대한방사선종양학회지 2008;26(4):280~288 DOI: 10.3857/jkstro.2008.26.4.280

Treatment Margin Assessment using Mega-Voltage Computed Tomography of a Tomotherapy Unit in the Radiotherapy of a Liver Tumor

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Purpose: To identify the inter-fractional shift pattern and to assess an adequate treatment margin in the radiotherapy of a liver tumor using mega-voltage computed tomography (MVCT) of a tomotherapy unit.
Materials and Methods: Twenty-six patients were treated for liver tumors by tomotherapy from April 2006 to August 2007. The MVCT images of each patient were analyzed from the 1st to the 10th fraction for the assessment of the daily liver shift by four groups based on Couinard's proposal. Daily setup errors were corrected by bony landmarks as a prerequisite. Subsequently, the anterior-, posterior-, right-, and left shifts of the liver edges were measured by maximum linear discrepancies between the kilo-voltage computed tomography (KVCT) image and MVCT image. All data were set in the 2-dimensional right angle coordinate system of the transverse section of each patient's body.
Results: The liver boundary shift had different patterns for each group. In group II (segment 2, 3, and 4), the anterior mean shift was 2.80±1.73 mm outwards, while the left mean shift was 2.23±1.37 mm inwards. In group IV (segment 7 and 8), the anterior-, posterior-, right-, and left mean shifts were 0.15±3.93 mm inwards, 3.15±6.58 mm inwards, 0.60±3.58 mm inwards, and 4.50±5.35 mm inwards, respectively. The reduced volume in group II after MVCT reassessment might be a consequence of stomach toxicity.
Conclusion: Inter-fractional liver shifts of each group based on Couinard's proposal were somewhat systematic despite certain variations observed in each patient. The geometrical deformation of the liver by respiratory movement can cause shrinkage in the left margins of liver. We recommend a more sophisticated approach in free-breathing mode when irradiating the left lobe of liver in order to avoid stomach toxicity.

Key Words: MVCT, Liver tumor, Tomotherapy

Introduction

Accurate delineation of gross tumor volume (GTV) and clinical target volume (CTV) can render dose escalation and toxicity reduction in spite of vulnerable liver tissue and is required for high accuracy radiotherapy such as intensity modulated radiotherapy (IMRT) or tomotherapy. However, there are still limitations in liver tumor radiotherapy despite high accuracy radiotherapy techniques. Dose delivery is limited by liver motion and concomitant geometrical deformation by respiratory movement. Furthermore, there are setup errors, interfractional discrepancies of tumor location, and other factors. Thus, when liver tumors are irradiatied, proper internal target volume (ITV) and planning target volume (PTV) margin should be considered.

As a conventional method, cranio-caudal PTV margin usually reflects respiratory diaphragmatic shift and anterior, posterior, right, and left PTV margins are based upon these cranio-caudal PTV margin. Some papers reported 5 to 10 mm PTV margin for GTV without reflecting geometrical deformation.[1~3] For more sophisticated PTV delineation, deform-

Submitted September 25, 2008, accepted November 13, 2008
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This study was selected for a poster presentation at the 50th annual meeting of the American Society for Therapeutic Radiation Oncology (ASTRO) in Boston, on September 21-25, 2008.

ations associated with respiration should be reflected because liver is essentially soft tissue.[4~7] ICRU report 62 recommended ITV concept for more accurate radiotherapy.[8] For these reasons, more accurate verification system for patient setup and tumor location is needed. There have been many verification systems so far, but mostly they were 1 or 2 dimension-based. The typical x-ray fluoroscopic verification with fiducial marker can be helpful for tumoral location or tumor motion, but mostly it cannot reflect volumetrical location.

3-dimensional analysis with conventional system is difficult for liver motion pattern study, compared with 1- or 2-dimensional assessments. Other organ motions including lung tumor, prostate gland have been analyzed because of quite clear image.[9,10] Recently, helical tomotherapy is spreading and Mega-voltage computed tomography (MVCT), a volumetric image-guidance system, within helical tomotherapy unit is known to be useful for daily setup error correction by image fusion with kilo-voltage based simulation CT.[11~13] For prostate cancer, some authors reported papers on interfractional prostate contour change.[9,14] Despite less clear MVCT image contour of liver tumor, liver boundary confirmation is possible because of organ density difference. By understanding liver boundary shift pattern around the liver tumors using MVCT image, it is possible to assess proper treatment margin.

