Int. J. Radiation Oncology Biol. Phys., Vol. 80, No. 3, pp. 938–946, 2011

0360-3016/$ - see front matter

doi:10.1016/j.ijrobp.2010.08.003

PHYSICS CONTRIBUTION

INTERFRACTION LIVER SHAPE VARIABILITY AND IMPACT ON GTV POSITION DURING LIVER STEREOTACTIC RADIOTHERAPY USING ABDOMINAL COMPRESSION

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Purpose: For patients receiving liver stereotactic body radiotherapy (SBRT), abdominal compression can reduce organ motion, and daily image guidance can reduce setup error. The reproducibility of liver shape under compression may impact treatment delivery accuracy. The purpose of this study was to measure the interfractional variability in liver shape under compression, after best-fit rigid liver-to-liver registration from kilovoltage (kV) cone beam computed tomography (CBCT) scans to planning computed tomography (CT) scans and its impact on gross tumor volume (GTV) position.

Methods and Materials: Evaluable patients were treated in a Research Ethics Board–approved SBRT six-fraction study with abdominal compression. Kilovoltage CBCT scans were acquired before treatment and reconstructed as respiratory sorted CBCT scans offline. Manual rigid liver-to-liver registrations were performed from exhale-phase CBCT scans to exhale planning CT scans. Each CBCT liver was contoured, exported, and compared with the planning CT scan for spatial differences, by use of in house–developed finite-element model–based deformable registration (MORFEUS).

Results: We evaluated 83 CBCT scans from 16 patients with 30 GTVs. The mean volume of liver that deformed by greater than 3 mm was 21.7%. Excluding 1 outlier, the maximum volume that deformed by greater than 3 mm was 36.3% in a single patient. Over all patients, the absolute maximum deformations in the left–right (LR), anterior–posterior (AP), and superior–inferior directions were 10.5 mm (SD, 2.2), 12.9 mm (SD, 3.6), and 5.6 mm (SD, 2.7), respectively. The absolute mean predicted impact of liver volume displacements on GTV by use of center of mass displacements was 0.09 mm (SD, 0.13), 0.13 mm (SD, 0.18), and 0.08 mm (SD, 0.07) in the left–right, anterior–posterior, and superior–inferior directions, respectively.

Conclusions: Interfraction liver deformations in patients undergoing SBRT under abdominal compression after rigid liver-to-liver registrations on respiratory sorted CBCT scans were small in most patients (<5 mm). © 2011 Elsevier Inc.

Liver radiotherapy, Abdominal compression, Deformable registration.

INTRODUCTION

The use of stereotactic body radiotherapy (SBRT) to treat unresectable primary and metastatic liver cancers has shown high rates of local control (1–6). Safe delivery of SBRT is ensured by use of image-guided treatment (IGRT) strategies, reproducible patient immobilization, accurate treatment delivery and planning correlations, pretreatment quality assurance, and methods accounting for tumor/organ motion during treatment. A major challenge in achieving safe, accurate liver radiotherapy is defining and limiting respiratory liver motion during treatment. Liver motion occurs primarily in the superior–inferior (SI) direction in the range of 5 to 50 mm (7, 8). If not minimized or properly accounted for, motion of this magnitude could lead to adverse radiotherapy planning and delivery effects including the introduction of artifacts on planning computed tomography (CT) scans, inaccurate tumor volumes (9–11), altered dosimetry from use of a static plan (9), an increased

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Research supported in part by Elekta Oncology Systems, the Canadian Cancer Society, and National Institutes of Health grant 5RO1CA124714. Dr. Brock is also supported as a Cancer Care Ontario Research Chair.

Conflict of interest: Dr. Brock receives grant funding from Philips Medical Systems, Elekta Oncology Systems, and RaySearch Laboratories, and is on the Physics Advisory Board for IMPAC. Dr Dawson has clinical research funding from Bayer Healthcare Pharmaceuticals, and has had prior research funding from Elekta Oncology Systems

Acknowledgment—The authors thank Douglas Moseley for his support in this research.

