Physica Medica xxx (2017) xxx–xxx

Contents lists available at ScienceDirect

Physica Medica

journal homepage: http://www.physicamedica.com

Original paper

The influence of plan modulation on the interplay effect in VMAT liver SBRT treatments

Emily Hubley [a,b,*], Greg Pierce [a,b,c]

[a] Department of Medical Physics, Tom Baker Cancer Centre, 1331 29 Street NW, Calgary, AB T2N 4N2, Canada
[b] Department of Physics & Astronomy, University of Calgary, 2500 University Drive NW, Calgary, Alberta T2N 1N4, Canada
[c] Department of Oncology, University of Calgary, 2500 University Drive NW, Calgary, Alberta T2N 1N4, Canada

ARTICLE INFO

Article history:
Received 2 March 2017
Received in Revised form 23 July 2017
Accepted 31 July 2017
Available online xxxx

Keywords:
Respiratory motion
Interplay effect
VMAT
SBRT

ABSTRACT

Volumetric modulated arc therapy (VMAT) uses multileaf collimator (MLC) leaves, gantry speed, and dose rate to modulate beam fluence, producing the highly conformal doses required for liver radiotherapy. When targets that move with respiration are treated with a dynamic fluence, there exists the possibility for interplay between the target and leaf motions. This study employs a novel motion simulation technique to determine if VMAT liver SBRT plans with an increase in MLC leaf modulation are more susceptible to dosimetric differences in the GTV due to interplay effects. For ten liver SBRT patients, two VMAT plans with different amounts of MLC leaf modulation were created. Motion was simulated using a random starting point in the respiratory cycle for each fraction. To isolate the interplay effect, motion was also simulated using four specific starting points in the respiratory cycle. The dosimetric differences caused by different starting points were examined by subtracting resultant dose distributions from each other. When motion was simulated using random starting points for each fraction, or with specific starting points, there were significantly more dose differences in the GTV (maximum 100 cGy) for more highly modulated plans, but the overall plan quality was not adversely affected. Plans with more MLC leaf modulation are more susceptible to interplay effects, but dose differences in the GTV are clinically negligible in magnitude.

1. Introduction

Respiratory motion in the thorax and abdomen causes uncertainties in radiotherapy treatment delivery. Tumours that move with respiration are susceptible to a reduction in target coverage due to a blurring of the dose distribution, seen as a broadening of the penumbra at the edges of high-dose regions [1]. In the case where a tumour moving with respiration is treated with a dynamic treatment modality, such as intensity modulated radiation therapy (IMRT) or volumetric modulated arc therapy (VMAT), an additional source of error, termed the interplay effect is also present [2].

The interplay between the jaws and multileaf collimator (MLC) leaf motions and the target motion may cause differences in the planned and delivered doses in all regions of the target, rather than just at the edges. Decreased target coverage due to the interplay effect has been studied thoroughly in dynamic jaw deliveries [3], IMRT [2,4–6], and more recently for VMAT treatments [7–9]. Studies of both IMRT and VMAT cases have found that over the course of a conventional fractionation schedule, the dose differences in the target due to interplay average out to negligible levels [2,6,10].

Stereotactic body radiation therapy (SBRT) delivers larger per fraction doses in fewer fractions and is widely used to treat lesions in the lung and liver, both susceptible to respiratory motion. The interplay effect in SBRT lung treatments has been thoroughly studied and it has been found that, despite the lack of interfraction averaging seen in conventionally fractionated treatments, the dosimetric effects due to interplay are negligible [9,11–14].

In contrast to lung, liver lesions are embedded in a dose-limiting organ with a lower tolerance to radiation [15] and are often adjacent to numerous organs at risk with low tolerances to radiation, such as the bowel [16]. The location of these tumours leads to the need for very conformal dose distributions, which the treatment planning system achieves by increasing the amount of fluence modulation performed by MLC leaves. Previous work has focused on the effect of interplay in liver for sliding window IMRT and conformal arc therapies and found the overall effects to be negligible [17,18]. However, VMAT liver SBRT treatments have the added complexities of a continuously rotating gantry and very

* Corresponding author at: Department of Medical Physics, Tom Baker Cancer Centre, 1331 29 Street NW, Calgary, Alberta T2N 4N2, Canada.
E-mail address: emilyhubley1@gmail.com (E. Hubley).

http://dx.doi.org/10.1016/j.ejmp.2017.07.025
1120-1797/

few fractions. The effect of these added complexities has not been as thoroughly studied [19,20]. In addition, it has been suggested that for VMAT liver SBRT plans, the level of plan modulation may determine the influence of interplay [8,19]. The effect of plan modulation has not been explicitly studied by isolating the interplay effect from dose blurring in hypofractionated VMAT liver plans for more than a small number of patients.

In this work, the effect of the amount of MLC aperture modulation on a plan's susceptibility to interplay effects is studied by simulating realistic respiratory motion from the perspective of the MLC leaves. Overall plan quality, and therefore the effect of interplay in conjunction with dose blurring, is evaluated by looking at the GTV coverage, mean liver dose (MLD), and dose-volume parameters in the liver in close proximity to the target. In addition, the effect of interplay on these plans is isolated through a novel analysis of the effect of treatment starting point within the respiratory cycle on the dose distributions.