The purpose of this study is to identify the interfractional liver shift pattern in free-breathing mode and to assess adequate treatment margin in radiotherapy of liver tumor using MVCT image.

Materials and Methods

1. Patients

Between April 2006 and August 2007, 29 patients were treated for liver tumor with helical tomotherapy. Three patients were excluded because of poor performance and long period of rest. Thus, 26 patients were enrolled and for these patients daily liver shift pattern were analyzed with MVCT image from 1st to 10th fraction in order to assess interfractional change. The number of measurement for shift was restricted up to 10th fraction to minimize body contour factors such as weight loss or breathing pattern change during radiotherapy. In all, fifteen of these patients were diagnosed with hepatocellular carcinoma, six patients were diagnosed with biliary duct cancer, three patients had gallbladder cancer, and three patients had metastatic liver tumors. All patients with bile duct cancer and gallbladder cancer had tumors with liver parenchymal invasion or of intrahepatic origin. We verified the respiratory diaphragmatic movement by x-ray fluoroscopy and all patients had diaphragmatic movement of less than 20 mm.

2. Setup error correction

Simulation kilo-voltage computed tomography (KVCT) and daily MVCT scan were performed on supine position with free breathing for all patients. The thickness of every slice was 5 mm for simulation KVCT. Setup errors were corrected by three steps. First, the simulation KVCT was scanned based upon laser system and the skin tattoo location with supine

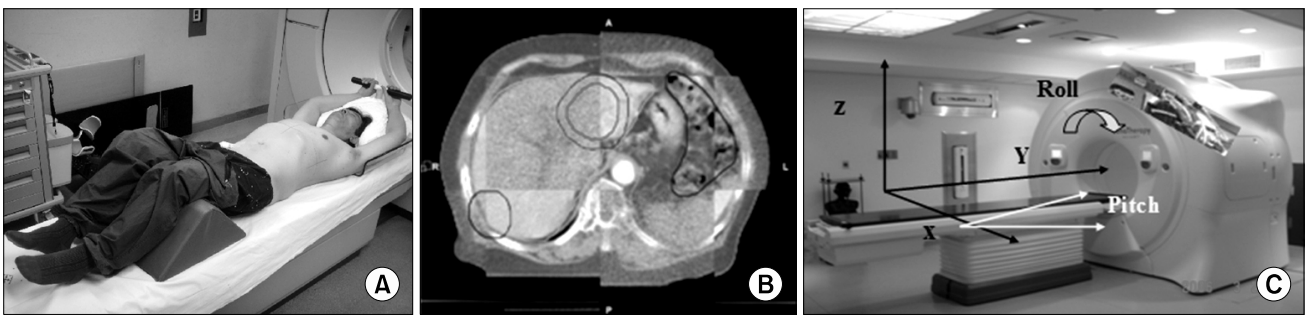

Fig. 1. Daily setup error verification (A) laser system with conventional skin tattoos (room isocenter), (B) MVCT scan and image fusion with KVCT, (C) new isocenter by bony structure and couch translation and rotation.

