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Analysis of Set-up Errors during CT-scan, Simulation, and Treatment Process in Breast Cancer Patients

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Purpose: Although computed tomography (CT) simulators are commonly used in radiation therapy department, many institution still use conventional CT for treatments. In this study the setup errors that occur during simulation, CT scan (diagnostic CT scanner), and treatment were evaluated for the twenty one breast cancer patients.

Materials and Methods: Errors were determined by calculating the differences in isocenter location, SSD, CLD, and locations of surgical clips implanted during surgery. The anatomic structures on simulation film and DRR image were compared to determine the movement of isocenter between simulation and CT scan. The isocetner point determined from the radio-opaque wires placed on patient's surface during CT scan was moved to new position if there was anatomic mismatch between the two images.

Results: In 7/21 patients, anatomic structures on DRR image were different from the simulation image thus new isocenter points were placed for treatment planning. The standard deviations of the diagnostic CT setup errors relative to the simulator setup in lateral, longitudinal, and anterior-posterior directions were 2.3, 1.6, and 1.6 mm, respectively. The average variation and standard deviation of SSD from AP field were 1.9 mm and 2.3 mm and from tangential fields were 2.8 mm and 3.7 mm. The variation of the CLD for the 21 patients ranged from 0 to 6 mm between simulation and DRR and 0 to 5 mm between simulation and treatment. The group systematic errors analyzed based on clip locations were 1.7 mm in lateral direction, 2.1 mm in AP direction, and 1.7 mm in SI direction.

Conclusion: These results represent that there was no significant differences when SSD, CLD, clips' locations and isocenter locations were considered. Therefore, it is concluded that when a diagnostic CT scanner is used to acquire an image, the set-up variation is acceptable compared to using CT simulator for the treatment of breast cancer. However, the patient has to be positioned with care during CT scan in order to reduce the setup error between simulation and CT scan.

Key Words: Breast cancer, Setup error

Introduction

Advanced radiotherapy techniques such as three dimensional conformal radiotherapy, non-coplanar radiotherapy, and intensity modulated radiotherapy (IMRT) have been developed and used widely. These techniques promise to improve tumor volume coverage by delivering high radiation dose to the target while sparing normal tissue.

Despite the improvement of treatment delivery techniques, there exist failures in local control and normal tissue complication due to variation in patient setup, internal organ motion or placement of beam shaping device. Thus, optimization of the techniques is based largely on improvement of the localization of target volumes. In ICRU report,[1] a planning target volume (PTV) was defined as a geometrical concept to account for the set-up errors and internal organ motions. In order to determine the PTV, it is recommended to evaluate local variations and uncertainties in each institution.

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Many researchers have addressed the problem of geometric uncertainties caused by patient setup and internal organ motion in radiotherapy for various anatomy sites.[2~6] Accordingly, they performed studies to calculate systematic and random setup errors during simulation and treatment for various sites.[5~7] The effects of intrafractional patient movement on dosimetry for breast radiotherapy have been investigated.[8~10] However, no studies were performed to determine setup error between computed tomography (CT) scan and simulation. Usually systematic error is a setup error averaged over all fraction and random error is the standard deviation of the mean error.[11] Once the standard deviation (SD) of the systematic errors (SD=Σ) and of the random errors (SD=σ) are known from the analysis, the planning target volume (PTV) can be calculated using the expression $M=2\Sigma+0.7\sigma$.[12]

Since CT-based treatment planning had become a standard in radiotherapy, many institutions uses CT simulator to acquire image. The CT simulator is imaging equipment that is developed for radiotherapy only. Nevertheless, there are still number of institutions that use conventional simulators due to financial problem. For those, conventional CT scanner is used to acquire 3 dimensional image data for treatment planning. Greater setup error would be expected because the conventional CT scanner is manufactured for diagnostic purpose.

In this study, setup errors that occur during simulation, CT scan, and treatment process were evaluated by calculating setup differences in isocenter location, source to surface distance (SSD), central axis lung distance (CLD), and clip positions.

Materials and Methods

Twenty-one breast cancer patients with invasive carcinomas of the breast, who had previously undergone lumpectomy, were selected for the study. As shown in Fig. 1, patients were positioned on a breast tilting board with both arms elevated. A conventional simulation was undertaken and simulation films were obtained at gantry zero position and medial tangential directions. Computed tomography (CT) scans were followed to acquire 5 mm images from 10 cm above the upper border and 10 cm below the lower border of the breast tangent fields. At the time of the patient's CT scan, radio-opaque markers were placed on the patient's skin to identify the isocenter and field edges determined at simulation.

