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The systematic and random errors determination using real-time 3D surface tracking system in breast cancer

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Abstract. The purpose of this study to determine the patient setup uncertainties in deep inspiration breath-hold (DIBH) radiation therapy for left breast cancer patients using real-time 3D surface tracking system. The six breast cancer patients treated by 6 MV photon beams from TrueBeam linear accelerator were selected. The patient setup errors and motion during treatment were observed and calculated for interfraction and intrafraction motions. The systematic and random errors were calculated in vertical, longitudinal and lateral directions. From 180 images tracking before and during treatment, the maximum systematic error of interfraction and intrafraction motions were 0.56 mm and 0.23 mm, the maximum random error of interfraction and intrafraction motions were 1.18 mm and 0.53 mm, respectively. The interfraction was more pronounce than the intrafraction, while the systematic error was less impact than random error. In conclusion the intrafraction motion error from patient setup uncertainty is about half of interfraction motion error, which is less impact due to the stability in organ movement from DIBH. The systematic reproducibility is also half of random error because of the high efficiency of modern linac machine that can reduce the systematic uncertainty effectively, while the random errors is uncontrollable.

1. Introduction

Radiotherapy is a standard treatment for breast cancer patient. The side effect may be occurred by irradiated of radiation dose to critical organ included suddenly and long-term effect. An increased risk of heart disease is associated with patient who treated with left side of breast cancer radiotherapy when compared with the right side [1, 2]. In left sided breast cancer radiotherapy, left ventricle (LV) and left anterior descending artery (LAD) are the organ at risk (OAR) that dose of both organs could be reduced during end-inhale or deep inspiration breath hold (DIBH) [3-6]. The increasing of lung volume is expanded to push heart up and make more distance between heart and chest wall. The larger the distance between heart and chest wall, the lower the received heart dose. The successful of DIBH technique is occurred if the patient is still in the same position during treatment as the position in simulation process. The AlignRT system is the real-time 3D surface tracking system with completely



non-invasion, not requires ionizing radiation and easy to use. This system is applied to setup and monitor the breast patient's position during treatment with DIBH technique to improve precision and stability of patient's position and avoid the long-term side effect of heart.

In this study, the systematic error and random error both before treatment (interfraction motion) and during treatment (intrafraction motion) of left sided breast cancer treated with the DIBH technique were determined by using AlignRT system.

2. Material and methods

2.1. Image acquisition system

The new 3D surface base monitoring system, AlignRT (VisionRT, London, UK) was installed in treatment room with TrueBeam linear accelerator as shown in Figure 1. This system consists of 3 camera pods, which 2 of them are ceiling mounted at 30 degree angled with treatment couch and another at the centrally foot end of treatment couch. Each camera pods compose of 2 data cameras, white light flash and speckle projector. The data from every camera are combined to generate 3D surface image. The registration software is designed for patient positioning by aligning the real-time 3D surface image with reference image that can be generated from CT body image (CT_S) or captured surface image of AlignRT (ART_S) at first fraction of treatment. The registration algorithm of AlignRT was used to determine 3D transformations. The six directions of the position shift were reported in vertical, longitudinal, lateral, yaw, pitch and rotation that real-time displays at the computer workstation, however this study considered in only first three directions. When the position shifts are larger than setting tolerance limit, the AlignRT will hold radiation beam immediately until the shift back in setting tolerance, the AlignRT will release radiation beam on again.



Figure 1. The 3 camera pods of 3D surface tracking system in TrueBeam linear accelerator.

2.2. Clinical protocol

The 6 left breast cancer patients who treated by DIBH technique aged between 39 to 62 years (mean 49 years) were randomly selected. All patients were simulated by CT scanner (GE Medical System, Waukesha, WI, USA) for acquisition of patient image data with 0.5 cm slice thickness for DIBH and free breathing series. The breast posibord system (CIVCO, Kalona, USA) was used to immobilize patient's positioning with both hand over head on support arm and place knee on knee support. The skin markers were marked with laser system for patient setup.