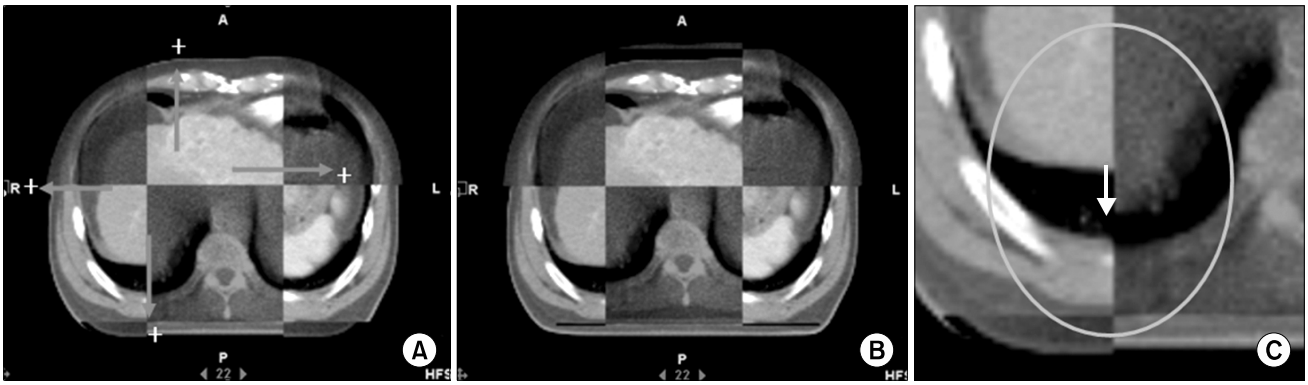

Fig. 2. Measurement of interfractional liver boundary shift (A) quantification of shift length to 4 directions (anterior, posterior, right, left) in transverse cross frame reference system, (B) MVCT image movement according to posterior direction to match posterior liver boundary of KVCT image, (C) magnification of (A).

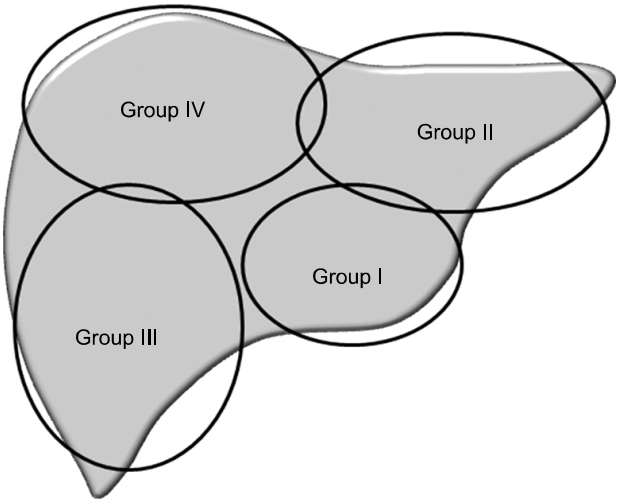

Fig. 3. Group I~IV according to Couinaud's proposal (Group I=segment 1; Group II=segment 2~4; Group III=segment 5, 6; Group IV=segment 7, 8).

position before the tomotherapy session. Second, MVCT was scanned for the tumor area with the same position to get the KVCT image. After that, MVCT scan was done with 6 mm thick cross section slices. When the KVCT image and MVCT image were fused with each other, bony landmarks of each scan such as vertebral bodies and ribs were made consistent. Consequently the location of couch was changed and the couch shift lengths were measured in 3-dimensional right angle coordinate system; x-axis (left-right), y-axis (cranio-caudal), and z-axis (anterior-posterior), and rotation. By shift length for each axis, that is, the point difference between the skin tattoo and new point, the couch was moved along each axis to establish a new reference point for 1^{st} to 10^{th} tomotherapy session (Fig. 1).

3. Measurement of liver (tumor) boundary shift

Likewise, after setup error correction as a prerequisite, we measured the liver or tumor boundary shift discrepancies from 1^{st} to 10^{th} through the comparison MVCT image with simulation KVCT image on milimeter degree. Most of liver tumors were unrespectably large and extensive, and the tumor edges were correspondent or adjacent to outer boundaries of liver parenchyma. Thus, liver parenchyma edge or tumor edge was resolved into the basis for boundary shift. We set up a two-dimensional orthogonal coordinate system on the cross-section of each patient's body. There were 4 directions according to each axis such as anterior, posterior, right, and left in this system. We measured the shift by comparing the measured discrepancies between liver or tumor boundary of MVCT and simulation KVCT in 2 to 4 directions according to tumor location on which MVCT scan was focused. One or two directions of liver or tumor boundary shift could not be measured in some cases because of low contrast resolution and relatively small tumor size. The final value of each session was determined by the maximum difference among each slice. When liver or tumor boundaries in MVCT was extended beyond the body area of simulation KVCT, they were valued positive in each direction. If vice versa, they were valued negative (Fig. 2). For cranio-caudal direction, we used the routinely measured diaphragmatic movement range in free breathing obtained from a x-ray fluoroscopy because of poor

