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Evaluation of biology-guided radiotherapy treatment delivery patterns based on beamlet sequence log data from daily treatments

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ABSTRACT

Purpose: To evaluate beamlet sequence delivery patterns in biology-guided radiotherapy (BgRT) on a linac machine with an integrated PET scanner and a binary multileaf collimator (MLC) using beamlet sequence log data from daily treatments.
Methods: Beamlet sequence data from both the treatment plan and daily treatment delivery were retrieved for patients treated by BgRT at our institution. Nine patients were treated to bone lesions with non-periodic motion while eleven patients treated to bone or lung lesions with periodic motion. The prescription dose ranged from 7 to 18 Gy per fraction in one to five fractions. A 64-leaf binary MLC modulates the beam at 50 gantry firing positions in each gantry rotation while the gantry rotates at 60 RPM. In delivery, the couch makes four passes (couch travel into or out of the gantry). Gantry angle, couch position, delivered monitor units (MU), and MLC leaf opening status were recorded at each beam firing position and were analyzed.
Results: The BgRT treatment plans had an average MU per fraction of 6,684±1,880 MU (range: 2,860 – 9,898) with an average total gantry firing positions of 15,835±4,391 (range: 9,566 – 21,817). In daily delivery, the average percentage of MU delivered in the first pass was 39.5±5.1% (range: 30.4 – 47.9%), which was significantly higher than those in the other three passes (two-tailed p-value < 0.05 in paired t-tests for targets with both periodic and non-periodic motion). The delivered MU showed an average increase of 3.3±3.9% (range: -6.5 – 13.0%) compared to the plan MU, with no statistically significant difference between targets with periodic motion and those with non-periodic motion.
Conclusion: Delivery accuracy is more important in the first BgRT pass as more MU is given compared to the other three passes. This is true for targets with both periodic and non-periodic motions.

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INTRODUCTION

Biology-guided radiotherapy (BgRT) utilizes positron emission tomography (PET) imaging signals from tumor metabolic activities to guide radiation delivery. A BgRT-capable radiotherapy machine (X1, RefleXion Medical, Hayward, California) uses a 6-MV linac mounted on a ring gantry. It integrates kVCT and PET imaging subsystems on the ring gantry of the linac. The ring gantry rotates at 60 RPM. A 64-leaf binary multi-leaf collimator (MLC) modulates the beam at 50 firing positions per gantry rotation. In a previous study, we evaluated the performance of the binary MLC on the X1 machine [1]. In that study, beamlet sequence data from daily deliveries were analyzed and compared against beamlet sequence data in the treatment plan for image-guided radiotherapy (IGRT) treatments where real-time PET guidance is not used.

In this current study, we aimed to characterize beamlet sequent patterns in both BgRT treatment plans and in daily BgRT deliveries on the X1. In BgRT deliveries, four couch passes are used in BgRT delivery. Real-time Fluorodeoxyglucose F 18 (18F-FDG) signals from the PET detectors on the ring gantry are used to dynamically deliver beamlets based on the current position of the FDG-avid target. The goal of this study is to assess the unique beamlet sequence delivery patterns in BgRT plans and in daily BgRT deliveries on the X1 and to explore the clinical implications.

METHODS AND MATERIALS

Beamlet sequence data from both the treatment plan and daily treatment deliveries were retrieved for patients treated by the BgRT technique on the X1 at our institution. Among them, nine patients were treated to bone lesions with non-periodic motion while eleven patients were treated to bone or lung lesions with periodic motion.

The prescription dose ranged from 7 to 18 Gy per fraction in one to five fractions. In BgRT delivery, the couch makes four passes (couch travel into or out of the gantry). Gantry angle, couch position, delivered monitor units (MU), and MLC leaf opening status were recorded at each beam firing position in beamlet sequence data files and were analyzed.

Using in-house developed software tools [2], beamlet sequence data from the treatment plan and from daily treatments were analyzed and compared.

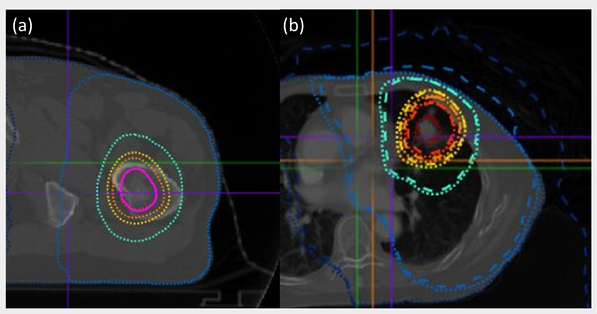

Figure 1: Representative dose distributions in BgRT plans for (a) a bone lesion and (b) a lung lesion, respectively.