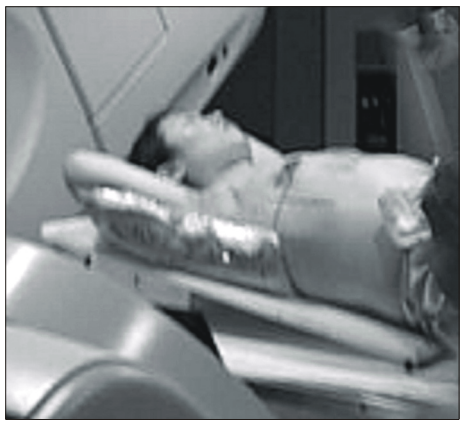

Fig. 1. Photograph of a breast cancer patient in treatment position with breast tilting board.

For each patient, CT images were imported into 3D treatment planning system (Pinnacle, Philips Medical, Milpitas, CA). Radiation isocenter point and the border of the treatment fields were outlined based on the landmark attached during CT scans. An anterior, a medial, and a lateral tangential field were added using the isocenter placed on the basis of the markers attached on a patients' skin during CT scan. Digitally reconstructed radiography (DRR) was generated in two gantry directions (anterior-posterior (AP) and medial-tangent). Simulation film was used as a reference image in evaluating the accuracy of isocenter placement.

The anatomic structures displayed on DRR at gantry zero and medial directions were compared to that of simulation film. The new isocenter point was placed on CT data if there was mismatch of anatomic structures between simulation and DRR images. The movement of isocenter point was measured. Set up errors between diagnostic CT scan and simulation were analyzed by calculating the mean error and standard deviation in lateral (left and right), longitudinal (superior and inferior), and AP directions.

The SSD in AP and medial directions were measured during simulation. These values were compared to the SSD values measured from CT image using 3D radiation treatment planning (RTP) software. In addition, the CLD value, which is the distance from the posterior field margin to the inner chest wall along the horizontal axis of the tangential field, was measured from simulation film, CT image and portal films for each patient as shown in Fig. 2.

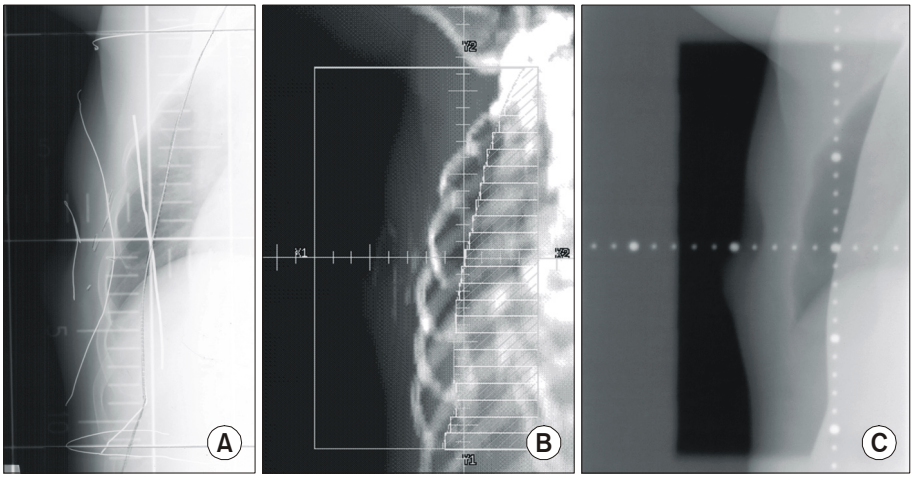

Fig. 2. Images showing central lung distances on (A) simulation film, (B) DRR, and (C) portal film.

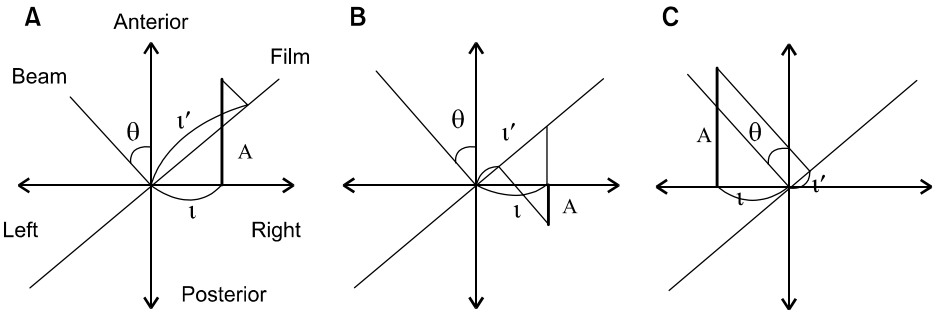

Fig. 3. Geometric representation for the calculation of clip's AP coordinates.

