fractions and thus do not affect overall treatment accuracy. Although interplay effects produce random errors owing to differences in the organ motions of different patients, our study shows that gating window time length is a determinant of systematic error and thus should be considered when planning gated RapidArc treatments.

A stable respiratory pattern is a basic prerequisite of accurate gated RapidArc treatment, and gating window time, which determines the number of stop-and-go motions, should be as long as possible. The suitable respiratory pattern for gated RapidArc includes a long flat respiratory phase in the region of end exhalation rather than a steep sinusoidal phase pattern. Proper training of patients will enable stable, flat respiratory patterns that result in longer gating window times during gated RapidArc treatment.

### Conclusion

Because the dosimetric accuracy of gated RapidArc increases as the number of gantry stop-and-go motions decreases, efforts should be made to increase gating window time during the RapidArc treatment process. Training patients to maintain a flat respiratory pattern during end exhalation will help increase gating window time in gated RapidArc.

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## 호흡연동 래피드아크 치료 시 빔 조사 구간 설정에 따른 선량 변화 분석

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호흡연동 래피드아크 치료는 무거운 하중의 선형가속기 갠트리의 회전과 정지의 반복과정에서 갠트리 회전 재시작점의 오차와 다엽조리개의 정확한 움직임 및 갠트리 속도와 같은 래피드아크의 선량정확도를 결정하는 요소들의 오차 가능성으로 인한 선량 오류가 발생할 수 있다. 본 연구에서는 이러한 갠트리의 회전과 정지의 반복적인 동작이 호흡연동 래피드아크 치료의 정확도에 어떠한 영향을 끼치는지 치료 시 총 회전과 정지 동작 수를 결정하는 빔조사 구간 길이의 변화를 통해 분석하였다. 총 10명의 간암 환자를 대상으로 래피드아크 치료계획을 수립하였고, RPM 호흡연동 장치와 정확한 빔조사 구간 길이를 설정하기 위해 동적 팬텀을 사용하였다. 각 래피드아크 치료계획 당 EPID를 사용한 portal dosimetry delivery quality assurance (DQA) 계획과 이차원 다이오드 검출기배열장치인 MapCHECK2를 사용한 DQA 계획을 수립하여 호흡연동 방사선 치료과정에서 누적된 선량분포의 정확도를 분석하였다. 모든 환자의 호흡주기는 4초로 설정하였고, 수립한 DQA 계획들을 호흡연동 없이 연속적으로 조사하는 것과, 1초의 빔조사 구간과 2초의 빔조사 구간, 총 3가지의 경우에 대해 실제 방사선량 측정과 감마평가를 통해 선량의 정확도를 분석하였다. Portal dosimetry DQA 경우 평균 감마평가의 합격률은 호흡연동 없이 연속적일 때  $98.72 \pm 0.82\%$  였고, 1초의 빔조사 구간의 경우  $94.91 \pm 1.64\%$ , 2초의 빔조사 구간의 경우  $98.23 \pm 0.97\%$ 이었다. MapCHECK2 DQA 경우 평균 감마평가의 합격률은 호흡연동 없이 연속적일 때  $97.80 \pm 0.91\%$  였고, 1초의 빔조사 구간의 경우  $95.38 \pm 1.31\%$ , 2초의 빔조사 구간의 경우  $97.50 \pm 0.96\%$ 였다. 본 연구 결과를 통해 빔조사 구간의 길이가 증가하여 갠트리 정지 동작 수가 감소할수록 호흡연동 래피드아크의 선량 정확도가 증가함을 확인할 수 있었으며, 이러한 특성을 호흡연동 방사선치료 대상 환자의 선정 및 호흡방식에 대한 교육과정에 고려되어야 할 것으로 판단되었다.

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**중심단어:** 호흡연동 래피드아크, 포탈 선량측정, MapCHECK2, 감마평가