



# Dosimetric Evaluation of Target Dose in Stereotactic Body Radiation Therapy (SBRT) of Lung Lesions Using a Dynamic Motion Anthropomorphic Phantom

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## INTRODUCTION

Stereotactic Body Radiation Therapy (SBRT) represents an exciting new development in the field of radiation therapy wherein large hypofractionated doses of radiation may be delivered conformally to targets of liver and lung. The delivery of large conformal doses to such targets poses numerous challenges, which can include the presence of significant degrees of target motion. A Dynamic thorax phantom has been designed and constructed to allow for motion studies of targets in lung. The phantom is constructed from a CIRS IMRT Thorax phantom (CIRS Inc., Norfolk, VA) with custom modifications, and allows for complex motion of a unit-density target in lung equivalent material. Through a combination of translational and rotational motion, the motion actuator can facilitate three-dimensional motion. Linear motion in the superior/inferior (S/I) direction can be isolated from lateral and anterior/posterior (A/P) motion in both frequency and amplitude, and the two sets of motions may be phase-synchronized to each other. Sinusoidal and other complex motions are achievable. The phantom is capable of facilitating the study of several important aspects of SBRT to lung, to include 1) characterization of volume aliasing effects encountered when acquiring treatment planning CT's of a moving target and 2) characterization of the dosimetric ramifications of target motion in lung, in the presence of temporally modulated radiation therapy delivery beams (i.e. IMRT).

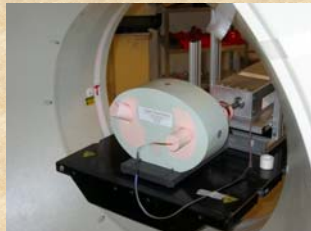


Figure 1



Figure 2

## MATERIALS and METHODS

- Volume Aliasing** - The Dynamic IMRT Thorax phantom (CIRS Inc., Norfolk, VA) was used to study the aliasing of target volume encountered when acquiring treatment planning CT's of a moving target in lung. The unit was programmed for periodic craniocaudal (S/I) motion of  $\pm 5$  or  $\pm 15$  mm, right-left (R/L) and anteroposterior (A/P) displacements of  $\pm 1$ mm and  $\pm 2.5$ mm respectively, about a point, all with period of 4s. Targets consisted of two spheres of unit density, 1cm and 2cm in diameters. Spiral CT scanning was performed on a PQS CT scanner (Philips Medical Systems, Bothell, WA, USA) on both stationary and dynamic targets. A pitch of 1.5 was used to acquire CT scan slices of thicknesses 1mm and 3mm. Scan speeds of 1s and 1.5s were investigated, and a consistent image acquisition to motion phase synchronization scheme was used on all scans that involved moving targets.
- Delivered Dose Variation Due to Motion** - Serial tomotherapy IMRT plans were designed based on CT scans of a stationary target using CORVUS V5.0 (NOMOS Corporation, Cranberry Township, PA, USA) inverse treatment planning software. The plans were then

delivered on a Varian 600C (Varian Medical Systems, Inc., Palo Alto, CA, USA) linear accelerator equipped with the PEACOCK (NOMOS Corporation, Cranberry Township, PA, USA) serial tomotherapy delivery system (1 cm Mode), to the static target *and* to the moving target, with varying degrees of motion and PTV margin "adequacy". Absolute dose measurements at the center of the spherical targets were taken using the MOSFET 20 dose verification system (Thomson & Nielsen Electronics Ltd., Ottawa, ON, Canada), "standard" bias supply setting, standard detector sensitivity, with reported  $2\sigma$  precision of  $\pm 4\%$ . A consistent delivery to motion phase synchronization scheme was used on all measurements that involved moving targets. The intent was to investigate the difference in dose delivered to the target for the static (i.e. *planned*) target versus the moving target scenario.