During breast conserving surgery, five to six surgical clips were left in the excision cavity to delineate tumor bed in the breast. These clips were used as a basis for the analysis of setup error during simulation and CT scan. Clips on simulation film were marked and coordinates in lateral, longitudinal directions were determined from AP films. Tangential film was used to obtain the coordinates of clips in AP direction indirectly. Fig. 3 shows geometric representation of the method. 'A' in the Fig. 3A indicates the AP coordinates of a clip and is given by

$$A = -l \cdot \tan\theta - \frac{l' - \frac{l}{\cos\theta}}{\sin\theta}$$

where θ: gantry angle, *l:* lateral distance of a clip from the center on AP film, and *l'*: lateral distance of a clip from the origin on tangential film

In Fig. 3B and C, 'A' is

$$A = \frac{l}{\tan\theta} - \frac{l'}{\sin\theta}$$

In these two equations, *l* and *l'* are positive when the clip is on the left compared to the center.

After the CT scan, clip locations on CT images were obtained using RTP software. The differences in clip positions determined from simulation film and CT image were calculated in lateral, AP, and longitudinal directions. Based on the difference, systematic error was obtained to determine PTV margin contributed from setup error between simulation and CT scan.

Results and Discussions

Fig. 4A is the AP simulation image of a patient taken at the time of simulation. Fig. 4B is the DRR images plotted at the isocenter placed on the basis of skin marking attached during CT scan, and Fig. 4C is the corresponding axial image. Yellow point on Fig. 4D and 4E is the isocenter determined from skin marker. Comparing anatomic structures on simulation (Fig. 4A) and DRR image (Fig. 4B), there was trend of movement in lateral and SI directions. To match the anatomic structures between simulation image and DRR image, the isocenter point was moved to anterior and lateral directions. The green point on Fig. 4D and 4E is the new

