Active Breathing Coordinator™

Reproducibility of liver position using Active Breathing Coordinator™ for liver cancer

Institution: **Princess Margaret Hospital, Toronto, Canada**

Purpose: To measure the intra-breath hold liver motion and the intrafraction reproducibility of liver position, relative to vertebral bodies, using Active Breathing Coordinator™ in patients with unresectable liver cancer treated with hypofractionated stereotactic body radiation therapy (SBRT).

The purpose of this paper is to describe the reproducibility of liver position using Active Breathing Coordinator in a larger series of patients with more advanced liver cancer, consecutively planned for SBRT delivered in six fractions over two weeks. In this study, repeat megavoltage (MV) verification imaging, real-time beams-eye-view MV movies, conventional kV fluoroscopy, cone beam kV fluoroscopy and deformable registration of repeat CT scans in the breath hold position are used to measure liver stability during active breathing coordination and intrafraction reproducibility of the liver position relative to the vertebral bodies.

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Accuracy study

ELEKTA

Princess Margaret Hospital
University Health Network

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Radiographer: C. Eccles, MRT(T).
Physicists: J.P. Bissonette, PhD., K. Brock, PhD.
Oncologists: L.A. Dawson, MD., M. Hawkins, MD.

Active Breathing Coordinator is a device that holds the patient breath at a pre-determined phase of the breathing cycle.

The dose is controlled using a remote laptop computer with a graphical readout of tidal volume over time.

Active Breathing Coordinator consists of a digital spirometer, mouthpiece, nose clip, patient-controlled enabling switch and a balloon valve which, when triggered to inflate by the care-giver, prevents airflow to and from the patient. The patient-controlled switch must be enabled for any breath hold to be applied and signifies that the patient is prepared and has given their consent. The volume and length of breath hold are chosen to maximize organ stability, reproducibility and comfort for the patient.

Method

Patients were positioned supine, with their arms above their head using either a carbon fiber breast board or Vac-Lok™ system (Civco) immobilization cushion and knee bolster. In patients screened suitable for Active Breathing Coordinator™, the system was used to immobilize the liver during the CT planning session and for treatment.

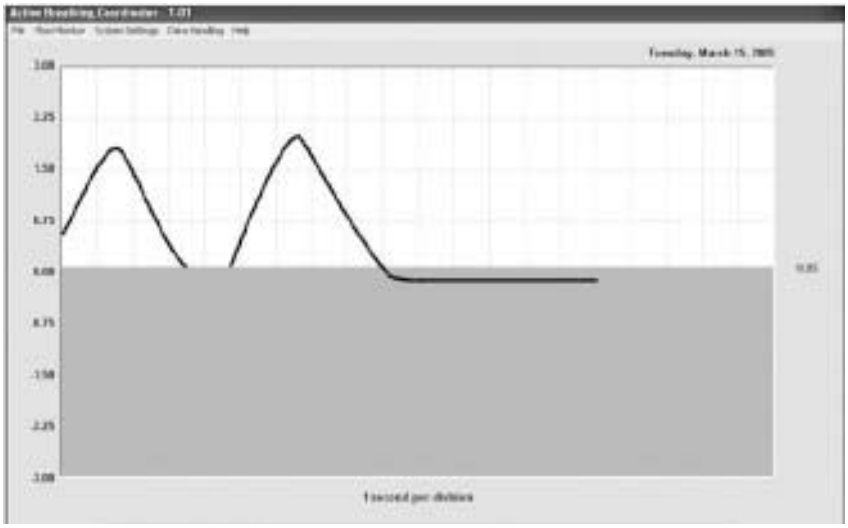

Figure 1: Active Breathing Coordinator screen display where exhale breath hold is triggered, as shown by the flat line.

3D forward planned segmental intensity modulated radiation therapy (IMRT) was used to treat all patients. Between three and eight beam angles were used for each isocenter with one to four segments per beam. The prescription dose was customized per patient and determined by the effective liver volume irradiated.

