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ORIGINAL ARTICLE

The Effect of Abdominal Compression on Intra-fractional Motion in Stereotactic Body Radiotherapy in Liver Tumors

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OBJECTIVE

The aim of this study was to evaluate the intra fractional tumor displacement by CBCT of patients with liver cancer who underwent stereotactic body radiotherapy in the presence of abdominal compression.

METHODS

Twenty patients with liver cancer, scheduled for stereotactic body radiotherapy, were included in the study. An abdominal compression was applied to all patients to reduce tumor motion amplitude and ensure repeatable tumor movement. To determine the extent of intra fractional tumor displacement in the presence of abdominal compression, pre- and post-treatment CBCT images for all fractions were evaluated.

RESULTS

The analysis of 3D-CBCT images taken before and after treatment revealed the following average tumor position errors: 1.frx: 0.60±0.64 mm in the AP direction, 0.82±1.00 mm in the CC direction, 0.35±0.28 mm in the ML direction, and a total displacement vector (VT) of 1.29±0.98 mm. 2.frx: 0.21±0.24 mm in the AP direction, 0.47±0.62 mm in the CC direction, 0.26±0.32 mm in the ML direction, and a VT of 0.68±0.64 mm. 3.frx: 0.15±0.30 mm in the AP direction, 0.37±0.48 mm in the CC direction, 0.74±1.91 mm in the ML direction, and a VT of 1.04±1.89 mm.

CONCLUSION

Respiratory-related liver motion can lead to the creation of a large ITV for liver tumors, and therefore this effect should be reduced by appropriate immobilization techniques. Abdominal compression is a quite effective equipment to prevent intra-fractional position errors by limiting the movement of intra-abdominal organs. This study demonstrated that when the abdominal compression method is used, the intra fractional motion of liver tumors remains within the 5 mm PTV margin.

Keywords: Abdominal compression; image-guided radiotherapy; liver radiotherapy; stereotactic body radiotherapy.

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INTRODUCTION

Stereotactic body radiotherapy (SBRT) is a highly effective treatment for patients with primary or metastatic liver cancer. The use of the SBRT technique, with its high dose gradient, allows for the effective preservation of normal tissues while reducing treatment-related side effects.[1] The success of SBRT treatment is related to minimizing geometric uncertainties in the treatment area. One of the most significant sources of uncertainty affecting the success of SBRT treatments for liver tumors is tumor motion due to respiration. By employing respiratory control techniques, ITV (Internal Target Volume) and PTV (Planning Target Volume) volumes can be reduced, thereby minimizing the volume of normal tissue exposed to high doses.[2–7] Respiration-related tumor motion can be reduced using two methods. One involves treatment during the deep inspiration phase, which requires the patient to hold their breath (DIBH), and the other is through treatment with abdominal compression (AC). However, many patients cannot tolerate treatment with the DIBH technique; therefore, free breathing is preferred.[8]

Image-guided radiotherapy (IGRT) has the potential to detect and correct baseline movements in the liver's position relative to the bone, respiratory motion, or pre-treatment deformations. Unlike lung tumors, imaging of liver tumors is difficult due to the lack of soft tissue contrast of image-guided radiotherapy modalities such as computed tomography (CT) and cone-beam tomography (CBCT).[4–6] For liver SBRT, given that direct visualization of the tumor is not feasible using X-ray-based IGRT systems such as two-dimensional fluoroscopy or 3D-CBCT. But, reference structures like bony landmarks, the whole liver, and fiducial markers placed inside or near the tumor can be tracked to indirectly monitor the tumor's position.[9,10]

This study is important in highlighting the impact of abdominal compression in liver tumors on the geometric uncertainties and positional errors occurring in the ITV due to respiratory motion.

MATERIALS AND METHODS

Patient preparation for CT simulation

This study was conducted in accordance with the declaration of Helsinki and was approved by the by the Ethics Committee of Memorial Şişli Hospital Ethics Committee (Ethical Approval No: 004/ 26.12.2024).

