Original Article

PROGRESS in MEDICAL PHYSICS Vol. 26, No. 1, March, 2015
http://dx.doi.org/10.14316/pmp.2015.26.1.6

Rotation Errors of Breast Cancer on 3D-CRT in TomoDirect

Jae Hong Jung*[†], Kwang Hwan Cho*, Seong Kwon Moon*, Sun Hyun Bae*, Chul Kee Min*, Eun Seog Kim*, Seung-Gu Yeo*, Jin Ho Choi[†], Joo-Yong Jung[†], Bo Young Choe[‡], Tae Suk Suh[‡]

*Department of Radiation Oncology, College of Medicine, Soonchunhyang University of Korea, Bucheon, [†]Department of Radiation Oncology, Gachon University Gil Medical Center of Korea, Incheon, [‡]Department of Biomedical Engineering and Research Institute of Biomedical Engineering, The Catholic University of Korea, Seoul, Korea

The purpose of this study was to analyze the rotational errors of roll, pitch, and yaw in the whole breast cancer treated by the three-dimensional radiation therapy (3D-CRT) using TomoDirect (TD). Twenty-patient previously treated with TD 3D-CRT was selected. We performed a retrospective clinical analysis based on 80 images of megavoltage computed tomography (MVCT) including the systematic and random variation with patient setup errors and treatment setup margin (mm). In addition, a rotational error (degree) for each patient was analyzed using the automatic image registration. The treatment margin of X, Y, and Z directions were 4.2 mm, 6.2 mm, and 6.4 mm, respectively. The mean value of the rotational error for roll, pitch, and yaw were 0.3°, 0.5°, 0.1°, and all of systematic and random error was within 1.0°. The errors of patient positioning with the Y and Z directions have generally been mainly higher than the X direction. The percentage in treatment fractions in less than 2° at roll, pitch, and yaw are 95.1%, 98.8%, and 97.5%, respectively. However, the edge of upper and lower (i.e., bottom) based on the center of therapy region (point) will quite a possibility that it is expected to twist even longer as the length of treatment region. The patient-specific characters should be considered for the accuracy and reproducibility of treatment and it is necessary to confirm periodically the rotational errors, including patient repositioning and repeating MVCT scan.

Key Words: Breast cancer, Setup error, Rotation error, MVCT

Introduction

The whole-breast radiation therapy (WBRT) is important delivery to target with uniformity dose through an appropriately correcting for unequal dose distribution due to the irregular surface. Typically, treatment methods are the three-dimensional conformal radiotherapy (3D-CRT) using opposed tangential beams while avoiding the contralateral breast (CB) and minimizing dose to the normal organs such as the lung, heart, and liver. The intensity-modulated radiation therapy (IMRT) also can use to improve dose distributions compared with 3D-CRT while showing a clinical benefit.[1,2)]

Tomotherapy (Accuray Inc., Sunnyvale, CA) combines a linear accelerator (LINAC), and achieved by the use of a gantry head with a 360° rotating and couch motion that the possibility to deliver IMRT with megavoltage computed tomography (MVCT) imaging system. Radiation delivering by gantry rotation is not appropriate in WBRT because of increasing delivered volume to the normal organs. However, TomoDirect (TD) uses the fixed-beam treatments on a Tomotherapy unit platform that enables IMRT option as well as 3D-CRT for various diseases.[3-6)] The image-guided radiation therapy (IGRT) by using MVCT scans provides an opportunity to improve the accuracy and reproducibility of tumor targeting while reducing

This research was supported by the Radiation Technology R&D program (No. 2013M2A2A7043498), the Leading Foreign Research Institute Recruitment program (Grant No. 2009-00420) through the National Research Foundation of Korea (NRF) funded by the Ministry of Science, ICT & Future Planning (MSIP), and the Radiation Safety Research Programs (1305033) through the Nuclear Safety and Security Commission.