Before each treatment, patients were positioned using external tattoos, a three-point laser system and Active Breathing Coordinator. Orthogonal MV verification images were obtained using Active Breathing Coordinator before each fraction. The verification images were analyzed using iViewGT™ software. The diaphragm, which has been previously determined to be a good surrogate for the liver[1], was used for craniocaudal (CC) positioning, whereas the vertebral bodies were used for anteroposterior (AP) and medial-lateral (ML) positioning. The patient position was adjusted for all offsets of 3mm or more. Repeat MV images, of the final set-up position before each fraction, were obtained. In the event that no adjustments were required, repeat AP verification images were obtained to ensure good diaphragm positional reproducibility using Active Breathing Coordinator. Radiation was planned to be delivered only during Active Breathing Coordinator breath holds.

The intra-breath hold liver stability was evaluated using the digitized fluoroscopic movies obtained at the time of simulation. The maximum CC diaphragm motion was documented for each recorded breath hold.

AP kV fluoroscopy was obtained at the treatment unit in the treatment position at the time of each radiation fraction for the last 10 patients treated in the study. The intra-breath hold diaphragm position stability was measured using iViewGT™ 3D fluoroscopic software. The maximal CC diaphragm motion was quantified for each fluoroscopy session. MV BEV cine loop images were acquired during treatment for all patients. The treatment fields demonstrating a diaphragm/air interface were reviewed off-line using iViewGT to measure any motion of the diaphragm/liver during Active Breathing Coordinator breath hold treatment.

Intrafraction liver position reproducibility (based on repeat Active Breathing Coordinator™ breath holds obtained within the time period of one treatment fraction) was evaluated using three methods;
1 – repeat kV images at simulation
2 – repeat CT scans at simulation and
3 – repeat MV images immediately before treatment.

Finally, interfraction reproducibility was also evaluated at the time of treatment by comparing final* AP MV verification images obtained before each treatment fraction in the breath hold position using Active Breathing Coordinator.

Results

The free breathing CC diaphragm motion ranged from 5mm to 41mm in all patients. 21 of 34 patients (62%) were screened to be suitable for Active Breathing Coordinator. Of the 21 patients selected for Active Breathing Coordinator treatment, 20 completed all six fractions, whereas one was taken off the study permanently for reasons unrelated to Active Breathing Coordinator.

The free breathing CC diaphragm motion in the 21 patients selected for Active Breathing Coordinator ranged from 5mm to 41mm. These 21 patients were treated in the end exhale breath hold position using Active Breathing Coordinator. This position was preferred because exhale has been reported to be the most stable phase of the breathing cycle[2].

A total of 121 radiation therapy treatment fractions were administered to 21 patients using Active Breathing Coordinator. Each fraction was delivered using repeat breath holds of up to 32s with a break between each breath hold of at least three normal breathing cycles, tailored to each patient's needs. Extra time was required to deliver radiation using Active Breathing Coordinator™, which included orthogonal MV imaging, on-line matching, table adjustments, repeat MV imaging and, in the case of the final 10 patients, kV fluoroscopy and cone beam CT imaging (used to acquire AP fluoroscopic projections). The average treatment time, including all verification imaging, image analyses, repositioning, repeat imaging and treatment, was 21 minutes in patients treated with one isocenter, with a range from 13 to 47 minutes. The average treatment time, excluding verification imaging was 13 minutes (range five to 32 minutes).

** The interfraction reproducibility (day-to-day) was measured using the final AP verification image for each patient.*

Intra-breath hold liver position stability

Excellent liver stability was observed during Active Breathing Coordinator breath holds based on kV conventional fluoroscopy. AP cone beam fluoroscopy sessions, and exit beam MV movies are summarized in table 1.

	kV fluoroscopy simulation	kV fluoroscopy treatment	MV BEV exit beam movies
Average	1.4mm	1.2mm	0.5mm
Maximum	3.4mm	2.5mm	4.2mm
Minimum	0.0mm	0.4mm	0.0mm

Table 1: maximum diaphragm motion during Active Breathing Coordinator breath hold, based on AP kV fluoroscopy at simulation, cone beam kV fluoroscopy at the time of treatment and BEV MV cine loops obtained during treatment.

Intrafraction liver position reproducibility

The intrafraction liver position reproducibility was measured in 223 repeat AP MV verification images from 120 fractions in 20 patients. The relative diaphragm to vertebrae distance from the first daily MV verification image taken was compared with each subsequent verification image taken before treatment.