Twenty patients treated with hypo-fractionated liver SBRT between 2016–2018 at our clinic were included in the study. The clinical features and treatment planning schemes of the patients are shown in Table 1. In all patients, an Elekta body frame was used in conjunction with an abdominal compression plate. This combination was utilized to reduce tumor motion due to respiration and ensure reproducible positioning. Patients were set up in the head-first-supine (HFS) position with their arms above their heads. The patients were prepared as shown in Figure 1 and three-phase CT images (at 30, 90, and 180 seconds) with contrast were acquired during free breathing using a Siemens Somatom Computed Tomography system (Siemens Medical Systems, Germany) to assess internal target movement for ITV determination.

Pre-treatment and post-treatment 3D-CBCT images of each patient were evaluated with IGRT protocol that was routinely applied at our clinic. Patients underwent to treatment after daily position corrections were made on pre-treatment 3D-CBCT images. After each daily treatment session, a second set of 3D-CBCT images was acquired from the same patient and recorded. Planning CT and 3D-CBCT registrations were done based on the entire liver. It was calculated the Anterior-Posterior (AP), Cranial-Caudal (CC), and Medial-Lateral (ML) shifts of the PTV, as well as the three-dimensional displacement vector (VT), using 3D-CBCT images taken before and after treatment for first 3 treatment fractions.

Determination of internal target volume (ITV)

For helical-mode contrast-enhanced scans (rotation time: 1 sec), CT images of 2.5 mm cross-sectional thickness were obtained 30, 90 and 180 sec after intravenous administration of a contrast agent. All CT images were transferred to the Eclipse treatment planning system (Version13, Varian, Palo Alto-USA). GTVs in images obtained at 30, 90 and 180 seconds were named as GTV_{30}, GTV_{90} and GTV_{180}, respectively. In addition to the planning tomography, magnetic resonance (MR) images for each patient were imported into the system and co-registered with the tomography images to define the Gross Target Volume (GTV_{MR}). To obtain the ITV, the GTV structures defined in each imaging set were combined using the following formula.

$$ITV = GTV_{30}+GTV_{90}+GTV_{180}+GTV_{MR}$$

PTV was created ITV+ 5 mm.

Planning process of Volumetric Modulated Arc Therapy (VMAT)

For the planning of SBRT treatment, 6 or 10 FFF (Flattening Filter Free) photon energies were se-

Table 1 Clinical characteristics of the patients

Patient	Tumor position (segment)	Volume of GTV (cm^3)	Liver volume (cm^3)	Liver-GTV volume (cm^3)	Planned treatment dose (Gy)
1	8–5–7–4a–4a	2.3–6–1.7–1–1.2	1645	1633	5*12
2	5–4	1–2.7	1410	1406	3*15
3	8	22	1591	1569	3*18
4	5–6	5.3–29	1276	1242	3*15
5	6	11.8	2123	2111	3*15
6	4b–3	42.6–38.6	1975	1894	5*12
7	8	15.5	2190	2175	3*15
8	8–5–4b	33.5–1.4–1	1301	1265	5*12
9	7–4b	7.4–3.4	1582	1571	3*18
10	4a–3–4a	5.7–6.6–0.4	1284	1271	5*12
11	4b	8.9	1157	1148	3*15
12	4b	35	1362	1327	3*15
13	6	3.2	1870	1867	3*18
14	4b	46.2	2144	2098	3*15
15	5–4b	2.9–1	1164	1160	3*15
16	6–4b–6	4.1–3.5–3.8	1816	1805	5*12
17	8	7.3	1583	1576	3*15
18	7	11.8	760	748	3*18
19	4b–3–3	19.1–4.6–2.5	1385	1359	5*12
20	8	3.1	1735	1732	3*15

GTV: Gross tumor volume

Fig. 1. The setup and immobilization method used in patients with liver tumors.

lected according to the depth of the tumor among the energies available in the Varian Truebeam STX. Dose rate was selected as 1400 cGy / min. and 2400 cGy / min. for 6 MV FFF and 10 MV FFF photon beams respectively. All VMAT plans were used at 30–330 degrees' collimator angles to reduce the ef-