Received 2 March 2015, Revised 12 March 2015, Accepted 17 March 2015

Correspondence: Kwang Hwan Cho (medphy@schmc.ac.kr)
Tel: 82-32-621-5881, Fax: 82-32-621-5885

the patient setup errors during the treatment. It is only possible that the adjustment can be translational directions (medio-lateral; X, superior-inferior; Y, and anterior-posterior; Z) and rotational angle (axis of Y; roll). However, correction of the axis of X (pitch) and Z (yaw) angles are impossible due to couch limitations with similar properties like CT platform.[7-9]

The patient setup variations by occurred the translational and rotational displacement can cause the geometric uncertainty during the treatment. Kaiseret et al.[8] has analyzed the rotational errors for patients with the head and neck cancer, and reported that the rotational setup errors have effect depend on the couch hardware design in Tomotherapy. Boswell et al.[7] has suggested the methods to correct by lateral moving technique with Tomotherapy couch. Moreover, several studies on the dosimetric impact of uncorrected setup errors, respiratory, and inter- or intra-fraction motion have been performed in WBRT.[10-14] It is true that small errors of patient setup affect to the actual delivered dose during the course of the treatment.

In particular, it is necessary to verify the treatment iso-center and perceiving trend of the patient specific setup contain the translational and rotational adjustments in WBRT using TD. However, daily MVCT scans is not easy to performing due to increasing dose to the patient and machine time in clinic. Uncorrected the pitch and yaw need to identify the rotational errors, such as the pitch and yaw due to impossible correcting and that finally affect treatment uncertainty. The purpose of this study was to analyze of the rotational errors of the whole breast cancer treated by TD 3D-CRT.

Materials and Methods

We selected a total of 20 patients with the whole breast cancer previously treated using TD 3D-CRT. Right, left, and both breasts were treated in sixteen, four, and one patient, respectively. This study was approved by the institutional ethics review board (IRB; 2014-10-007). All patients underwent treatment simulation using a CT simulator (SMOATOM EMOTION, SIEMENS, Germany) in this study. The slice-thickness was 5 mm with a 500 mm of the FOV and resolution of 512 mm×512 mm, and scan length is from the level of the mandible with the spine at L2 including the whole breast. Patients were placed in the supine position, on a wing board (Klarity, Klarity Medical Products, USA), with both arms abducted alongside the head. Three reference markers were placed along the mid-sternum area of anterior and both lateral body skins.

The kVCT image data were transferred to a commercial treatment planning system (Pinnacle version 8.0; Philips Medical systems, Andover, MA). Where the clinical target volume (CTV) was defined by SK radiation oncologist, and the organ at risks (OARs), both lungs, heart, liver, and contralateral breast, were contoured in the Pinnacle planning system. All regions of interest (ROIs) were transferred to Tomotherapy Hi-Art II planning system (Accuray Inc., Sunnyvale, CA). TD 3D-CRTplans consisted of 2 parallel-opposed beams angled to irradiate the CTV while avoiding CB and minimizing dose the heart and lung, and used a 2.5 cm field width (FW) and 0.250 of pitch. The prescribed dose was 50.4 Gy to 98% of the CTV as a target in 28 fractions.

Three reference markers which indicated at CT simulation were used to patient setup in the treatment room. The MVCT scans were performed to verify the treatment iso-center point prior to first fraction during the over the treatment, and used once per week by course mode as 6 mm of the reconstruction slice-thickness. To correct of daily setup errors, the planning kVCT and daily MVCT images were used in the image registration process in Tomotherapy system. Patients were treated with corrected setup error which the translational errors were corrected by computerized couch adjustments, and the roll angle also corrected by the gantry repositioning. A total of 80 MVCT image set was retrospectively analyzed in this study.