The average reproducibility (patient σ) of diaphragm to vertebral bodies was 1.5mm (range 0.6 to 3.0mm). The average absolute difference in relative diaphragm to vertebral body position was 1.7mm. 86% of the absolute differences in intrafraction diaphragm-to-vertebral body position were 3mm or less, table 2.

	Patient σ			Pooled absolute errors	
	Average σ	Maximum σ	Minimum σ	Average	% offsets <3mm
Intrafraction reproducibility	1.5mm	3.9mm	0.6mm	1.7mm	86%
interfraction reproducibility	3.4mm	7.9mm	1.5mm	3.7mm	54%

Table 2: patient intrafraction and interfraction reproducibility (σ) of diaphragm position relative to the vertebral bodies and pooled absolute errors in diaphragm to vertebral body position based on repeat AP MV verification images.

Intrafractional 3D reproducibility of liver position was also measured on repeat Active Breathing Coordinator CT scans obtained at the time of simulation. 36 repeat end exhale Active Breathing Coordinator CT scans from 14 patients were available for analysis. The reproducibility of liver position was evaluated for each patient using a finite element mesh-based surface analysis (see figure 2). The average mean difference in the liver surface position from the first two repeat breath hold CT scans in 14 patients was –0.9mm, –0.5mm and 0.2mm in the CC, AP and ML directions respectively, with a standard deviation (σ) of 1.5mm, 1.5mm and 1.5mm respectively. The average absolute mean difference in liver surface position on repeat Active Breathing Coordinator CT scans was 1.7mm, 1.2mm and 1.1mm in the CC, AP and ML directions, respectively. On average 95% of the liver surface had an absolute difference in position between repeat Active Breathing Coordinator CT scans of less than 4.1mm, 3.3mm and 3.3mm in the CC, AP and ML directions, respectively. For eight patients who had a third repeat CT, comparison of the second venous phase CT to the third arterial phase CT revealed better reproducibility (CC, AP and ML average mean difference 0.1mm, 0.1mm, –0.1mm; σ = 1.2mm, 1.3mm, 1.2mm; 95% absolute difference 2.2mm, 2.6mm, 2.3mm), table 3.

