Surface Guidance for Lung SBRT: A Large-Cohort Analysis of Intrafraction Motion and Setup Accuracy

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Nima Soltani, PhD[1]; Marcin Wierzbicki, PhD[1,2,3]; Sahar Darvish-Molla, PhD[1,2,3]; Thomas Mu-Ya Chow, PhD[1]
[1]Department of Medical Physics, Juravinski Cancer Centre at Hamilton Health Sciences, Hamilton, ON, Canada , [2]Department of Physics and Astronomy at McMaster University, Hamilton, ON, Canada, [3]School of Interdisciplinary Sciences at McMaster University, Hamilton, ON, Canada

Juravinski Hospital and Cancer Centre

ABSTRACT

Purpose: To quantify time-resolved intrafraction motion in six degrees of freedom (vertical, longitudinal, and lateral translations; yaw, roll, and pitch rotations) during lung SBRT delivered under optical surface monitoring system (OSMS) guidance and to derive clinically relevant motion metrics for tolerance selection.

Methods: OSMS log files from more than 1,100 lung stereotactic body radiotherapy (SBRT) patients (more than 6,000 fractions) were retrospectively analyzed. Beam-time–stamped surface positions were grouped into consecutive 5s intervals from beam-on to beam-off. For each fraction and time bin, the mean displacement and standard deviation (SD) (representing "jitter") were computed for all six degrees of freedom. Across all fractions and bins, distributions of means and jitter were summarized using 90th and 95th percentiles. This study was approved by the Hamilton Integrated Research Ethics Board (HiREB; Project #19836).

Results: Fractions with irradiation duration ranging from 30 to 480s were selected for analysis. The mean irradiation time was 150s and 95% of irradiations were completed within 270s. The 95th percentiles of mean translations were within ± 1.4 mm (vertical), ± 2.3 mm (longitudinal), and ± 1.3 mm (lateral). The 95th percentiles of mean rotational motions were within ± 0.4° (yaw), ± 0.3° (roll), and ± 0.4° (pitch). Longitudinal translation and pitch showed the largest variability, while lateral translation and roll were the most stable.

Conclusion: In this large lung SBRT cohort, OSMS-derived intrafraction motion remained predominantly sub-millimeter and sub-degree over typical 2–4 minute beam-on times. These results support the adequacy of our current surface guided radiotherapy (SGRT)-guided immobilization strategy and provide quantitative benchmarks for center-specific motion limits and margin design.

CONTACT

Nima Soltani
Hamilton Health Sciences, Juravinski Cancer Centre
699 Concession St, Hamilton, ON L8V 5C2
soltanin@hhsc.ca

INTRODUCTION

SBRT for lung cancer delivers high doses in a small number of fractions, making accurate patient positioning and intrafraction motion management critical. At our center, pre-treatment cone-beam CT is mandatory for image guidance, while a surface-guided radiotherapy system based on an OSMS is used as an additional tool to monitor patient position during beam delivery (Figure 1).

SGRT is widely implemented for different anatomies including breast, brain and head and neck and guidelines have been developed for its use [1,2]; however, there are limited large-cohort, time-resolved data describing how patients actually move during lung SBRT across all translational and rotational degrees of freedom ([3] with 75, [4] with 25, [5] with 12 and [6] with 13 patients). Such information is important for validating current immobilization practices, setting SGRT tolerance thresholds, and partially validating planning target volume margins. Our center has accumulated OSMS log files for more than 1,000 lung SBRT patients, providing a unique opportunity for a detailed, retrospective motion analysis without any additional patient interventions.