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Table 2 3D-CBCT-guided intra-fractionated PTV volume displacement in patients with liver tumor

	1st fraction				2nd fraction				3rd fraction			
No	**AP**	**CC**	**ML**	**V_T**	**AP**	**CC**	**ML**	**V_T**	**AP**	**CC**	**ML**	**VT**
1	-0.05	0.18	-0.07	**0.20**	-0.09	-0.25	-0.15	**0.31**	-0.07	-0.04	-0.04	**0.09**
2	-1.29	-0.02	-0.08	**1.29**	0.04	0.08	-0.03	**0.09**	0.03	-0.04	-0.01	**0.05**
3	8.14	0.94	-0.35	**8.20**	0.29	0.11	-0.61	**0.68**	-0.24	-1.36	-5.64	**5.81**
4	0.33	0.03	-0.39	**0.51**	0.07	0.11	-0.02	**0.13**	0.04	-0.03	-0.02	**0.05**
5	0.45	-3.59	-0.52	**3.66**	-0.20	0.05	-0.03	**0.21**	0.05	-0.85	-0.02	**0.85**
6	0.16	-0.61	-0.07	**0.63**	-0.06	-0.33	0.03	**0.34**	-0.05	-0.84	0.16	**0.86**
7	0.08	1.32	0.37	**1.37**	0.58	0.15	1.08	**1.24**	0.06	0.49	-0.5	**0.70**
8	0.88	0.52	-0.24	**1.05**	0.17	0.44	0.34	**0.58**	0.61	0.15	-7.74	**7.77**
9	0.48	2.65	-1.21	**2.94**	0.03	-0.13	-0.24	**0.27**	-0.04	-0.05	-0.24	**0.25**
10	-0.77	3.33	0.32	**3.43**	-0.09	0.06	-0.17	**0.20**	0.03	-0.02	-0.08	**0.09**
11	0.24	-0.23	-0.13	**0.36**	-0.13	-0.16	0.08	**0.22**	-0.11	-0.1	-0.09	**0.17**
12	-0.21	-0.62	0.46	**0.80**	-0.58	-2.98	0.14	**3.04**	-0.32	0.29	-0.12	**0.45**
13	-1.13	0.11	0.72	**1.34**	0.09	0.19	0.15	**0.26**	0.06	-0.17	-0.4	**0.44**
14	-0.08	0.48	0.32	**0.58**	-0.35	0.53	0.03	**0.64**	-0.08	0.39	0.04	**0.40**
15	-0.91	-0.02	-1.05	**1.39**	-0.12	1.18	-0.04	**1.19**	-0.11	1.87	0.13	**1.88**
16	0.20	0.51	0.21	**0.59**	-0.06	-0.23	-0.36	**0.43**	-0.26	0.36	0.02	**0.44**
17	1.14	0.24	0.10	**1.17**	0.03	0.41	0.14	**0.43**	0.06	-0.34	0.39	**0.52**
18	-0.65	0.53	-0.10	**0.84**	-0.09	0.75	-0.12	**0.76**	0.09	0.09	0.59	**0.60**
19	-2.99	0.13	-0.36	**3.01**	1.04	-0.05	-0.14	**1.05**	0.98	0.05	0.08	**0.98**
20	0.35	-0.84	-0.60	**1.09**	0.23	-0.73	-0.95	**1.22**	0	-0.02	-0.01	**0.02**
Avg	0.60	0.82	0.35	**1.29**	0.21	0.47	0.26	**0.68**	0.15	0.37	0.74	**1.04**
SD	0.64	1.00	0.28	**0.98**	0.24	0.62	0.32	**0.64**	0.23	0.48	1.91	**1.89**

CBCT: Cone-beam tomography; PTV: Planning target volume; AP: Anterior-posterior; CC: Cranial-caudal; ML: Medial-lateral; V_T: Total displacement vector in millimeters

fects of leakage caused by tongue and grove effect and allow transverse planar modulation during gantry rotation. The collimator aperture was adjusted to encompass the PTV throughout the entire gantry rotation, with an additional margin of approximately 10 mm. The primary goal during planning was to ensure adequate PTV coverage for all patients, and the secondary objective was to reduce individual critical organ doses as much as possible. All plans were made to give 95% of the prescribed total dose, which ranged from 45 Gy to 60 Gy delivered in 3 to 5 fractions, to the PTV.