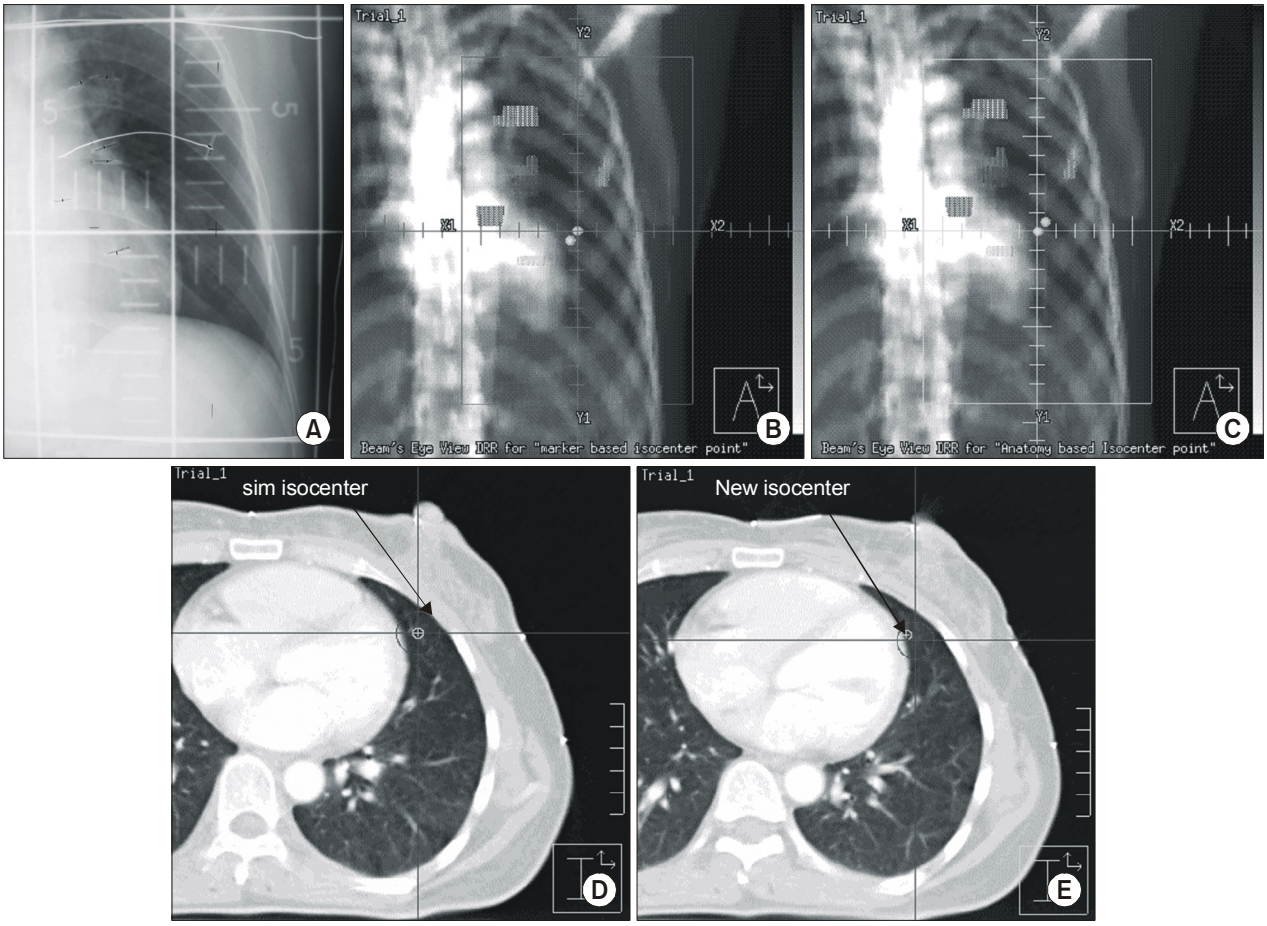

Fig. 4. Illustration of the isocenter adjustment procedure. (A) Simulation image (B) DRR image at the isocenter determined from skin marking (C) corresponding axial image showing simulation isocenter (note that wires are attached to identify isocenter point), (D) DRR image of AP beam after isocenter is moved to new isocenter (E) corresponding axial image showing newly determined isocenter.

isocenter determined based on CT image.

The movement of isocenter point for the 21 breast cancer patients after it is adjusted on the basis of anatomic structure is listed in Table 1. For a patient 1, the isocenter point is moved to 4.5 mm right and 2.8 mm posterior directions. For the 8 patients (out of the 21 patients), there was no need to adjust the isocenter point since the anatomic structure on DRR image match well with the simulation image. Except one patient, the isocenter movement was less than 5 mm in all directions (lateral, AP, and SI directions). The average movements of isocenter point were 1.6 mm (lateral), 1.2 mm (AP), and 1.1 mm (SI). The SD of the systematic error between simulations and CT scans for the 21 patients were 2.3 mm in lateral, 1.6 mm in AP, and 1.6 mm in SI directions. Although isocenter dislocation was not necessary in most of the patients, it is still required to check the location of iso-center by comparing the anatomic structures on simulation film and DRR image after the CT image is imported into the planning system.

Fig. 5 shows the SSD values in AP (gantry zero position) and medial tangential directions both measured during simulation and from the CT image. As shown in the figure, the SSD values ranged from 92 to 97 cm in AP and 89 to 92 cm in tangential directions. The average depth of the medial tangential field for the breast cancer patients treated in our institution was 9.4 cm. The group mean errors and the SD of the SSD values in AP direction were 1.9 and 2.3 mm and 2.8 and 3.7 mm in medial tangential direction. Slightly large group mean error was found in medial tangential direction as compared to AP direction. This result reflects the fact that

Table 1. Movements of Isocenter after CT Scan to Acquire Same Setup as Simulation

Patient no	Lateral (mm)		AP* (mm)		SI† (mm)	
1	4.5	R	2.8	P	0.0	
2	0.0		0.0		0.0	
3	0.0		0.0		0.0	
4	1.0	R	2.3	P	4.0	S
5	3.2	R	1.8	P	2.5	S
6	0.0		0.0		2.0	I
7	8.6	R	5.6	A	0.0	I
8	0.0		0.0		0.0	
9	0.0		0.0		0.0	
10	0.0		0.0		0.0	
11	0.0		0.0		2.0	S
12	0.0		0.5	A	0.5	I
13	2.7	R	2.0	P	3.0	I
14	0.0		0.0		0.0	
15	2.8	L	0.2	P	0.0	
16	0.1	R	3.8	A	2.5	I
17	0.0		0.0		0.0	
18	3.9	R	2.0	A	5.0	I
19	2.1	R	1.7	A	0.0	
20	0.0		0.0		2.0	I
21	3.7	R	3.3	A	0.0	