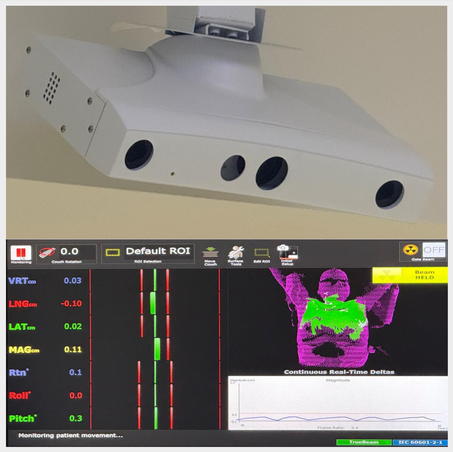

Figure 1. The VisionRT AlignRT HD camera unit (top) and software interface (Bottom)

METHODS AND RESULTS

Table 1 and Table 2 summarize methods and results of this study respectively. Figures 2 and 3 are sample results from translational and rotational motions respectively.

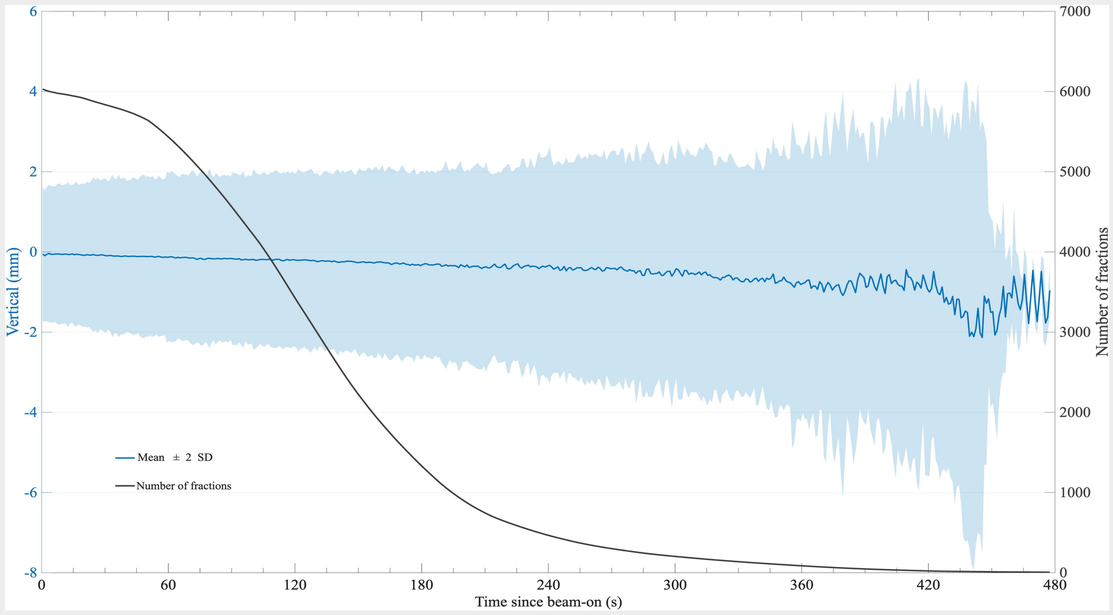

Figure 2. Time-resolved vertical translational motion during lung SBRT. The curve shows the cohort summary of per-fraction mean ± 2SD in 1s bins.