## RESULTS

- Figures 3 and 4 are coronal views of CT scans of the 2cm target. Figure 3 is an image of the target scanned stationary while figure 4 is of the target scanned moving (S/I motion amplitude of  $\pm 5$ mm). Figure 4 illustrates some of the effects of CT scanning a dynamic target. Two common distortions that the figure depicts are volume aliasing and geometric misses, both of which are consequences of CT imaging being a snapshot in time of the target. Volume aliasing occurs when a given plane on the target intersects with, and is captured in, the scan plane of the CT scanner farther from the true margins of the target, margins that are defined by the stationary target. Volume aliasing thus causes the margins of the target to grow in a manner that is not proportionate to the original target size, as can be seen when the contours on both figures 3 and 4 are compared (i.e. a 30.2% volume increase). Geometric miss, which is predominantly observed at the S/I extremes of the moving target image, causes portions of the target to be partially or completely absent on some scan slices.

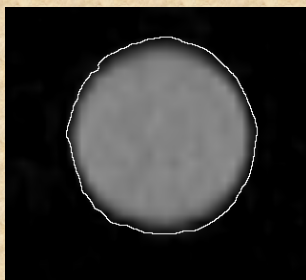


Figure 3



Figure 4

Table 1 summarizes the effects of CT imaging of dynamic targets of diameters 1cm and 2cm. A distortion that can be readily seen is the overall increase in dynamic target volume relative to stationary target volume due to volume aliasing. The 1cm dynamic target shows aliased growth of between 24% and 84%, while the increase in the 2cm target volume ranges from 20 to 35%. Obvious gaps due to "geometric misses" were contoured as extrapolations of the preceding slice.

Table 1

Scan Speed (s)	Slice Thickness (mm)	Target Size (cm)	Volume Aliasing (% Increase)
1.5	1.0	1.0	77.1
1.5	3.0	1.0	84.3
1.0	1.0	1.0	37.3
1.0	3.0	1.0	24.1
1.5	1.0	2.0	30.2
1.5	3.0	2.0	45.2
1.0	1.0	2.0	20.3
1.0	3.0	2.0	35.7

- Table 2 is a summary of point dose measurements at the center of dynamic and stationary targets. The delivered serial tomotherapy plan was based on a CT scan of the stationary target. Margins of varying degree of adequacy were added to account for varying degrees of target motion. These margins are labeled as less than adequate (LTA) and more than adequate (MTA) for moving targets, and adequate for the stationary target (ADQ-ST). LTA implies there is no margin added to account for target motion. MTA implies there is a generous margin to account for target motion. ADQ-ST utilizes no growth of margins around the stationary target. There is evident dose deficit at the center of the moving target delivery compared with the stationary target delivery (e.g. 28.2% dose deficit for 1 cm Less Than Adequate relative to static target).

Table 2

Target Size (cm)	PTV	Margins			Dose Deficit %
		A/P (+/- mm)	R/L (+/- mm)	S/I (+/- mm)	
1	LTA	0	0	0	-28.2
1	MTA	5	2	10	-1.5
1	ADQ-ST	0	0	0	0.0
2	LTA	0	0	0	-21.3
2	MTA	5	2	10	-3.6
2	ADQ-ST	0	0	0	0.0

## CONCLUSIONS

The CIRS Dynamic Thorax Phantom proved a useful tool for quantifying the degree of volume aliasing in CT imaging of a moving target.

The CIRS Dynamic Thorax Phantom proved a useful tool for quantifying the degree of delivered dose variation due to serial tomotherapeutic treatment of a moving target.

## FUTURE WORK

A comprehensive analysis and characterization of 1) volume aliasing when acquiring treatment planning CT's of a moving target and 2) the dosimetric ramifications encountered in the presence of temporally modulated radiation therapy delivery beams, is currently in progress.

## REFERENCES

- Langen KM, Jones DJ, "Organ Motion and its Management," *Int. J. Radiat. Oncol., Biol., Phys.* 50, 265–278 (2001).