Evaluation of the patient setup errors was divided into two procedures in this study. First, the translational directions and roll angles were recorded, and calculated a mean (M), systematic (Σ), and random errors (σ) for population patients based on the methodology introduced by van Herk.[15] Here, the systematic error is equal to the standard deviation of the patient-specific systematic errors, and random is determined by calculating the root-mean-square (RMS) of the random setup errors for each patient. We also calculated the treatment setup margin (mm). Next, the rotational errors (roll, pitch, and yaw) were analyzed by using the automatic image registration as well as translations. However, the automatic image registration procedure can be applying different control parameters depending on the density value (g/cm^3) and resolution (pixel). For the deviation of different control parameters, we had previously verified and presented with analyzing of a lot of patients in clinic.[16] We demonstrated that a combination of the full image and standard resolution function has smaller than another, therefore, were used to reduce the deviations for each patient in this study.

We also analyzed the coefficient of correlation between the translational and rotational adjustments by using Pearson's product-moment coefficient, and the independent t-test was conducted to find the significant difference location of breast cancer at a level of $P<0.05$.

Results and Discussion

The present study was to analyze the patient setup errors and rotation errors for a total of 20 patients with the whole breast cancer treated using TD 3D-CRT. A total of 80 MVCT image set was analyzed, and an average of MVCT scan length was 234.7 mm in this study.

Table 1 shows the patient setup errors and calculated treatment setup margin of a population. The mean of the translational directions (X, Y, and Z) and roll angle were −0.4 mm, −0.8 mm, 1.0 mm, and 0.3°, respectively. For the calculated treatment setup margin, directions of X, Y, and Z were 4.5 mm, 6.2 mm, and 6.4 mm, respectively. Setup margin by defining the ICRU Report 62 should be included the planning target volume (PTV), which includes an internal margin (IM) to account for variations in size, shape, and the CTV.[9,15] The setup margin formulas used the systematic and random errors. Multiple factors, including treatment goals, tumor stages, tumor/normal tissue locations, immobilization technique, and confidence level, should be considered before treatment planning and during the treatment.[9] In our study, Y and Z directions were higher than at X. Moreover, the maximum displacements at X, Y, Z, and Roll were 3.9 mm, −7.9 mm, 6.7 mm, and 1.5°, respectively. For a variation of Z direction, we estimate due to the effect of couch sagging between CT simulation and treatment couch. In our institution, this difference was about 4 mm in verified the mechanical QA for couch travel. Therefore, the couch sagging should be considered when higher than usual condition during treatment.

The respiratory motion has affected to uncertainty of patient setup errors and the dosimetric impact during treatment. Furuya et al.[14] has been evaluated the dosimetric impact of respiratory breast motion and daily setup error by a different technique in WBRT, and reported that the dosimetric impact was largest at the anterior-posterior directions (*i.e.* Y direction). TD 3D-CRT is no more complex than irregular surface compensator (ISC) and IMRT for whole breast cancer. However, the treatment result finally can be different whether recognizing of

Table 1. Patient setup errors and calculated treatment setup margin (mm) for 20 breast cancer.

Directions	Mean (M)	Systematic error (σ)	Random error (Σ)	Setup margin (mm)	Maximum displacement
X (mm)	−0.4	1.4	1.5	4.5	3.9
Y (mm)	−0.8	1.9	2.0	6.2	−7.9
Z (mm)	1.0	2.0	2.0	6.4	6.7
Roll (°)	0.3	0.4	0.5	N/A	1.5

N/A: not applicable.

Table 2. Magnitude of the translational and rotational adjustment by the automatic image registration.

