Analysis of Overall Setup Accuracy Using On-Board Imager®

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We evaluated the overall setup accuracy for the On-Board Imager (OBI, Varian Medical Systems Inc., Palo Alto, CA, USA), with attention to the laser, the gantry, and operator performance. We let experienced technicians place the marker block on the couch using a lock bar system, with alignment to the isocenter of the laser, every morning. A pair of radiographic images of the marker block was acquired at 0^{o} and 270^{o} angles to the kV arm to correct the position using a 2D/2D matching technique. Once the desired match was achieved, the couch was moved remotely to correct the setup error and the parameters were saved. The average for the vertical and the longitudinal displacements were 0.65 mm and 0.66 mm, and 0.01 mm for the lateral displacement. The average for the vertical and longitudinal displacements were statistically significant at the 0.05 level (p value=0.000 for both), while the p value for the lateral direction was 0.829. These results show that the tendencies to displacement in vertical and longitudinal directions occur through systematic error, while systematic error was not found in the lateral displacement. This daily overall evaluation is practical and easy to find the systematic and random errors in the setup system; however, a daily QA for laser and OBI alignment is still needed to minimize the systematic error in aligning patients.

Key Words: On-board imager, 2D/2D matching, Setup error

INTRODUCTION

Through recent refinements in radiotherapy, such as intensity-modulated radiotherapy (IMRT) and stereotactic body radiotherapy (SBRT), accurate and reproducible 3D positioning of the patient during every treatment fraction became more important. Image-guided radiation therapy uses spatially registered imaging settings available on treatment machines to position the patient and deliver the treatment accurately. Many researchers have shown that correcting for errors in patient setup improves dosimetric accuracy.[1-5]

The On-Board Imager® (OBI, Varian Medical Systems, Inc., Palo Alto, CA, USA) kV imaging system delivers image-guided radiation therapy with options to correct patient setup using kV images before and during treatment. We correct the setup for every patient treated with the IMRT and the 3D-CRT in our department using the OBI system. We use mostly the 2D/2D match technique in the clinic, rather than 3D/3D, to avoid excessive radiation dosing with the 3D cone beam in CT imaging.[6,7] The OBI system moves the patient couch to match the corrected parameters obtained by 2D/2D or 3D/3D matching.

The setup error can be divided into two components: random error and systematic error.[8] Random error is always present in a measurement. It is caused by inherently unpredictable fluctuations in the technician's skill of setup. Random errors show up as different results for ostensibly the same repeated measurement. Systematic error cannot be discovered this way because it always pushes the results in the same direction. It is caused by misalignment of the laser or the OBI. If the cause of a systematic error can be identified, then it can usually be eliminated.

In addition to the laser alignment, the daily mechanical QA for OBI alignment is important. The OBI kV imaging system is a final decision tool before treatment in our department,

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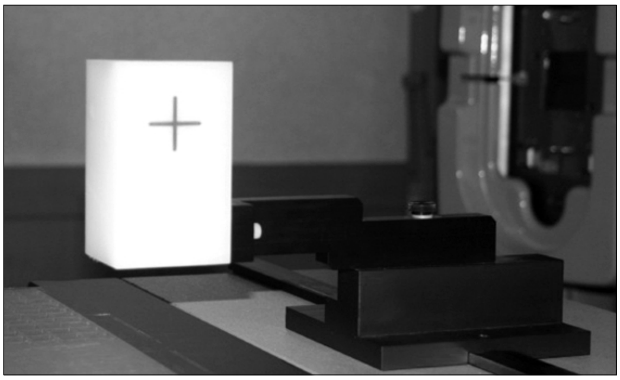


Fig. 1. Experimental setup of the marker block to verify geometric accuracy of the OBI by comparing DRR images.

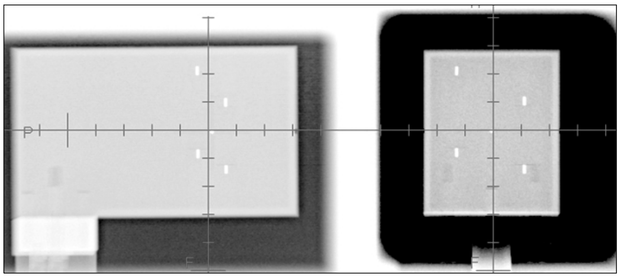


Fig. 2. Lateral (left) and anterior (right) views of a 2D radiograph of the marker block; five radiopaque markers are shown on both radiographs.

hence OBI alignment directly affects targeting accuracy.[9,10)]

In this study, we tried to find the systematic errors in the setup system such as the laser and OBI alignment, including the radiation technician's performance.