RESULTS

The BgRT treatment plans included in this study had an average MU per fraction of 6,684 ± 1,880 MU (range: 2,860–9,898). The average number of beam stations (i.e., couch positions) was 34 ± 5 (range: 26–41). The number of gantry rotations per beam station ranged from 8 to 14 rotations. Table 1 lists average percentage of MU in each of the four couch passes in the BgRT treatment plan beamlet sequences. For all BgRT treatment plans, the first three passes showed identical MU with an average percentage MU of 24.6 ± 0.2%, whereas the fourth couch pass showed an average percentage MU of 26.1 ± 0.5%, which is significantly higher compared to the first three couch passes ($p < 0.05$ in paired t tests).

Table 1 also lists average percentage of MU in each of the four couch passes in daily BgRT treatment delivery beamlet sequences. In daily BgRT treatment deliveries, the average percentage of MU delivered in the first pass was 39.5±5.1% (range: 30.4 – 47.9%), which was significantly higher than those in the other three couch passes (two-tailed p-value < 0.05 in paired t-tests for targets with both periodic and non-periodic motion). On the other hand, the average percentage of MU delivered in the last pass was 14.5 ± 3.6% (range: 6.8 – 22.7%), significantly lower than that in the first three couch passes. They are 19.6 ± 4.8% and 26.4 ± 3.7% in the second and third passes, respectively. Figure 1 shows MLC leaf open counts at each couch position in the plan and in a treatment delivery fraction for a representative BgRT case in this study.

In daily BgRT treatments, the delivered MU showed an average increase of 3.3±3.9% (range: -6.5 – 13.0%) compared to the plan MU, with no statistically significant difference between targets with periodic motion and those with non-periodic motion.

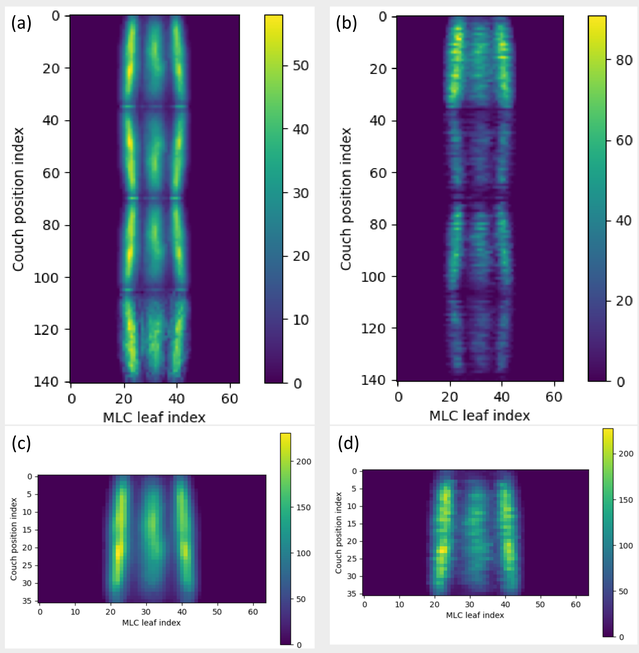

Figure 2: Comparison of beamlet sequence between the treatment plan and (b) a delivered fraction in a BgRT treatment. (a) Beamlet sequence in the treatment plan showing all four couch passes. (b) Beamlet sequence in the delivery showing all four passes. (c) Beamlet sequence in the treatment plan that combines MLC openings at each couch position in all four passes. (d) Beamlet sequence in the delivery that combines MLC openings at each couch position in all four passes.

DISCUSSION

While the expected MU in each couch pass was similar in magnitude in BgRT treatment plan beamlet sequences, beamlet sequence data in daily deliveries showed significant deviations in MU delivered per couch pass from that in the treatment plan. In particular, MU delivered in the first and last passes of couch movement had statistically significant deviations from that in the treatment plan beamlet sequence for targets with both periodic and non-periodic motion, as illustrated by one representative case in Figure 1.

Results from this study indicate that beam delivery in the first pass of BgRT treatment is more important for delivery accuracy as significantly higher percentage of total MU was given in the first pass, whereas it was least important in the last couch pass. As both physical and biological decays happen during treatment, delivery accuracy in the first couch pass could be aided with real-time PET-guided target tracking when the target signal strength is the strongest compared to subsequent couch passes.

	Treatment Plan	Daily Delivery
Couch Pass 1	24.6 ± 0.2%	39.5 ± 5.1%
Couch Pass 2	24.6 ± 0.2%	19.6 ± 4.8%
Couch Pass 3	24.6 ± 0.2%	26.4 ± 3.7%
Couch Pass 4	26.1 ± 0.5%	14.5 ± 3.6%
Total	**100%**	**100%**

Table 1. Average percentage MU delivered in each of the four couch passes in BgRT treatment plans and in daily BgRT treatment deliveries.

CONCLUSIONS

This study reveals unique beamlet sequence patterns in daily BgRT treatment delivery on the X1 machine and shows that more MU is delivered the first couch pass of BgRT delivery compared to the other three couch passes. Beamlet sequence in BgRT delivery is significantly different from that in the BgRT treatment plan, and it is true for targets with both periodic and non-periodic motions.

The methods from this study can also be adopted for routine treatment delivery quality assurance.

REFERENCES

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