Adjustments		Mean (M)	Systematic error (σ)	Random error (Σ)	Maximum displacement
Translation (mm)	X	−0.5	1.5	1.7	−7.0
	Y	−1.4	2.7	1.9	−7.6
	Z	1.9	2.3	2.0	7.9
Rotation (°)	Roll	0.3	0.9	0.7	3.5
	Pitch	0.5	0.6	0.5	2.2
	Yaw	0.1	0.8	0.6	3.0

small variations depends on the respiratory motion, treatment machine feature, and patient positioning. In particular, immobilization devices important because of that the varying arm position on the device has affected to daily varying at overall directions. Jassal K, et al.[17] has been compared the setup uncertainties between two different immobilization methods, vacuum cushion and standard breast board, by cone beam computed tomography (CBCT) scan data. They reported no significantly different between the two methods with respect to the patient setup errors, and commented the specific patients such as very bulky and obese conditions.

Table 2 shows the variation of translational directions and rotational angles through analyzed by using the automatic image registration. The mean of roll, pitch, and yaw were 0.3°, 0.5°, and 0.1°, respectively. The systematic and random errors were mostly less than 1.0°. The variation was smaller than that we expected in the designing our study. However, the maximum displacement in roll, pitch, and yaw were 3.5°, 2.2°, and 3.0°, respectively. We suppose that error was probably caused by inappropriate patient positioning with varying arm position or the patient has the tension during treatment.

The rotational variation has previously been described.[7,8] In head and neck cancer, 96.6% of the rotational corrections were less than 4° by Kaiser et al.[8] It seems that these variations are very larger than our results. Fig. 1 shows the distribution in treatment fractions (%) of the rotation errors. These roll, pitch, and yaw with $0 \leq 1°$ were 62.6%, 81.3%, and 77.5%, respectively. 1−2° were 32.5%, 17.5%, and 20.0%. 2°> were 5.0%, 1.3%, and 2.5. However, Kaiser et al.[8] commented that if roll is and a 15-cm target is centered on the origin of the coordinate system, then the resultant positional variation at the edge of the target is about 4 mm. In our study, the target length was less than about 234.7 mm as MVCT scan length. When the target length (*i.e.*, 234.7 mm) has applied at 1° and 2°, these errors at the edge of the target are about 1 mm and 2 mm, respectively. As a consequence, the distribution in treatment fractions in less than 2° at roll, pitch, and yaw are 95.1%, 98.8%, and 97.5%, respectively. Our results have shown smaller variation compared with by Jain et al.[11] They reported that the rotations $>2°$ in any axis occurred on 53/106 (50%) occasions.[11]

A correlation between the translational and rotational errors is shown in Table 3. A small correlation with statistically significant was confirmed among directions and angles. In particular, Z and pitch have shown a positive disposition (Factor=0.30; $P<0.01$). This is probably expected that the varying arm position on device in daily. However, the correlation coefficient with a small value is not great significance in the clinic with mentioned by Kaiser et al.[8] No significant for locations of breast cancer for the translational and rotational errors in this study ($P>0.05$) that the p-values in roll, pitch, and yaw were 0.099, 0.413, and 0.380, respectively.

It is not possible yet for correction of pitch and yaw angles due to specific features of treatment couch. Although several methods are proposed, it was still not resolved.[7] Boswell et al.[7]

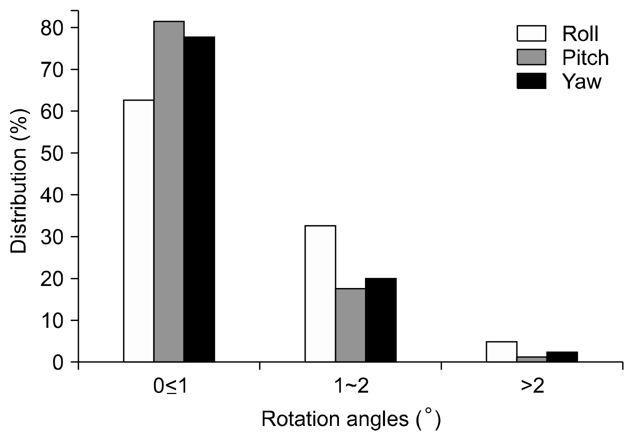

Fig. 1. Percentage of distribution in treatment fractions of the rotational errors in overall patients that roll, pitch, and yaw in less than 2° are 95.1%, 98.8%, and 97.5%, respectively.