Determination of the total displacement vector within the fraction

The displacement vectors were measured in the anterior-posterior (AP), cranial-caudal (CC), and Medial-Lateral (ML) directions based on pre- and post-treatment CBCT images. The total displacement vector (V_T) was calculated using the following formula:

$$V_T = \sqrt{(AP)^2+(CC)^2+(ML)^2}$$

RESULTS

Table 2 and Figure 2 shows the intra-fractional PTV displacement data for the patients. The largest shift was observed during the first fraction of Patient 3. This patient exhibited a displacement of 8.14 mm in the AP direction, 0.94 mm in the CC direction, -0.35 mm in the ML direction, resulting in a total displacement vector (VT) of 8.2 mm. This disposition in the patient's intact tissues and PTV was shown in Figure 3. The impact of the tumor movement on Dose-Volume Histogram (DVH) of PTV was shown in Figure 4. In Figure 3 and Figure 4, PTV1 refers to the initial planned target volume based on the 3D-CBCT image acquired at the start of the patient's first treatment, while PTV2 represents the planned target volume based on the 3D-CBCT obtained at the end of the patient's first treatment. To show the effect of intra-fractional movements on patient PTV dose, the DVH of patient number 3, which has the highest intra-fractional change, is given as an example in Figure 4. As shown in Figure 4, The DVH evaluation of the patient revealed a 25% decrease in PTV coverage.