Patient data were transferred to treatment planning system, Eclipse (Varian Medical System, Plato Alto, CF, USA). Target as tumor and Organs at risk (OAR) were delineated by radiation oncologist. The target volume covers of whole breast tissue with started 5 mm under the skin. The treatment plan using 3D conformal radiotherapy composed of two tangential fields with 200 cGy per fraction in 25 fractions to a total dose of 5000 cGy and the boost at tumor phase was performed with 6 MeV electron beams for 1500 cGy in 5 fractions after photon beam irradiated cover of whole breast tissue

2.3 Image acquisition

At the first fraction of treatment, the patients were setup position by align marker with laser to reproduce the position in CT simulator room. The patients are instructed by intercom to take deep inhale for DIBH technique. During deep inhalation, the patient's position would be matched with CT_S and captured the position in suddenly to generate ART_S. This image was used the reference image for remainder fractions. Before treatment in each fraction, the 3D image was captured, compared with reference, ART_S and reported the error as interfraction motion. During irradiated radiation, the surface images were captured 6 times in each field and the error from ART_S references were reported as intrafraction motion. The setup errors of each patient along the three axis oriented compose along the anterior-posterior, craniocaudal and left-right direction was called vertical, longitudinal and lateral errors, respectively. The mean and standard deviation (SD) were calculated from reported data to illustrate as systematic errors (Σ) and random errors (σ) of each patient along the 3 axis from 3D surface registration (AlignRT). The systematic error of population was represented by the standard deviation of mean of each patient, while the random error of population was defined by the mean error of standard deviation for individual patient. The root mean square was performed to combined the effect of inter-and intrafraction motion to one index as express in equation (1) and (2)

$$\Sigma_{\text{tot}}^2 = \Sigma_{\text{setup}}^2 + \Sigma_{\text{Patient motion}}^2 \quad (1)$$

$$\sigma_{\text{tot}}^2 = \sigma_{\text{setup}}^2 + \sigma_{\text{Patient motion}}^2 \quad (2)$$

3. Results

From 6 patients of 180 images tracking before and during treatment, the comparison result with the reference image for all setup error were less than 1.3 mm. The maximum systematic error of interfraction and intrafraction motion were 0.56 mm and 0.23 mm, the maximum random error of interfraction and intrafraction motion were 1.18 mm and 0.53 mm, respectively as shown in figure 1. The interfraction was more pronounce than the intrafraction, and the systematic error was less impact than random error.

Table 1. Show the population systematic and random error from inter-and intrafraction of LMT and LLT fields.

	LMT						LLT					
	Inter-Fraction			Intra-Fraction			Inter-Fraction			Intra-Fraction		
	Ver.	Long.	Lat.									
Systematic error (mm)	0.46	0.39	0.24	0.23	0.22	0.12	0.48	0.33	0.56	0.21	0.20	0.10
Random error (mm)	1.00	1.18	1.07	0.53	0.50	0.27	0.99	1.13	1.01	0.37	0.32	0.19

Table 2. The systematic and random error after combined effect of inter- and intrafraction motion.

	LMT			LLT		
	Ver.	Long.	Lat.	Ver.	Long.	Lat.
Systematic error (mm)	0.51	0.45	0.27	0.52	0.38	0.57
Random error (mm)	1.13	1.28	1.11	1.06	1.17	1.02

As shown in table 2, the systematic and random errors of left medial tangential field were 0.51 mm and 1.13 mm for vertical, 0.45 mm and 1.28 mm for longitudinal and 0.27 mm and 1.11 mm for lateral, respectively. The systematic and random errors of left lateral tangential field were 0.52 mm

and 1.06 mm for vertical 0.38 mm and 1.17 mm for longitudinal and 0.57 mm and 1.02 mm for lateral, respectively.

4. Discussion

There are many studies about 3D surface tracking system (AlignRT) used to verify patient setup uncertainty have been published over the few years ago [7-10]. Then demonstrated that AlignRT could improve the precision of patient's setup position on breast cancer radiotherapy treatment. In this study, the AlignRT was applied to determine the systematic error and random error in a level of sub millimetre that showed the maximum value less than 1.5 mm along the 3 axis.

Breast cancer radiotherapy treatment with DIBH technique was able to treat with more stability and same position of chest wall in each fraction. From the result systematic error was less impact than the random error because the using of modern machine and advance IGRT can reduce the influence from the systematic error while the random error cannot control. The result was agree with the study of Letizia D. *et al.* [11], who investigated the clinical application of a technique for patient set-up verification in breast cancer radiotherapy based on a 3D surface image registration system.

When compared with the Bert *et al.*, [12] study, that investigated breast patient setup uncertainty in free breath using AlignRT, the mean displacement of 1 ± 1.2 mm was shown. Our result was lesser error than Bert study that may be due to more stable in organ movement from DIBH technique. From this reason, our results exhibited the lesser value of intrafraction motion than interfraction motion.

5. Conclusion

The intrafraction motion error from patient setup uncertainty is about half of interfraction motion error, which is less impact due to the stability in organ movement from DIBH. The systematic reproducibility is also half of random error because of the high efficiency of modern linac machine. It can reduce the systematic uncertainty effectively, while the random errors is uncontrollable.

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