resolution of reconstructed coronal and sagittal MVCT images. All patients were classified into 4 groups according to Couinaud's proposal on the basis of the tumor location in order to assess the shift pattern of each group. Group I was composed of the patients who have liver tumor in segment 1. Group II was composed of the patients with liver tumor located in segment 2, 3, and 4, which were mostly left lobe of the liver. Group III was composed of the patients with liver tumor in segment 5 and 6, which usually occupied the right lower lobe of the liver. And group IV, which was composed of the patients with liver tumor in segment 7 and 8, mostly had tumors of liver dome area (Fig. 3). In addition to the analysis of an individual patient, patient's age, gender, surgery, transarterial chemoembolization or transarterial chemoinfusion (TACE/TACI), and re-irradiation were reviewed for correlation with liver or tumor boundary shift pattern. We used PQ-5000-CT simulator (Philips, Eindhoven, Netherlands) for simulation KVCT, Ximatron (Varian Medical Systems, Palo Alto, USA) for recognizing diaphragmatic movement range, Tomotherapy Hi-Art system 2.0 (Tomotherapy, Madison, USA) for MVCT analysis, and Pinnacle 3 (Philips Medical System, Milpitas, USA) for MVCT reassessment.

Table 1. Patient Characteristics

Characteristics	No. of patients (%)
Age (years)	
≥60	17 (65.4)
<60	9 (34.6)
Sex	
Male	21 (80.8)
Female	5 (19.2)
Disease	
Hepatocellular carcinoma	15 (57.7)
Cholangiocarcinoma	6 (23.1)
Gall bladder cancer	3 (11.5)
Metastatic liver tumor	2 (7.7)
Operation	
Yes	6 (23.1)
No	20 (76.9)
TACE/TACI *	
Yes	9 (34.6)
No	17 (65.4)
Previous RT (in-field)	
Yes	1 (3.8)
No	25 (96.2)
Group	
I	10 (38.5)
II	6 (23.1)
III	4 (15.3)
IV	6 (23.1)
Total number of patients	26

* transarterial chemoembolization or transarterial chemoinfusion

Results

1. Patient characteristics

In all, patients with age 60 or older were 17 (65.4%), and the number of male patients was 21 (80.8%). Six patients had undergone surgical procedure (23.1%), and nine patients had been treated with TACE or TACI (34.6%). One patient was re-irradiated to the liver (3.8%). For the group according to tumor location, 10 patients belonged to group I (38.5%), 6 patients group II (23.1%), 4 patients group III (15.3%), and 6 patients group IV (23.1%) (Table 1).

2. Patient setup errors

The average setup errors by couch movement in a three-dimensional orthogonal coordinate system were 0.45±2.04 mm for x-axis (left-right), 0.97±4.06 mm for y-axis (cranial-caudal), and 8.38±4.67 mm for z-axis (anterior-posterior), respectively.

3. Liver or tumor boundary changes

The liver or tumor boundary shifts according to patient's age, gender, whether or not they had surgery and/or TACE/TACI are shown in Table 2. The shift patterns of each group had no correlation with the patient's age, gender, whether or not they had surgery and/or TACE/TACI. Effect of previous irradiation on shift pattern of liver was uncertain because only one case underwent re-irradiation.

In group I, anterior mean shift was 2.13±3.57 mm outwards, posterior mean shift was 0.07±0.99 mm outwards, right mean shift was 1.03±2.37 mm outwards, and left mean shift was 0.18±1.84 mm inwards. In group II, anterior mean shift was 2.80±1.73 mm outwards, and left mean shift was 2.23±1.37 mm inwards. In group III, there were 4 patients (15.4%), all of whom had posterior lesions, and anterior shift could not be measured because of poor resolution quality of MVCT between tumor and normal liver tissue. In group IV, anterior-, posterior-, right-, and left mean shifts were 0.15±3.93 mm inwards, 3.15±6.58 mm inwards, 0.60±3.58 mm inwards, 4.50±5.35 mm inwards, respectively. Posterior mean shifts of group I, II, and III were less than 1 mm and their standard