R: right, L: left, A: anterior, P: posterior, S: superior, I: inferior directions. *anterior posterior, †superior inferior

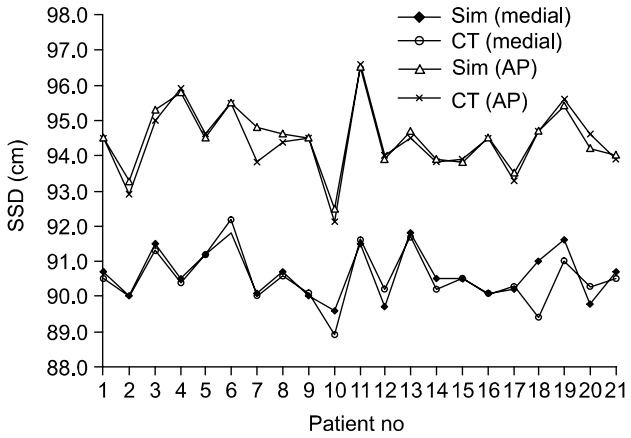

Fig. 5. Data showing the SSD values measured during simulation and from CT scan image.

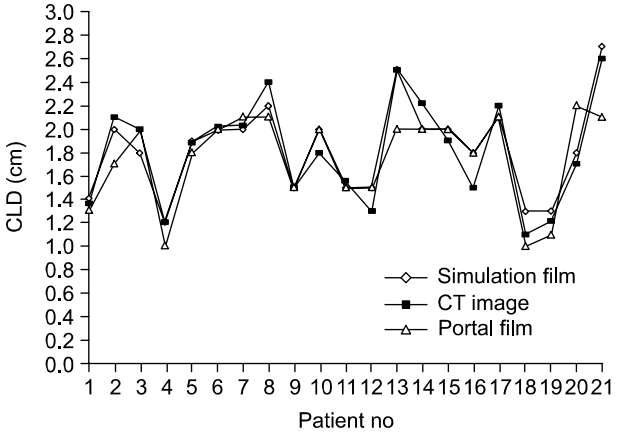

Fig. 6. Data showing the CLD values measured from simulation films, CT image, and portal films.

measurement of SSD in medial direction during simulation process is difficult and thus results large uncertainty. In 3/21 patients showed SSD difference larger than 5 mm for the medial tangential field and only one patient showed difference larger than 4 mm in AP direction. Although the largest SSD difference in AP direction is observed (10 mm) for the patient number 7, it is expected because the movement of isocenter was largest during isocenter relocation process. Maximum difference of 16 mm in tangential direction was observed for the patient 18. Considering many parameters such as anatomy matching, CLD, SSD in AP direction and patient position, the difference was caused by mistake in reading the SSD values during simulation. These results represents that at least 5% of error (1/21 patients) in measuring treatment depth could occur if SSD is measured by a therapist during conventional simulation. If the patient was treated without CT scan, the SSD measurement error may have been resulted in either overdose or underdose.

The CLD values measured from simulation film ranged from 12 mm to 27 mm for the 21 patients. When it is measured from DRR image and portal film, the values were ranged from 11 mm to 26 mm and 10 mm to 22 mm, respectively (Fig. 6). The minimum and maximum variation of the CLD for the 21 patients ranged from 0 to 6 mm between simulation film and DRR and 0 to 5 mm between simulation and treatment. Fein et al.[13] measured the CLD variation between simulation and interfraction and reported a total CLD measurements in the range 0.8 to 18.8 mm. In addition Smith et al.[14] measured interfraction variation of CLD and found the range to be 5.9 mm to 29.4 mm. When the CLD variation was compared to the values obtained from the literature, the CLD variation measured in this study is similar or even slightly better than published series.[15~17]

Finally, the differences of clip locations between simulation and CT scan for the tangential breast irradiation is measured.

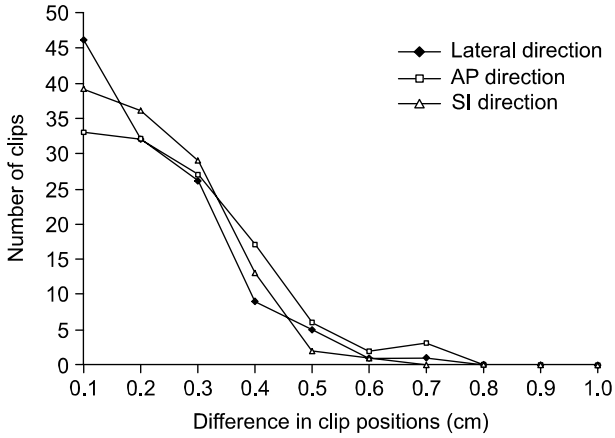

Fig. 7. Frequency plot of the variation of the clip positions on simulation and CT image.