2. Methods

2.1. Patient selection

Ten patients previously treated using VMAT SBRT at our institution for single lesions in the liver were selected for this study. The GTVs used in this study ranged in volume from 1.7–72.2 cm^3. Patients were grouped according to the distance of the lesion from the dome of the liver. The target characteristics for each patient are listed in Table 1.

2.2. Treatment planning

Two Rapidarc® plans with different levels of complexity were created to evaluate the effect of interplay. Complexity is measured using the modulation factor (MF) as a metric, which is defined as the number of monitor units (MUs) per fraction divided by the dose per fraction:

$$MF = \frac{\#\ of\ MUs\ per\ fraction}{dose\ per\ fraction}$$

Modulation factor is used as a measure of plan complexity in our institution's physics check process for VMAT plans due to its ease of calculation. These plans cover the range of what is considered acceptable for clinical plans at our institution with patients having a median MF increase of 12% (range: 5 to 38%). Beam characteristics for each plan are presented in Table 2.

Plans were created with two 6 MV arcs from gantry 0–180° around the patient's right side to deliver 54 Gy in 3 fractions to the target. Treatment plans were made based on the dose constraints outlined in the RAS trail treatment planning protocol [21]. The GTV used in the treatment plans was taken from the patient's original treatment plan. No CTV was used, as per the RAS trial protocol [21]. The phase the GTV was contoured on was assigned as end-exhale and an expansion of 1.8 cm was made inferiorly to create an ITV (Fig. 1). No margin from ITV to PTV was added as set-up uncertainties were not modelled in this study and the intent was to examine the effect of GTV coverage. The planning criteria and dose constraints used in planning are listed

Table 1
GTV volume, the maximum GTV length measured in the superior-inferior (SI) direction, and the minimum SI distance from the superior edge of the target to the inferior edge of the dome, for each patient.

Patient	GTV volume (cm^3)	GTV SI length (cm)	Target-Dome Distance (cm)
1	41.5	5.2	0
2	72.7	5.3	0
3	56.7	5.4	0
4	32.9	6.4	<1.8
5	4.5	2.2	<1.8
6	24.0	3.2	<1.8
7	7.8	2.9	<1.8
8	1.7	1.8	≥1.8
9	2.7	1.9	≥1.8
10	28.1	3.3	≥1.8

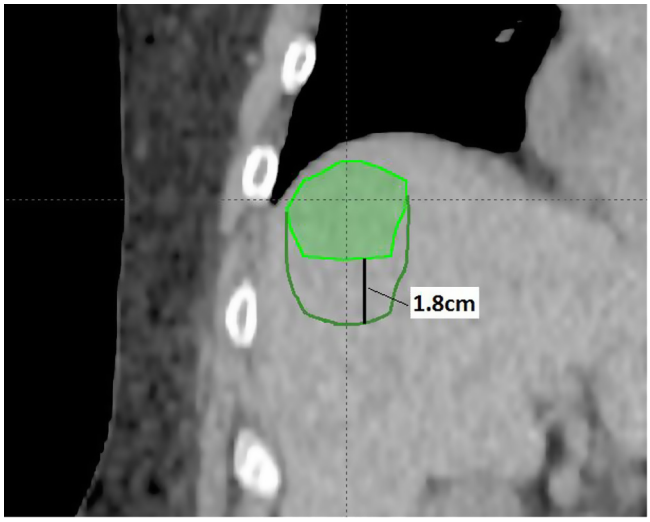

Fig. 1. The GTV is shown in light green. For all ten patients, the GTV was extended 1.8 cm in the inferior direction to create the ITV, shown in dark green. The example shown here is patient six, and the target-dome distance is less than 1.8 cm. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Table 2
Beam characteristics for each patient's high and low MF plans. The MU and delivery time are for both arcs together, and the mean gantry speed is the average over all control points in both arcs. Plans are delivered with the maximum dose rate.

Patient	MU		MF		Delivery Time (s)		Mean Gantry Speed (°/s)	
	low	high	low	high	low	high	low	high
1	3210	4414	1.78	2.45	321	441	1.12	0.82
2	4210	4419	2.34	2.46	421	442	0.86	0.81
3	3407	3791	1.89	2.11	341	379	1.06	0.95
4	3592	3886	1.98	2.16	359	389	1.00	0.93
5	4089	4771	2.27	2.65	409	477	0.88	0.75
6	3948	4353	2.19	2.42	395	435	0.91	0.83
7	4784	5068	2.66	2.82	478	507	0.75	0.71
8	3965	4610	2.20	2.56	397	461	0.91	0.78
9	3921	4426	2.18	2.46	392	443	0.92	0.81
10	3844	4366	2.14	2.43	384	437	0.94	0.82

Please cite this article in press as: Hubley E, Pierce G. The influence of plan modulation on the interplay effect in VMAT liver SBRT treatments. Phys. Med. (2017), http://dx.doi.org/10.1016/j.ejmp.2017.07.025