Table 2. Liver Boundary Shift According to Clinical Factors

Characteristics	Diaphragm (mm)	*P*	Anterior (mm)	*P*	Posterior (mm)	*P*	Right (mm)	*P*	Left (mm)	*P*
Age										
≥60	1.00±0.27	0.617	2.90±2.51	0.660	−0.35±4.53	0.827	0.70±3.00	0.907	−1.43±3.39	0.757
<60	1.14±0.42		1.45±3.43		−0.66±2.07		1.50±2.38		−1.04±1.73	
Sex										
Male	1.17±0.40	0.155	−0.22±3.00	0.624	−0.70±3.52	0.989	−0.46±2.39	0.069	−1.3±2.57	0.627
Female	0.70±0.40		5.20±1.53		−0.47±1.05		2.95±0.49		−0.6±2.27	
Operation										
Yes	1.00±0.29	0.617	0.45±1.01	0.580	0.43±1.01	0.412	0.30±0.92	0.854	−0.60±2.55	0.523
No	1.25±0.39		2.27±3.39		−0.94±3.53		0.68±2.91		−1.40±2.35	
TACE/TACI *										
Yes	0.90±0.41	0.125	2.73±2.12	0.519	0.35±1.30	0.304	0.80±1.45	0.805	−1.13±1.62	0.961
No	1.25±0.36		0.90±3.77		−1.12±3.75		0.20±2.94		−1.18±2.82	
Group										
I	1.25±0.45	0.911	2.13±3.57	0.728	0.07±0.99	0.296	1.03±2.31	0.928	−0.18±1.84	0.005
II	1.00±0.29		2.80±1.73		−0.07±1.38		1.10±0.78		−2.23±1.37	
III	1.00±0.29				0.50±0.47		0.30±0.49		0.15±0.41	
IV	1.10±0.50		−0.15±3.93		−3.15±6.58		−0.60±3.58		−4.50±5.35	