MATERIALS AND METHODS

1. On-Board Imager®

The OBI kV imaging system manufactured by Varian Medical Systems Inc. consists of a kV source and an amorphous silicon digital array (30×40 cm) mounted on robotic (Exact™) arms on either side of the gantry structure. The OBI positions automatically as we planned.

To correct the patient setup using the 2D/2D match technique, a pair of radiographic images is acquired with the kV arm set usually to 0^{o} and 270^{o} angles (actual angles of 90^{o} and 0^{o} for the gantry) in the planning system. The 90^{o} between a pair of kV setup fields is the most effective angle to see the displacement precisely in 3D. After a pair of images (e.g., AP and lateral images) has been acquired the patient position is analyzed by 2D/2D matching, a match environment where the kV images and DRRs are overlaid. The operator can apply both automated and manual matching tools to align the kV images with the corresponding DRR, with the couch shift parameters being updated as the match is adjusted. Once the desired match is achieved, the couch shift parameters are downloaded to the linear accelerator and the couch is moved remotely to correct the setup error.

2. Marker block

The marker block designed to view the OBI alignment consists of a radiopaque ball and four rods in a plastic block (Fig. 1). The radiopaque rods are placed so as not to be overlaid with rods in the AP and lateral portal images (Fig. 2). It is set using a lock bar system on the couch. Before the marker block was applied in the OBI alignment QA, it was scanned with CT and planned.

3. Daily setup QA for the OBI system

Setup fields were added in the treatment planning system (Eclipse 8.1, Varian Medical Systems, Inc., Palo Alto, CA, USA) using the CT images of the marker block. Both anterior and lateral DRR for each setup field were generated so that the patient repositioning process could be performed.

We let the experienced technicians place the marker block on the couch using the lock bar system with alignment to the isocenter of the laser every morning, just as they would do in a patient treatment procedure during 71 days. The reason that the experienced technician conducted the alignments is to minimize the bias in the technician's skill. The technicians acquired a pair of 2D radiographs for the marker block and adjusted the region of interest to match automatically (Fig. 3). After the 2D/2D match, the parameters to shift the couch were recorded. The parameters correspond to movements in vertical, longitudinal, lateral, and rotational directions.

4. Analysis

The displacement was divided into three directions of shift when it analyzed; one was vertical, another was longitudinal, and the other was lateral directions. To find the systematic errors in each displacement which were recorded for 71 days, we calculated average of them. And more we generated p value to see the average was statistically affected by systematic error.

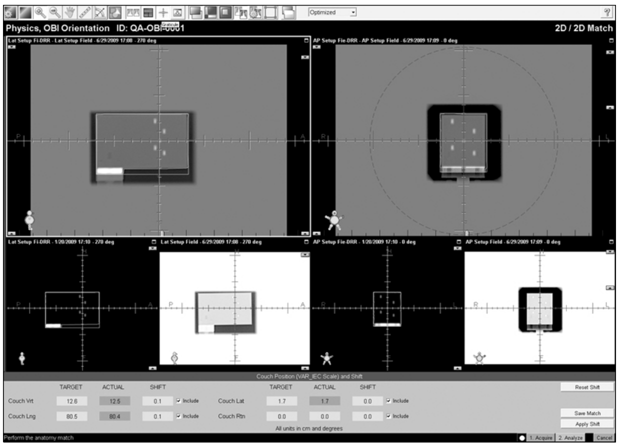
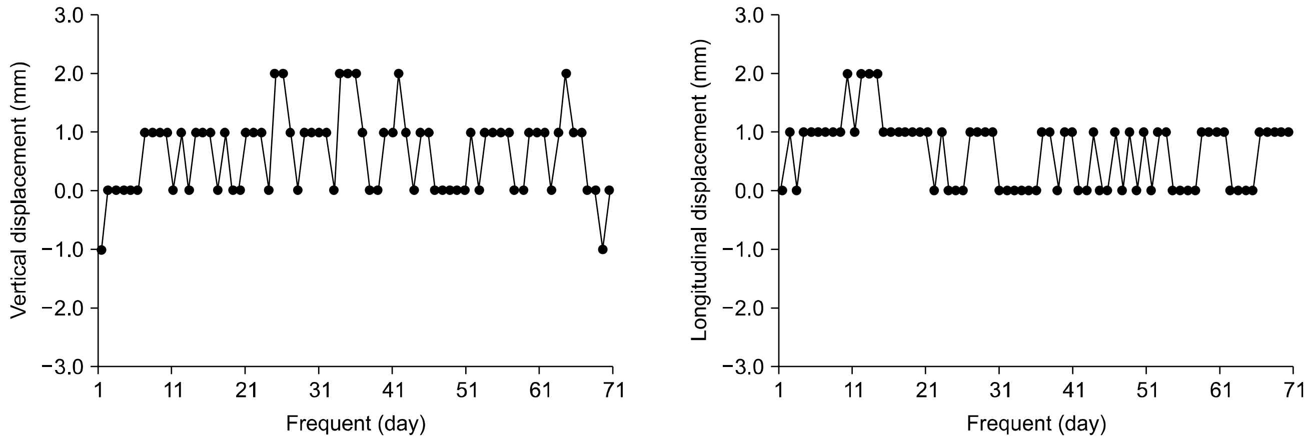