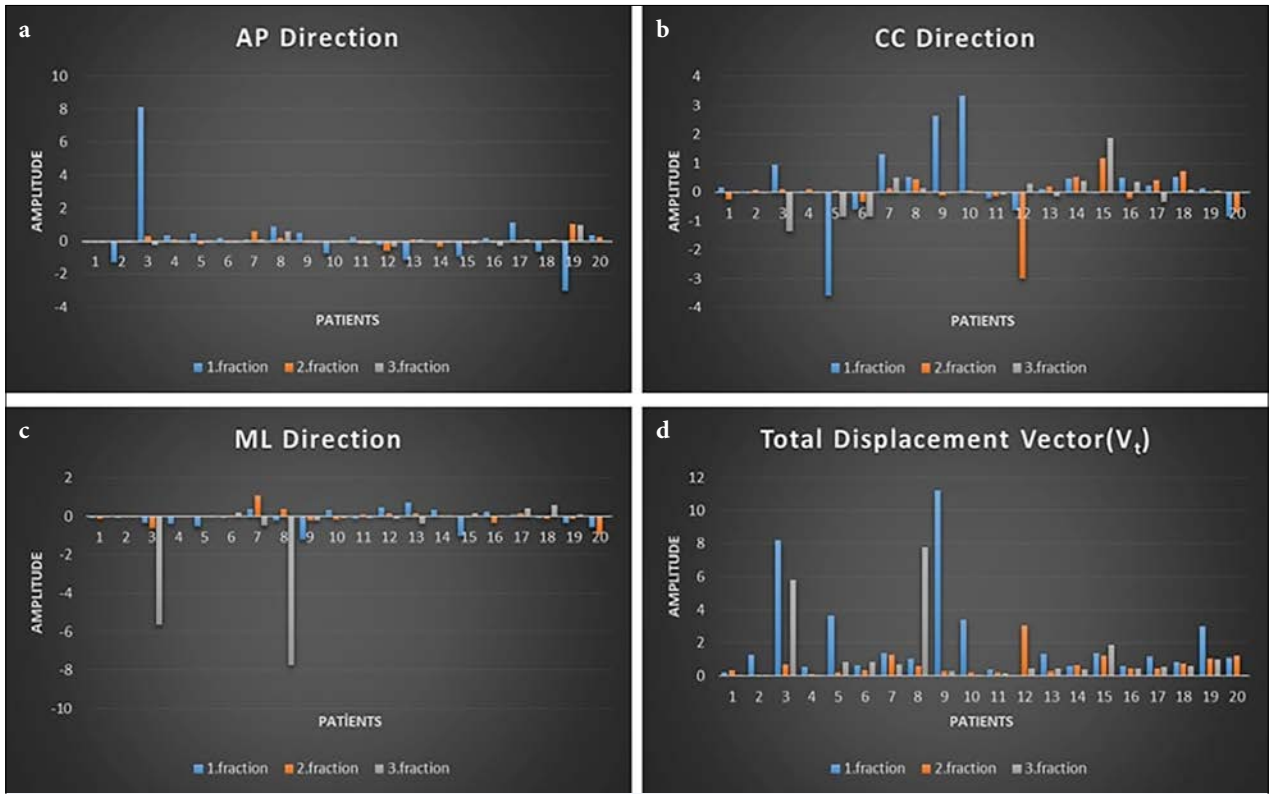

Fig. 2. 3D-CBCT- guided intra-fractionated PTV volume displacement in patients with liver tumor; AP: Anterior-posterior (a), CC: Cranial-caudal (b), ML: Medial-lateral (c) and V_T: Total displacement vector (d).
CBCT: Cone-beam tomography; PTV: Planning target volume.

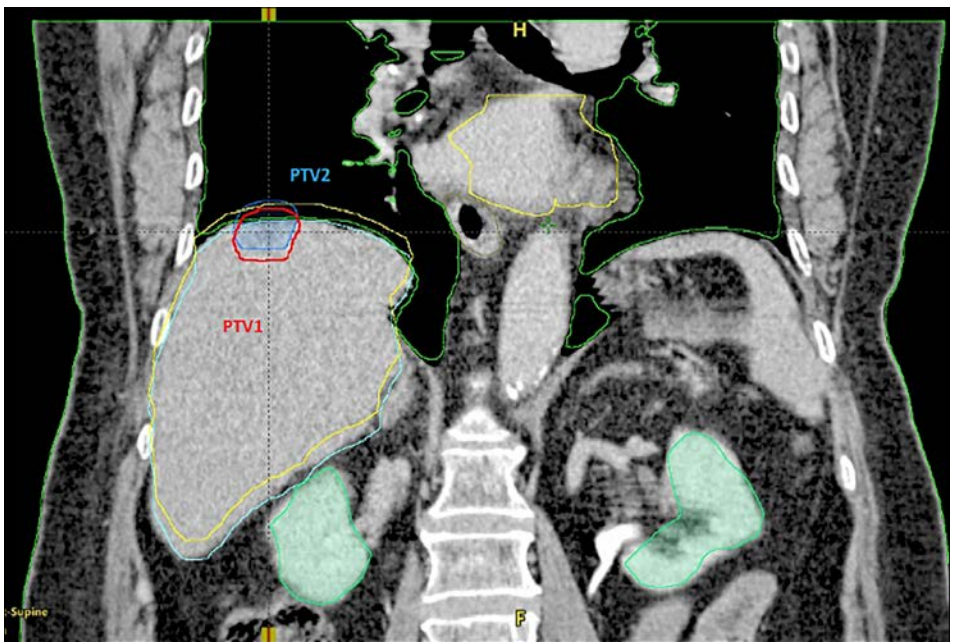

Fig. 3. The coronal image depicts a patient (No:3) with the maximum PTV displacement observed during the first treatment fraction.
PTV: Planning target volume.