Table 3. Correlations between the translational and rotational adjustment of 20 patients.

	Inter-construct correlations					
	Directions					
Directions	X	Y	Z	Roll	Pitch	Yaw
X	1.00					
Y	0.01	1.00				
Z	−0.05	−0.04	1.00			
Roll	0.07	−0.26*	0.09	1.00		
Pitch	0.13	−0.34†	0.30†	0.30†	1.00	
Yaw	−0.30†	0.24*	−0.06	−0.22	−0.28*	1.00

*Significance of these differences ($P<0.05$), †Significance of these differences ($P<0.001$).

reported that the correct method could correct the rotational setup errors by travel slowly along X and Z axes during treatment. These methods have limitation in terms of only correcting yaw offsets. It is difficult to correct both pith and yaw rotational errors until now. Patient repositioning and repeating MVCT scan will be useful in clinic unless new Tomotherapy couch developed. The limitation of this study is simply analyzing of the rotational errors for WBRT on TD 3D-CRT. Although we confirmed small magnitude variations of rotational angles, including the roll, pitch, and yaw, patient setup errors and treatment margin, these results would be useful information to consider patient positioning before treatment in the clinic. Future work will evaluate different diseases using TD 3D-CRT in terms of machine time, appropriate positioning, dosimetric impact, and correct method of rotational errors.

Conclusion

We analyzed the rotational errors in roll, pitch, and yaw of the WBRT using TD 3D-CRT. Overall, the rotational errors were small compared with other studies.[8,11] However, small errors can be affected to the edge of upper and lower based on the center of therapy regions with twisted positioning during treatment. The patient-specific characters, such as an unstable position, long target length, and as well as very bulky, should be considered for the accuracy and reproducibility of treatment. In addition, it is necessary to perform it that patient repositioning and repeating MVCT scan based on our results. Finally, confirming periodically the rotational errors will be help in WBRT using TD 3D-CRT.

References

1. **Fields EC, Rabinovitch R, Ryan NE, Miften M, Westerly DC**: A detailed evaluation of TomoDirect 3DCRT planning for whole-breast radiation therapy. Med Dosim 38:401-406 (2013)
2. **Chira C, Kirova YM, Liem X, et al**: Helical tomothreapy for inoperable breast cancer: a new promising tool. Biomed Res Int 2013:1-8 (2013)
3. **Jones R, Yang W, Read P, Sheng K**: Radiation therapy of post-mastoectomy patients with positive nodes fixed beam tomotherapy. Radiother Oncol 100:247-252 (2011)
4. **Langner UW, Molloy JA, Gleason JF Jr, Feddock JM**: A feasibility study using TomoDirect for craniospinal irradiation. J appl Clin Med Phys 14:104-114 (2013)
5. **Klein M, Gaede S, Yartsev S**: A study of longitudinal tumor motion in helical tomotherapy using a cylindrical phantom. J appl Clin Med Phys 14:52-61 (2013)
6. **Franco P, Catuzzo P, Cante D, et al**: TomoDirect: an efficient means to deliver radiation at static angles with tomotherapy. Tumori 97:498-502 (2011)
7. **Boswell SA, Jeraj R, Ruchala KJ, et al**: A novel method to correct for pitch and yaw patient setup errors in helical tomotherapy. Med Phys 32:1630-1639 (2005)
8. **Kaiser A, Schultheiss TE, Wong JY, et al**: Pitch, roll, and yaw variations in patient positioning. Int J Radiat Oncol Biol Phys 66:949-955 (2006)
9. **Zhou J, Uhl B, Dewit K, et al**: Analysis of daily setup variation with tomotherapy megavoltage computed tomography. Med Dosim 35:31-37 (2010)
10. **George R, Keall PJ, Kini VR, et al**: Quantifying the effect of intrafraction motion during breast IMRT planning and dose delivery. Med Phys 30:552-562 (2003)
11. **Jain P, Marchant T, Green M, et al**: Inter-fraction motion and dosimetric consequences during breast intensity-modulated radiotherapy (IMRT). Radiother Oncol 90:93-98 (2009)
12. **Reynders T, Tournel K, De Coninck P, et al**: Dosimetric assessment of static and helical TomoTherapy in the clinical implementation of breast cancer treatments. Radiother Oncol 93:71-79 (2009)
13. **Goddu SM, Yaddanapudi S, Pechenaya OL, et al**: Dosimetric consequences of uncorrected setup errors in helical Tomotherapy treatments of breast-cancer patients. Radiother Oncol 93:64-70 (2009)
14. **Furuya T, Sugimoto S, Kurokawa C, Ozawa S, Karasawa K, Sasai K**: The dosimetric impact of respiratory breast movement and daily setup error on tangential whole breast irradiation using conventional wedge, field-in-field and irregular surface compensator techniques. J Radiat Res 54:157-165 (2013)
15. **van Herk M.** Errors and Margins in Radiotherapy. Semi Int Radiat Oncol 14:52-64 (2004)
16. **Kim YL, Cho KW, Jung JH, et al**: Analysis of Automatic Rigid Image-Registration on Tomotherapy. Journal of Radiological Science and Technology 37:37-47 (2014)
17. **Jassal K, Bisht S, Kataria T, Sachdev K, Choughle A, Supe S**: Comparison of Geometrical Uncertainties in Breast Radiation Therapy with Different Immobilization Methods. J Nucl Med Radiat 4:1-6 (2013)

