Development and Evaluation of a Fast Patient Alignment Tool Using Megavoltage-Topogram on Helical TomoTherapy: a pooled analysis

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Purpose/objective(s)

To develop and systemically evaluate megavoltage (MV)-topogram as an alternative fast patient localization tool on helical TomoTherapy for three anatomical sites.

Innovation/Impact: The total patient operational time of MVCT acquisition and reconstruction significantly increases for patients that require a large longitudinal fields of view (FOV) for setup imaging, such as cranial-spinal irradiation (CSI) or Total Marrow Irradiation (TMI) procedures. The prolonged patient operational time would potentially lead to uncertainty due to undesirable patient motion. Given its unique geometric design, TomoTherapy allows for acquisition of megavoltage computed tomography (MVCT) image as well as two-dimensional (2D) radiographic images (MV-topograms) for patient alignment. The MVCT scan is current standard-of-care to ensure correct patient alignment prior to treatment delivery. We conducted an IRB-approved clinical trial designed to systematically study MV-topogram performance for patient alignment (as compared to the standard MVCT).

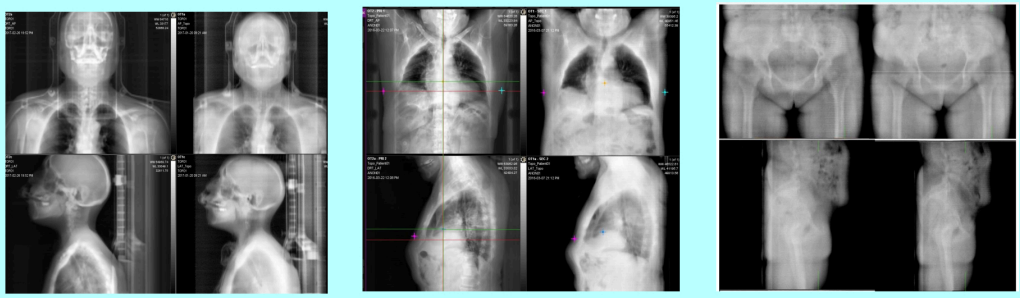
Materials and methods

We enrolled 19 head-and-neck, 12 thorax, and 18 pelvis cancer patients for the MV-topogram image acquisition under an IRB-approved clinical trial. Prior to the standard MVCT imaging and treatment procedure, each patient underwent weekly MV-topogram scans in AP/LAT views for 6-8 weeks. Each pair of the MV-topogram acquisition time ranged from 20-25 seconds at the couch speed of 4 cm/second. An in-house software was developed to reconstruct the MV-topograms offline. The relation between measurement of MVCT and MV-topogram imaging methods was assessed via linear mixed-effects model with site as random effect to account for within-site correlation. Two one-sided t-tests (TOST) equivalence procedure with paired design was used to analyze the patient shifts (R version.3.6.0*)*. The discrepancy was defined as the numerical distance between MV-topogram and MVCT. Two techniques were considered to be equivalent if the discrepancy were within ±2 mm with significance level <0.05.

Results

285 pairs of MV-topograms were reconstructed and compared to their corresponding MVCTs. The shifts, as the mean measure obtained from each subject, determined by MVCT and MV-topograms were found to be equivalent consistently in lateral (X), longitudinal (Y), and vertical (Z) directions across three anatomical sites and entire cohort (TOST p_values<0.02). With MV-topogram shift being independent variable and MVCT being response variable, the coefficients (and the standard errors) were 1.00 (0.04), 0.75 (0.07), and 0.77 (0.05) in the X, Y and Z directions, respectively.

Figure 1: The reconstructed DRRs (left) (from CT simulation) and MV-topograms (right) in AP (top) and LAT (bottom) views for (a) H&N case, (b) chest case and (c) a pelvis case. The contrast enhancement algorithm called contrast-limited adaptive histogram equalization (CLAHE) were used to improve the MV-topogram quality.



(a) a H&N case (b) a chest case (c) a pelvis case

Figure 2: An overview of mean shifts of each patient in three translational directions using two imaging techniques.

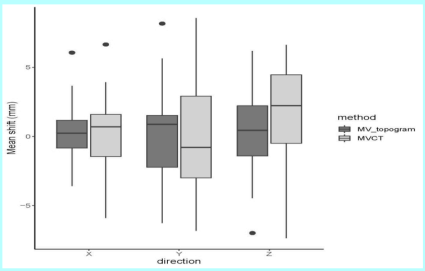


Table 1. Result for two one-sided t-tests (TOST) equivalence test by sites and entire cohort.

Site (#MV-topogram pairs)	Bound	P_value Lat. (X)	Long. (Y)	Vert. (Z)
Chest (56)	upper	<0.001	<0.001	<0.001
	lower	<0.001	<0.001	<0.001
Pelvis (96)	upper	<0.001	<0.001	0.02
	lower	<0.001	<0.001	<0.001
H&N (133)	upper	<0.001	<0.001	<0.001
	lower	< 0.001	<0.001	<0.001
Entire cohort (285)	upper	<0.001	<0.001	<0.001
	lower	<0.001	<0.001	<0.001

Table 2. Analysis result (without interaction term) for entire cohort using linear mixed effects model with site as random effect.

	Value	Std. Error	DF	t-value	p-value
(Intercept)	-0.16	0.42	205.00	-0.37	0.71
X_topogram	1.00	0.04	205.00	22.43	<0.001
(Intercept)	0.01	0.58	206.00	0.02	0.99
Y_topogram	0.75	0.07	206.00	11.01	<0.001
(Intercept)	1.03	0.87	205.00	1.18	0.24
Z_topogram	0.77	0.05	205.00	16.36	<0.001

Conclusions

MV-topograms showed equivalent clinical performance to the standard MVCT with significantly less acquisition time for the three anatomical sites. The MV-topogram can be utilized as an alternative or complimentary tool for bony landmark-based patient alignment on TomoTherapy.

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