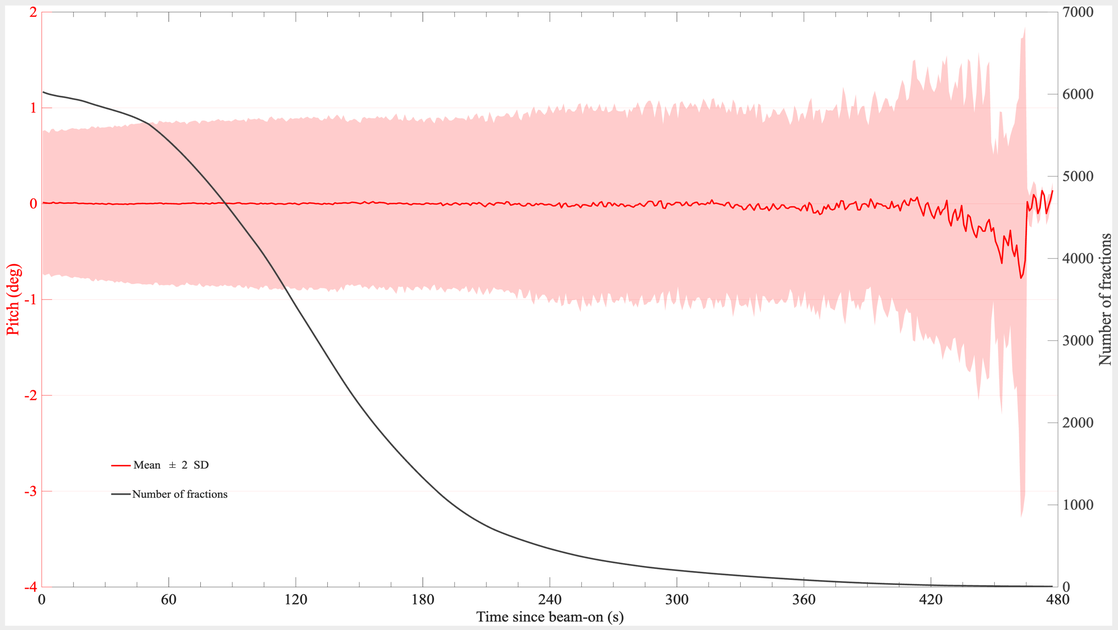

Figure 3. Time-resolved pitch rotational motion during lung SBRT. The curve shows the cohort summary of per-fraction mean ± 2SD in 1s bins.

Table 1. Study at a glance.

Item	Description
Study design	Single all Varian center retrospective OSMS log-file analysis
Population	More than 1,100 lung SBRT patients; approximately 6,000 fractions
Included beam-on duration	Fractions with irradiation duration ranging from 30–480s were selected
Time binning	1-s bins
Degrees of freedom	Vertical, longitudinal, lateral, yaw, roll, pitch
Metrics per fraction/bin	Mean displacement and standard deviation (SD) (jitter)
Units	Translations: mm; rotations: degrees
Outlier handling	Interquartile range bin-level exclusion was used in final analysis
Cohort summary	Mean ±2SD plots, values of overall mean and 2SD of each DOF across all fractions for all bins

Table 2. Key study outputs (95th Percentile of means and average min to average max range).

DOF	Overall mean	2SD	Interpretation
Vertical	-0.5 mm	± 2.7 mm	Low vertical drift
Longitudinal	0.1 mm	± 3.8 mm	Largest translational variability
Lateral	-0.1 mm	± 2.1 mm	Stable translation
Yaw	0.0°	± 0.8°	Small rotational offset
Roll	0.0°	± 0.8°	Most stable rotation
Pitch	0.0°	± 1.0°	Largest rotational variability

DISCUSSION

This large-cohort analysis shows that OSMS-derived intrafraction surface motion during lung SBRT is generally small, with translational motion predominantly within a few millimeters and rotational motion generally close to a degree (Table 2). The time-resolved plots provide practical benchmarks for expected surface stability during treatment. Longitudinal translation and pitch were the least stable directions, suggesting that these axes may warrant closer attention when reviewing SGRT tolerances or patient-specific motion. OSMS should still be interpreted as complementary to CBCT because external surface motion may not fully represent internal tumor motion, particularly for deep thoracic targets.

CONCLUSIONS

In this large lung SBRT cohort, time-resolved OSMS surface tracking demonstrated predominantly low-amplitude intrafraction motion across all six degrees of freedom. Translational motion was generally within a few millimeters, and rotational motion was generally below one degree over typical 1–3 minute beam-on times (Table 2). In the next phase of this study, to evaluate whether OSMS can effectively replace or optimize established clinical standards, the efficacy of various patient immobilization and positioning systems (e.g., vacuum cushion fixation, breath-hold techniques) will be investigated.

REFERENCES

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