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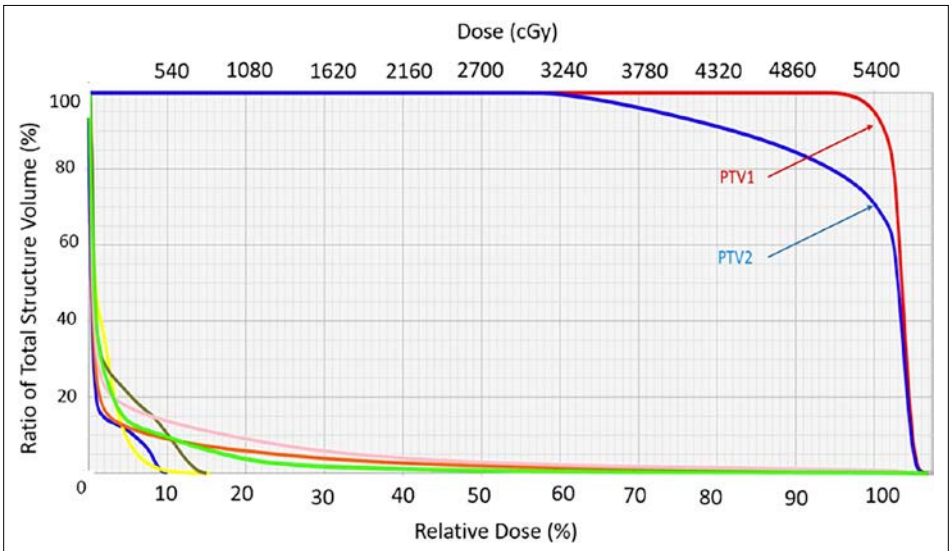

Fig. 4. Dose-volume histogram shows the coverage difference between PTV1 and PTV2.
PTV: Planning target volume.

DISCUSSION

Success in the treatment of liver SBRT depends on the correct definition of ITV. Displacement of the liver by free breathing causes a change in the GTV volume; therefore this effect should be reduced by appropriate immobilization techniques. Abdominal compression is a quite effective equipment to prevent intra-fractional and inter-fractional position errors by limiting the movement of intra-abdominal organs.

Park et al.[11] reported that the IGRT method with reference marks by 4D-CBCT by using fiducial marker movements during liver SBRT yielded more accurate results compared to IGRT procedure performed by liver contour or diaphragm position.

4D-CBCT was demonstrated to decrease the blurring of fiducial markers and liver anatomy in a considerable extent and be beneficial for liver SBRT performed by IGRT.[12–15] Case et al.[16] reported change in intra fractional liver movement using 4D-CBCT and demonstrated that it was <3mm in 80% of fractions in 29 patients.

Dreher et al.,[17] reported that use of abdominal compression (AC) limited tumour movements in their study that they performed to demonstrate the difference between the two types of immobilization in 54 patients with liver cancer. Vertical, lateral and cranial-caudal movements were examined in that study and the maximum displacement was reported to be in the cranial-caudal direction.

Studies have been published in the literature reporting that intra-fractional setup errors can be monitored and corrected by online imaging. Although it is possible to correct intra-fractional position errors with on-line adaptive radiotherapy methods, it is impossible currently to reflect the change in these position errors to the treatment plan of the patient.[18–21]

Twenty patients with liver tumors who underwent SBRT using the VMAT technique with the application of an abdominal compression plate were retrospectively included in the study. The SBRT technique has enabled application of high-dose radiotherapy for liver tumors. However, precise positioning and reduction of liver movement is very important to preserve the normal tissue and apply the required dose to the target. To accommodate potential uncertainties, such as the clinical margin, daily position errors, and in-target variations in fractionated conformal radiotherapy, a safety margin of approximately 1.5 cm in the horizontal plane and 2.5 cm in the cranio-caudal direction is commonly added to the GTV. This causes a quite extensive treatment area. Limiting patient and organ movements has been one of the important steps in SBRT treatments. Lax et al.[22] demonstrated that target malpositions could be limited to median 3 mm and maximal 7 mm by developing a frame including a vacuum pillow and an abdominal compression device for the SBRT treatment of liver tumors.