Total 121 clips were identified from the 21 breast cancer patients and the differences in clips locations were analyzed (Fig. 7). The movements of the clips between simulation and CT scan were not significant and the variation of the clip location was less than 5mm in 1/121 clips in lateral direction, 7/121 in AP direction, and 1/121 in SI directions. The group systematic error which is just overall mean error in lateral, AP, and SI directions are 1.7 mm, 2.1 mm, and 1.7 mm, respectively. The SD of the CT setup error calculated from the clips in lateral, AP, and SI directions are 1.3 mm, 1.4 mm, and 1.2 mm, respectively. Although it is difficult to compare the interfractional variation obtained from literature with our study directly the study design is different, the results obtained in this study with clips are fairly good.

Conclusions

The accuracy of patient set-up in radiation therapy is one of the most important factors for many reasons. Accordingly, many researchers have performed studies to calculate systematic and random setup errors during simulation and treatment.[18] These studies have shown that uncertainties exist in a patient's position when treating with tangential breast irradiation and can be greater than 5 mm in some instances. Therefore, it is concluded that when a diagnostic CT scanner is used to acquire an image, the set-up variation is acceptable compared to using CT simulator for the treatment of breast cancer. However, the patient has to be positioned with care during CT scan in order to reduce the setup error between simulation and CT scan.

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국문초록

유방암 환자의 모의치료, CT 스캔 및 치료 과정에서 발생되는 준비 오차 분석

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이 레 나

목 적: 방사선 치료 시 3차원 영상 획득에 방사선치료 전용으로 개발된 모의 CT를 사용하고 있으나 아직까지도 많은 병원에서는 일반 진단용 CT를 이용하고 있다. 따라서 본 연구에서는 21명의 유방암 환자를 대상으로 모의치료, 진단용 CT기를 이용한 CT 스캔, 및 치료 과정 사이의 준비 오차를 분석하였다.

대상 및 방법: 준비 오차는 isocenter, SSD, CLD, 및 수술 시 삽입된 클립의 위치들의 변화를 계산하여 분석하였다. 모의조사에서 얻어진 x-ray 영상에 나타난 해부학적 구조물과 CT 스캔 시 isocenter를 표시하기 위해 환자의 몸에 부착된 marker를 기준으로 정해진 isocenter에서 얻은 DRR 영상상의 구조물을 비교하여 잘 일치하지 않을 경우 새로운 isocenter가 정해졌고 이러한 isocenter의 위치 변화를 계산하였다.

결 과: 21명의 환자 중 7명의 경우 DRR상과 모의치료 필름상의 해부학적 구조물이 21명의 환자 중 7명이 일치하지 않았으므로 치료계획을 실행하기에 앞서 새로운 isocenter를 정하였다. Isocenter 이동을 근거로 계산된 진단용 CT와 모의 치료간에 발생되는 평균 준비오차의 표준편차는 횡측 방향으로 2.3 mm, longitudinal 방향으로 1.6 mm, 그리고 AP 방향으로 1.6 mm이다. 모의치료와 CT data의 AP 방향 및 tangential 방향에서 측정된 SSD 값의 평균오차 및 표준편차는 각각 1.9±2.3 mm 및 2.8±3.7 mm이다. 모의치료와 DRR간의 CLD 오차의 변화범위는 0 에서 6 mm 이고 모의치료와 portal 영상간의 오차범위는 0에서 5 mm이다. 클립을 기준으로 계산된 그룹의 systematic error는 횡측 방향으로 1.7 mm, AP 방향으로 2.1 mm, 그리고 SI 방향으로 1.7 mm이다.

결 론: 연구 결과 SSD, CLD, 클립의 움직임 및 isocenter의 위치변화 측면에서 분석될 경우 그다지 큰 오차는 발생하지 않았음을 보여준다. 그러므로 본 연구결과 유방암 환자의 경우 진단용 CT를 사용한다 하더라도 준비오차는 모의 CT를 사용하는 경우와 비교하여 차이가 없음을 알 수 있다. 그러나 모의치료와 CT 스캔 사이의 준비오차를 감소하기 위해서는 CT 영상 획득 시 환자 위치고정에 특별한 주의를 기울여야 한다.

핵심용어: 유방암, 준비오차