* transarterial chemoembolization or transarterial chemoinfusion

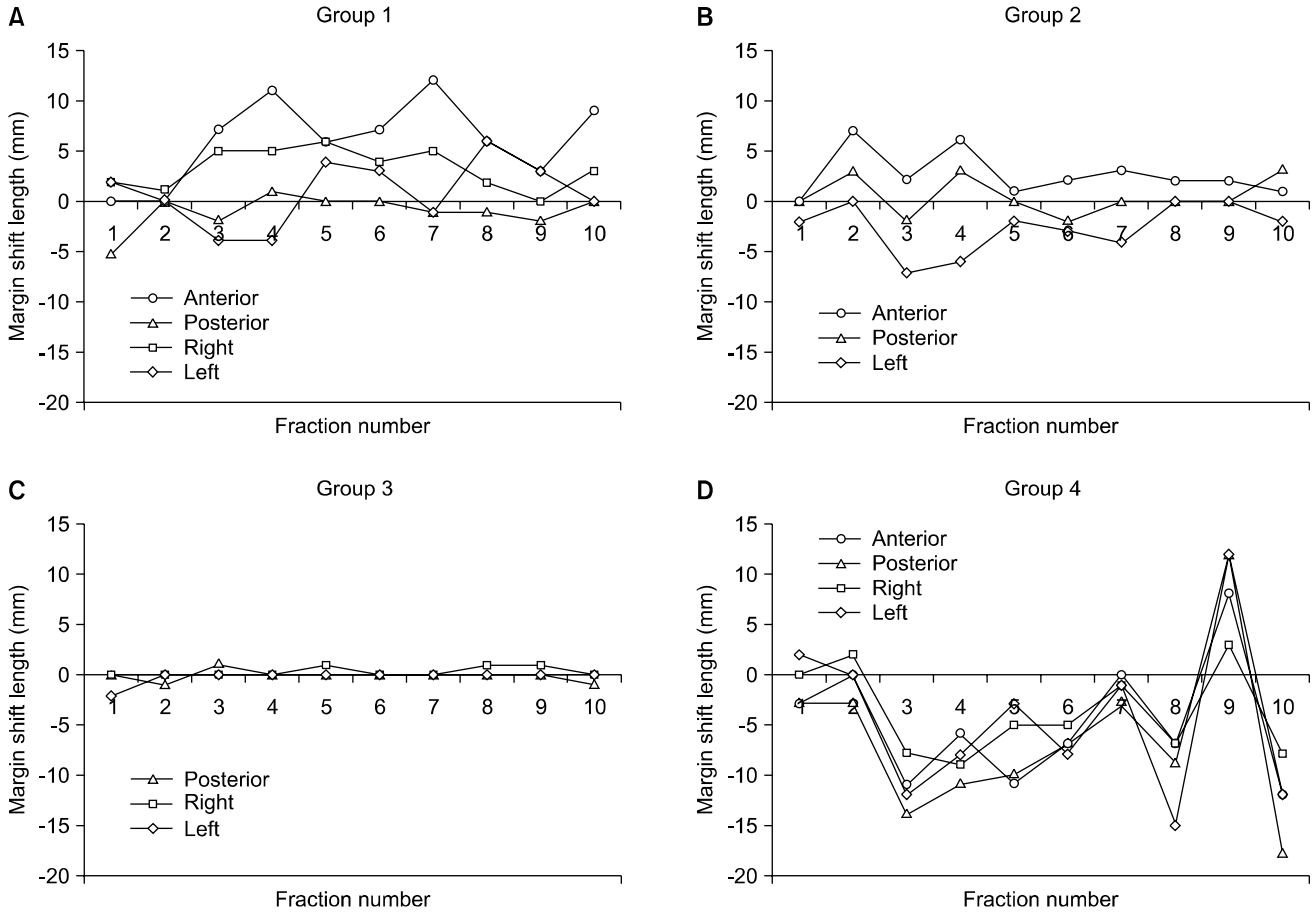

Fig. 4. Examples of daily liver boundary shift along anterior, posterior, right, and left directions of each four group from 1st to 10th fraction

Table 3. Gross Tumor Volume before and after Reassessment

	Mean gross tumor volume on KVCT (cm^3) *	Mean gross tumor volume on MVCT (cm^3) †	% of change ‡
Group I	1596.3	1554.0	−2.65
Group II	1032.1	1019.4	−1.23
Group III	1209.2	1227.4	1.51
Group IV	2176.3	2194.8	0.85
Overall	6013.9	5995.6	0.30

Abbreviation: KVCT=kilo-voltage computed tomography; MVCT= mega-voltage computed tomography, *Mean value of original gross tumor volume on simulation KVCT, †Mean value of modified gross tumor volume reflecting liver boundary changes on MVCT (for left-right and anterior-posterior directions, expanded or contracted as much as mean liver boundary shift minus mean setup shift; for cranio-caudal direction, no change was applied), ‡{(Mean gross tumor volume on MVCT) −(Mean gross tumor volume on KVCT)}/(Mean gross tumor volume on KVCT)×100

deviation values were low (0.07±0.99 mm outwards, 0.07± 1.38 mm inwards, and 0.50±0.47 mm outwards, respectively). Examples of each group from 1st to 10th fraction are shown in Fig. 4.

4. Gross tumor volume change after MVCT reassessment

Mean gross tumor volumes of each group before and after MVCT reassessment were calculated by Pinnacle 3 system (Table 3). Original values were obtained on simulation KVCT and modified values were obtained reflecting liver boundary shift and setup correction concomitantly. Cranio-caudal shift was not reflected because of rough image quality of coronal and sagittal MVCT view. The volume changes were within 3 percent, but in group II, the reduced volume was replaced by stomach wall. If the cranio-caudal shift were reflected, the volume change would be much larger. Thus, the actual volume change seems to be much larger and may cause severe normal tissue damage if irradiation field or beam arrangement were not modified properly.

Discussion and Conclusion

Precision radiation therapies such as 3-D CRT, IMRT, tomotherapy, and others or etc. have been able to enhance tumor control rates and reduce gastro-intestinal toxicities in treatment of liver tumors. Furthermore, recent incremental concern of hypofractionation radiotherapy and radiosurgery is now requiring more complicated precision in irradiating all anatomic sites including liver.[1,2,15] However, most of the abdominal organs including liver, diaphragm, pancreas, kidney as well as lung, diaphragm were validated to move with breathing. And this is considered great limitation in high-precision radiation therapy.[11,16] When irradiating liver, it is ideal to hold respiration during the beam-on time, that is, breath-hold techniques such as ABC[17] or deep inspiration breath hold (DIBH).[18] But there are practical limitation for application of respiratory control system to real patients because of the patients' compliance problem, poor pulmonary function, and/or lack of image-guiding equipments, etc. Moreover, the beam-on time per portal in precision radiation therapy is much longer than that of three-dimensional conformal radiotherapy. This makes it almost impossible to irradiate continuous beam without holding breath. Beam tracking requires special equipments.[19~21] as a prerequisite. Respiratory gating is considered to be accurate with the mandatory use of 4DCT, but technical problems remains to be resolved. Therefore, the best realistic alternative to breathing-hold method might be more accurate delineation of internal target volume and planning target volume in the state of natural breathing with proper treatment margin. With this concept, we assessed interfractional liver boundary shift deviation for proper establishment of treatment margin using MVCT, a volumetric image-guidance system of helical tomotherapy.