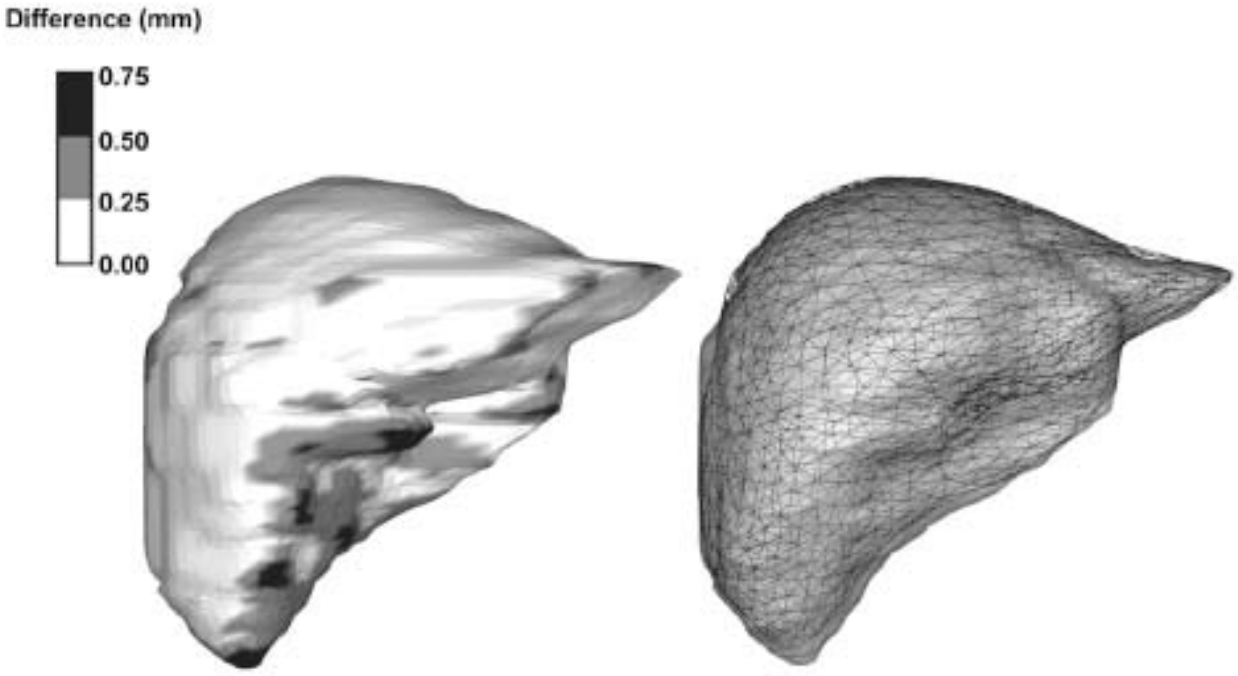

Figure 2: Example of a typical 3D liver intrafraction reproducibility from a patient who had two repeat Active Breathing Coordinator breath hold CT scans at the time of simulation. On the left, the liver from the second CT is registered to the liver from the first CT scan using a finite element mesh-based deformable registration tool. The grey scale shows the absolute difference in the position of the liver surfaces. White represents differences within 2.5mm, whereas black representing differences of 5 to 7.5mm. On the right, the first CT is shown in solid and the second is shown in wire frame[3].

		Offset (mm)			
		CC	AP	ML	3D vector
Average intrafraction	Mean	—0.9	-0.5	0.2	2.8
Reproducibility	SD	1.5	1.5	1.5	1.8
CT scan 1, 2 (4 patients)	Absolute mean	1.71.	1.1	2.8	2.8
	Absolute 95% percentile	4.1	3.3	3.3	6.1
Average intrafraction	Mean	—0.1	0.1	0.1	1.5
Reproducibility	SD	1.2	1.3	1.2	1.6
CT scan 2, 3 (8 patients)	Absolute mean	0.7	0.8	0.7	1.5
	Absolute 95% percentile	2.2	2.6	2.3	3.8
Contouring	Mean	0.2	—0.2	—0.2	1.8
Reproducibility	SD	1.2	1.5	3.3	3.4
CT scan 1, 2 (4 patients)	Absolute mean	0.7	0.8	1.2	1.8
	Absolute 95% percentile	2.3	2.4	3.3	4.6

Table 3: 3D intrafraction reproducibility of repeat Active Breathing Coordinator™ breath hold CT scans and liver contouring reproducibility. The first CT scan was a non-contrast CT (scan 1). The second and third were arterial and venous phase IV contrast scans (scan 2 and scan 3, respectively). All scans were obtained within a few minutes from each other in the exhale Active Breathing Coordinator breath hold position while in the same immobilization device. A typical example of liver reproducibility is show in figure 2.

Discussion

Active Breathing Coordinator™ can be used to reduce large planning target volumes required to account for liver motion. In this series, the liver motion was reduced from an average of 13mm (and a maximum of 41mm) to an average of 1.9mm (and a maximum of 4.2mm in a single patient) with Active Breathing Coordinator. Active Breathing Coordinator allows a reduction in normal liver irradiation and thus allows higher doses to be delivered for the same risk of liver toxicity. These gains are most marked in patients with a large magnitude of liver motion because of free breathing and with excellent intrafraction position reproducibility with Active Breathing Coordinator. In this series of screened patients, the intrafraction reproducibility was excellent (σ = 1.5mm).

During the period of a single fraction, examinations of liver position reproducibility demonstrated excellent liver reproducibility in the CC direction using Active Breathing Coordinator. A novel deformable image registration strategy[2] allowed analysis of repeat CT imaging with Active Breathing Coordinator to measure the reproducibility of liver position using Active Breathing Coordinator in 3D. This description of the reproducibility of the entire 3D liver surface provides much more information than the 2D analysis. The 3D analyses confirmed the excellent intrafraction reproducibility.

References

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(3) *Brock KK, Dawson LA, Sharpe MB, et al. Application of a novel deformable image registration technique to facilitate classification, tracking and targeting of tumor and normal tissue. Int J Radiat Oncol Biol Phys 2004; 60: 226-227.*

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Corporate Head Office, Stockholm, Sweden Tel +46 8 587 254 00 Fax +46 8 587 255 00 info@elekta.com

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Fax +81 78 271 7823
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info.china@elekta.com

Asia-Pacific,
Hong Kong, SAR China
Tel +852 2891 2208
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info.asia@elekta.com

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