Received July 2, 2009, and in revised form July 18, 2010. Accepted for publication Aug 3, 2010.

volume of normal tissue irradiated (4), the requirement of increased planning target volume margins (12), and greater risk of toxicity.

Methods used to manage and account for respiratory motion include abdominal compression (AC), active breathing coordination (ABC), and respiratory gating (9, 13–18). Abdominal compression is a widely reported method used in lung and liver SBRT, and it primarily uses a constant force applied to the abdomen to reduce diaphragmatic motion, which is verified by fluoroscopy (16, 19, 20). Heinzerling *et al.* (21) and Wunderink *et al.* (22) have reported the reproducibility of respiratory liver and tumor excursion under AC using four-dimensional computed tomography (4DCT) and fluoroscopy. Heinzerling *et al.* evaluated the effect of varying levels of compression on liver motion using 4DCT and determined that high levels of compression improved motion control over medium levels of compression. With gold fiducial markers implanted in healthy liver tissue surrounding the tumor, Wunderink *et al.* determined that AC effectively reduced liver tumor motion, yielding small, reproducible excursions in three dimensions. von Siebenthal *et al.* (23, 24) showed that local liver deformations in free-breathing (FB) patients varied depending on location within the liver. The effect of local deformations may be exaggerated or minimized when using AC and the diaphragm as a surrogate for liver motion. To date, no one has reported on the interfraction variability of liver shape and its impact on tumor position during liver SBRT under AC.

The purpose of this study was to measure the residual interfraction variability in liver shape in patients treated with liver SBRT under AC after the elimination of residual positional errors by use of deformable registration for kilovoltage (kV) cone beam computed tomography (CBCT) scans registered to planning CT scans and its impact on gross tumor volume (GTV) position.

METHODS AND MATERIALS

The first 16 patients (Table 1) treated consecutively with AC on local ethics–approved liver SBRT protocols, from July 2004 to May 2007, were evaluated.

All patients evaluated were ineligible for assisted breath hold but showed reduced respiratory liver motion under AC when compared with FB during screening at the time of treatment planning.

Motion assessment

At the time of treatment planning, FB respiratory liver motion was measured by use of anterior–posterior (AP) fluoroscopy as well as cine–magnetic resonance imaging (MRI) and 4DCT whenever feasible. For all patients with more than 5 mm of SI motion, motion management strategies were investigated including ABC and AC.

All patients included in this analysis had greater than 5 mm of FB respiratory motion and were deemed unsuitable for breath-hold radiotherapy because of an inability to repeatedly hold their breath for 15 seconds or more, communication concerns, or unstable breath holds. Patient ABC screening and motion management determination are described elsewhere (17, 25, 26). For all patients evaluated, AC reduced liver motion when compared with uninhibited FB.

Abdominal compression

Abdominal compression was applied to each patient, by use of one of three systems. Before the acquisition of a commercially

Table 1. Patient characteristics

	Sex	Diagnosis	Age (y)	No. of tumors	GTV (mL) (all GTVs)	Liver volume (mL)
Patient No.						
1	M	HCC	58	1	242	2402
2	F	HCC	78	1	161	1933
3	F	Cholangio	79	1	147	1285
4*	F	Mets	51	7	6	1049
5	F	Mets	79	1	223	1574
6	F	Mets	67	1	426	1935
7	M	HCC	78	3	134	1935
8	F	Mets	82	1	11	1495
9	M	Mets	75	5	45	1240
10	F	Mets	68	1	11	1300
11	F	HCC	78	4	346	1856
12	M	HCC	75	4	137	1583
13	M	Mets	74	1	12	1951
14	F	Mets	76	1	4	1660
15	M	HCC	82	1	170	1158
16	F	Mets	75	1	26	1194
All patients						
Mean			73.4	2.1	131.3	1596.9
Maximum			82.0	7.0	426.0	2402.0
Minimum			51.0	1.0	4.2	1049.0
SD			8.6	1.9	129.1	379.9

Abbreviations: GTV = gross tumor volume; HCC = hepatobiliary carcinoma; Cholangio = cholangiocarcinoma; Mets = metastatic liver disease.

* Outlier.