There have been some researches on whether the soft tissue of MVCT image is useful or not. MVCT was confirmed to provide an image of good quality for setup error verification in skeletal structures with dose of approximately 2～3 cGy.[12] In contrast, it has been known to be inappropriate for soft tissue delineation.[15] Fuss et al. reported that MVCT is a good image-guidance tool for skeletal system and lung tumors, but not for liver tumors because of low contrast in soft tissues.[22] On the contrary, Meeks et al. maintained despite low-resolution contrast of MVCT in soft tissues that MVCT image still could be used for soft tissue tumor delineation as well as patient setup by obtaining sufficient preparation up to 4 mm scale.[23] Actually, there was a report that prostate delineation was possible based on MVCT images.[14] However, there are

difficulties of using MVCT image in delineation of liver tumors. Lipiodol uptakes after TACE and surgical clips in surgeries does not help in MVCT image guidance because of poor image contrast with liver parenchymal tissue in MVCT image. For these reasons, we focused the locations of liver parenchymal boundaries adjacent to tumors and surrounding normal tissues as the main target of observation in analyses of shift patterns of each group.

The development of portal imaging technologies have made it possible to calibrate setup correction accurately. However, majority of them is not volumetric. On the contrary, the setup error correction with MVCT reduced the need to match skin tattoo with laser line through the precise location of couch after CT image registration. Therefore, improvement could be seen based on both precise and convenient volumetric three-dimensional images despite different condition for respiratory motion and scanning speed between simulation KVCT and MVCT.[13] Still, lower resolution of coronal and sagittal MVCT images, which were reconstructed from axial images, was not adequate for verifying the vertical movement of liver. This lead to difficulty in MVCT reassessment and gross tumor volume measurement in table 3. More accurate MVCT image quality might be needed in the future.

Orthogonal right angle coordinate system was appropriate in terms of automatic target volume expansion or contraction. The Pinnacle 3 program (Philips Medical System, Milpitas, USA) has 3 axis, 6 direction expansion/contraction tool for each target volume based upon 3-dimensional right angle coordinate system. Six directions are composed of anterior, posterior, left, right, superior, and inferior ones at every point of target drawing. There might be some distortions when the shift boundary between KVCT and MVCT has oblique line in terms of right angle coordinate system. However, it could be desirable in terms of couch location with current Tomotherapy Hi-Art system 2.0.

In group II patients, the left liver boundaries of MVCT images had a tendency to locate medially compared with those of simulation KVCT images while there were no definite relationships between each patient's liver boundary shift patterns and locations of each group in terms of diaphragmatic movements and liver boundary deviation in MVCT images from KVCT images. And the dose for tumor control usually exceeds the tolerance dose for gastric mucosa.[24~28] Thus, when the liver tumors adjacent to gastric wall are irradiated, more strict PTV margin might be needed in the state of empty stomach at least for four hours or more. This shows stomach toxicities, which is adjoining of left lobe liver, could be increased by the influence of breathing because the real-time movement of liver and stomach is not reflected. On the other hand, the PTV needs to be larger to maintain the same level of dose in terms of dosimetry because dose distribution in the boundary areas of target volume changes rapidly.[9] According to this, tight PTV margins could substantially result in insufficient dose distribution to the target volume in high-precision radiation therapies such as IMRT or tomotherapy. Thus, it is necessary to properly reflect the conflicting situations for defining the PTV volumes.

In group IV, the shift patterns of each fraction were quite irregular and there were high values of standard deviation in all directions (anterior, posterior, right, and left). In groups other than group IV, the posterior discrepancies were as small as 1 mm and had relatively stable distributions in each session. This shows posterior tumor shift ranges could be smaller with supine position and more accurate approach is possible.

The average shift values of each group do not stand for representation of each group because of low population number of patients and wide variation of interfractional values. Moreover, different characteristics among individual patients cannot be applied as a representative and even repeating measurements for the same patient has many constraints due to variation in patients' performance status or breathing patterns. The equipment to get the same condition will be needed in patient setup and treatment target confirmation in the future. In addition, the geometrical uncertainties of liver tissue make it difficult to apply our data uniformly to liver irradiation cases. Balter et al. mentioned the significance of individualized treatment with proper approach for geometrical uncertainties in the treatment of liver.[3] Both individual characteristics and values based on each group should be considered because of unpredictable deviations for each patient.