토모다이렉트 3D-CRT을 이용한 유방암 환자의 회전 오차

*순천향대학교 의과대학 방사선종양학교실, †가천의대 길병원 방사선종양학교실,
‡가톨릭대학교 의과대학 의공학교실, 생체의공학연구소

**정재홍*‡ · 조광환* · 문성권* · 배선현* · 민철기* · 김은석*
여승구* · 최진호† · 정주영‡ · 최보영‡ · 서태석‡**

본 연구의 목적은 토모다이렉트 3D-CRT (TD 3D-CRT)을 이용한 유방암 방사선치료에서 회전축(roll, pitch, and yaw) 오차를 분석하고 자 하였다. TD-3DCRT로 치료가 종료된 유방암 환자 총 20명을 선정하였고, 총 80회의 MVCT 영상을 바탕으로 시스템(systematic), 임의(random) 오류를 포함한 환자위치잡이 오차(patient setup errors)와 치료 여백(treatment margin, mm)을 후향적으로 분석하였다. 또한, 각 환자에 대한 회전축 오차 분석은 자동영상정합(automatic image registration)을 이용하였다. X, Y, Z 방향에 대한 치료여백은 각각 4.2 mm, 6.2 mm, 6.4 mm였다. 회전축 오차에 대한 평균 각도(degree)는 roll, pitch, yaw가 각각 0.3도, 0.5도, 0.1도였고, 시스템과 임의 오류는 모두 1도 이내였다. 전반적으로 환자 위치잡이 오차는 Y와 Z방향에서 X에 비하여 높게 나타났다. 본 연구에서 회전축 오차 각도가 2도 이내는 roll, pitch, yaw에서 각각 95.1%, 98.8%, 97.5% 분포였다. 그러나, 치료영역의 길이가 길어짐에 따라 치료 중심지점을 기준으로 상부와 하부의 가장자리(Edge)가 틀어지게(Twisted)될 가능성이 높아질 수 있다. 따라서 치료의 정확성과 재현성을 위하여 각 환자의 특성을 고려하고, 회전축 오차를 주기적으로 확인할 필요가 있다.

중심단어: 유방암, 환자위치잡이오차, 회전오차, MVCT