Kitamura et al.[23] conducted real-time tumor tracking in 20 patients with liver cancer, utilizing a gold marker. In their study, they observed tumor displace-

ments of 4±4 mm (ranging from 1 mm to 12 mm) in the ML direction, 9±5 mm (ranging from 2 mm to 19 mm) in the CC direction, and 5±3 mm (ranging from 2 mm to 12 mm) in the AP direction using real-time tumor tracking. In that study, the tumour was not affected by the movement in CC direction, although it was very much larger than the movements in other directions. Also in that study, tumour displacement in ML (2±1 mm) and AP (3±2 mm) in patients with left lobe tumours were lesser compared to the tumour displacement in ML (5±4mm) and AP (6±3 mm) in patients with right lobe tumours.

Wunderink et al.[24] found that tumour excursion had been reduced in CC and AP directions in all patients by abdominal compression but in majority of patients ML movement increased with compression. In our study was not correlate with those finding, it can be related with tumour location or intra-patient variations.

In this present study in which we had applied abdominal compression, mean position errors were found as; *for 1st fractions*: 0.60±0.64 mm in the AP direction, 0.82±1.00 mm in the CC direction, 0.35±0.28 mm in the ML direction and V_T=1.29±0.98 mm; *for 2nd fractions* 0.21±0.24 mm in the AP direction, 0.47±0.62 mm in the CC direction, 0.26±0.32 mm in the ML direction and V_T=0.68±0.64 mm; and *for 3rd fractions*: 0.15±0.23 mm in the AP direction, 0.37±0.48 mm in the CC direction, 0.74±1.91 mm in the ML direction and V_T=1.04±1.89 mm. This comparison of the AP, CC, ML position errors and total displacement vectors (V_T) are shown in Figure 2.

We demonstrated that this displacement decreased the dose in PTV coverage by 25 % by performing two different planning before and after the treatment in the patient No:3 with of 1591 cm^3 and with the largest position a liver volume error. Romero et al.[25] demonstrated that daily position corrections with IGRT were sufficient for the treatment volume but insufficient for critical organs in the treatment of liver SBRT in 23 patients. Romeo et al. performed two different planning for each patient in their study and demonstrated that setup errors caused 21% dose decrease in PTV coverage. Lovelock et al.[26] studied with larger numerous sample and found that the mean CC motion was reduced to average 4.4 mm with a range 1–8 mm. In our study we found that motion could be change with fraction number.

Zeng et al.[27] evaluated the amplitude changes and baseline shifts of respiratory motion in 24 liver patients using four-dimensional (4D) CT, interfraction, and intrafraction CBCT. To obtain the respiratory motion signal, the patients were immobilized with a thermoplastic full-body mask placed between the xiphoid process and the navel. The 4D CT scan was performed with free breathing using a 3 mm slice thickness. According to the baseline shifts, they recalculated the ITV-PTV margin and redesigned the plans to compare the dosimetric variation. Significant amplitude changes occurred during dose delivery compared to that in 4D-CT. They emphasized that using 4.0 mm left-right (LR), 7.0 mm superior-inferior (SI), and 4.0 mm anterior-posterior (AP) ITV–PTV margins could ensure target dose coverage and keep the dose limitation of normal tissues at an acceptable level. Sharma et al.[28] identified 9 studies with abdominal compression (AC) in a systematic review and meta-analysis to recommend PTV margins with different motion management strategies for liver SBRT. This study reported that an asymmetric margin for AC (4 mm in the AP, 6 mm in the SI and LR directions) may be appropriate.We can say that the results of our study investigating the intra-fractional movement of liver tumors during SBRT when AC was used are consistent with the literature.

CONCLUSION

Respiratory-related liver motion can lead to the creation of a large ITV for liver tumors, and therefore this effect should be reduced by appropriate immobilization techniques. Abdominal compression is a quite effective equipment to prevent intra-fractional position errors by limiting the movement of intra-abdominal organs. This study demonstrated that when the abdominal compression method is used, the intra fractional motion of liver tumors remains within the 5 mm PTV margin.

Ethics Committee Approval: The study was approved by the Memorial Şişli Hospital Ethics Committee (no: 004, date: 26/12/2024).

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