When high precision radiotherapy is implemented, tumor precision is not sufficient from the viewpoint of radiation oncologist. Normal tissue precision together with tumor precision can accomplish precision radiotherapy ultimately. For normal tissue precision, it is desirable to correct the setup errors as a prerequisite when the target volumes are irradiated

with image guidance such as gating or tracking. Existing gating or tracking systems have an aspect to consider tumor motions only, not normal tissue motions which accompany with breathing. More careful approach is needed when organs vulnerable to radiation are located around the target volumes. Our study suggests that image guidance should be performed with normal tissue precision as well as tumor precision by correcting setup errors and tumor discrepancies at the same time. In radiation treatment planning, further study on breathing-movement relationship will be required for what extent the proper PTV margin should be.

In conclusion, MVCT image might be useful for verification of interfractional liver boundary displacement in tomotherapy to liver tumors and appropriate PTV margin based on MVCT image will be able to provide useful information for precision radiation therapy in liver tumors. Interfractional liver shift patterns are somewhat systematic according to tumor locations despite certain variations in each patient. Geometrical deformation of the liver by respiratory movement can cause possible shrinkage of left margins of area including segment 2, 3, and 4, while it does not have significant influence upon stable segment 5 and 6 lesions. Therefore, more sophisticated approach is required in free-breathing mode when the left lobe of liver is irradiated in order to avoid stomach toxicity.

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국문초록

간종양 방사선치료 시 토모테라피 메가볼트 CT를 이용한 치료 여백 평가

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목 적: 토모테라피 영상유도장치인 MVCT (mega-voltage computed tomography) 영상을 이용하여 자유 호흡시 분할 치료 간 간조직의 위치변화 양상을 알아보고자 하였다.

대상 및 방법: 2006년 4월부터 2007년 8월까지 간종양에 토모테라피를 받은 환자 26 명을 대상으로 치료 시작 후 10 회까지 매회 치료시의 MVCT 영상을 분석하였다. 1차적으로 골격 구조에 따라 셋업오차보정을 한 상태에서 2차원 직교좌표계 상에서 간조직 경계부위의 위치 변화를 치료계획 KVCT (Kilo-Voltage Computed Tomography)와 MVCT의 영상융합을 통해 비교하여 오차 정도를 파악하였다. 간종양의 위치 별 변화 양상을 보기 위하여 종양 위치를 Couinaud's proposal을 기준으로 1군(Segment 1), 2군(Segment 2, 3, 4), 3군(Segment 5, 6), 4군(Segment 7, 8)으로 나누어 각 군별 위치 변화 양상을 비교하였다.

결 과: MVCT를 통해 알아본 평균 셋업오차는 각각 0.45±2.04 mm (좌-우), 0.97±4.06 mm (상-하), 8.38±4.67 mm (전-후) 이었다. 2군에서 전방 바깥쪽으로 2.80±1.73 mm, 좌방 안쪽으로 2.23±1.37 mm 이동하였고 4군에서는 전, 후, 좌, 우 각 방향으로 −0.15±3.93 mm, −3.15±6.58 mm, −0.60±3.58 mm, −4.50±5.35 mm 이동하였다. 1, 2, 3군에서 후방으로의 위치 변화는 평균 1 mm 이내였다(각각 0.07±0.99 mm, −0.07±1.38 mm, 0.50±0.47 mm). MVCT 값들의 적용 시 보이는 2군에서의 종양체적 감소는 위 독성을 증가시킬 것으로 생각되었다.

결 론: 분할치료 간 간조직의 위치 변화 양상은 각 군마다 편차가 있는 가운데 어느 정도 규칙적이었다. 호흡에 의한 간조직의 기하학적 변형은 segment 2, 3, 4에서 좌방 표적 체적의 감소를 가져오는 반면 segment 5, 6에서는 호흡에도 불구하고 안정적인 양상을 나타내었다. 따라서 자유 호흡 상태에서 간 좌엽에 대한 방사선치료 시 위에 대한 독성을 줄이기 위해 보다 세심한 접근이 필요하다.

핵심용어: MVCT, 간종양, 토모테라피