Fig. 3. Two-dimensional-two-dimensional (2D/2D) matching software on the On-Board Imaging workstation. Lateral and anterior digitally reconstructed radiographic (DRR) images were overlaid on each 2D kV portal image.

RESULTS

71-day records of the setup error are plotted in Fig. 4. The setup displacement is presented according to direction (vertical, longitudinal, and lateral). The averaged vertical, longitudinal, and lateral displacements were 0.65±0.70 mm, 0.66±0.58 mm and 0.01±0.55 mm, respectively (Table 1). However, each displacement from the isocenter was within the tolerance range (2 mm).

Fig. 5 shows histograms of the vertical, longitudinal, and lateral displacements. The vertical and longitudinal displacements tended to shift toward more positive values. The averages for displacement in the vertical and longitudinal directions were statistically significant at the 0.05 level (p value=0.000 for



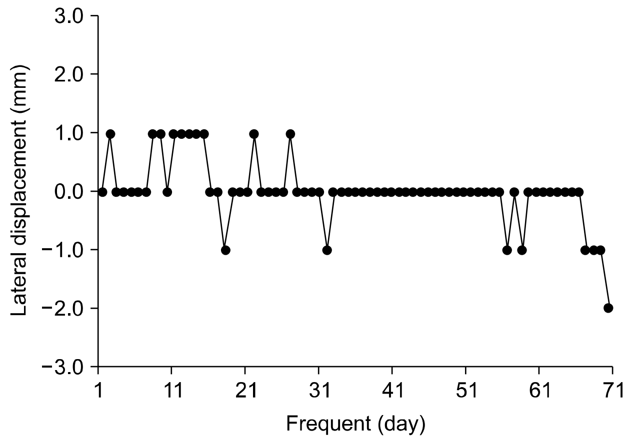


Fig. 4. Displacements in the vertical, longitudinal, and lateral directions between the marker block and the isocenter during 71 days.

both directions), while the p value for the lateral direction was 0.829. These results show that systematic error contributed the vertical and longitudinal, while systematic error was not found in the lateral displacement.

DISCUSSION AND CONCLUSION

Based on p values, the vertical and longitudinal errors represented systematic error in the setup system, while systematic error was not found in the lateral direction. The lateral direction may have no systematic errors or have more than two systematic errors which were averaged and could not find the systematic error. But in this study they do not affect to the overall systematic error and not important.

The systematic error may be caused by momentum induced by the weight of the OBI robotic arms. The alignment of the OBI relative to the isocenter directly affects the position of the reference images, since the center of the DRR is on the center of the imager.

Compared to 3D/3D matching, 2D/2D matching has the advantages of lower radiation exposure for the patient and faster image acquisition. However, 3D/3D matching can check the roll error as well as the shift, yaw, and sag. Digital tomosynthesis technology, currently in development, may soon be applied to maximize image quality and minimize exposure.[7)]

This study showed the long term stability of the overall set-

Table 1. Daily displacements in the vertical, longitudinal, and lateral directions were recorded for 71 days, and the mean, standard deviation, and p values for each direction were analyzed.

	Average	Median	Standard deviation	t	p
Vertical (mm)	0.65	1	0.70	7.811	0.000
Longitudinal (mm)	0.66	1	0.58	9.548	0.000
Lateral (mm)	0.01	0	0.55	0.217	0.829

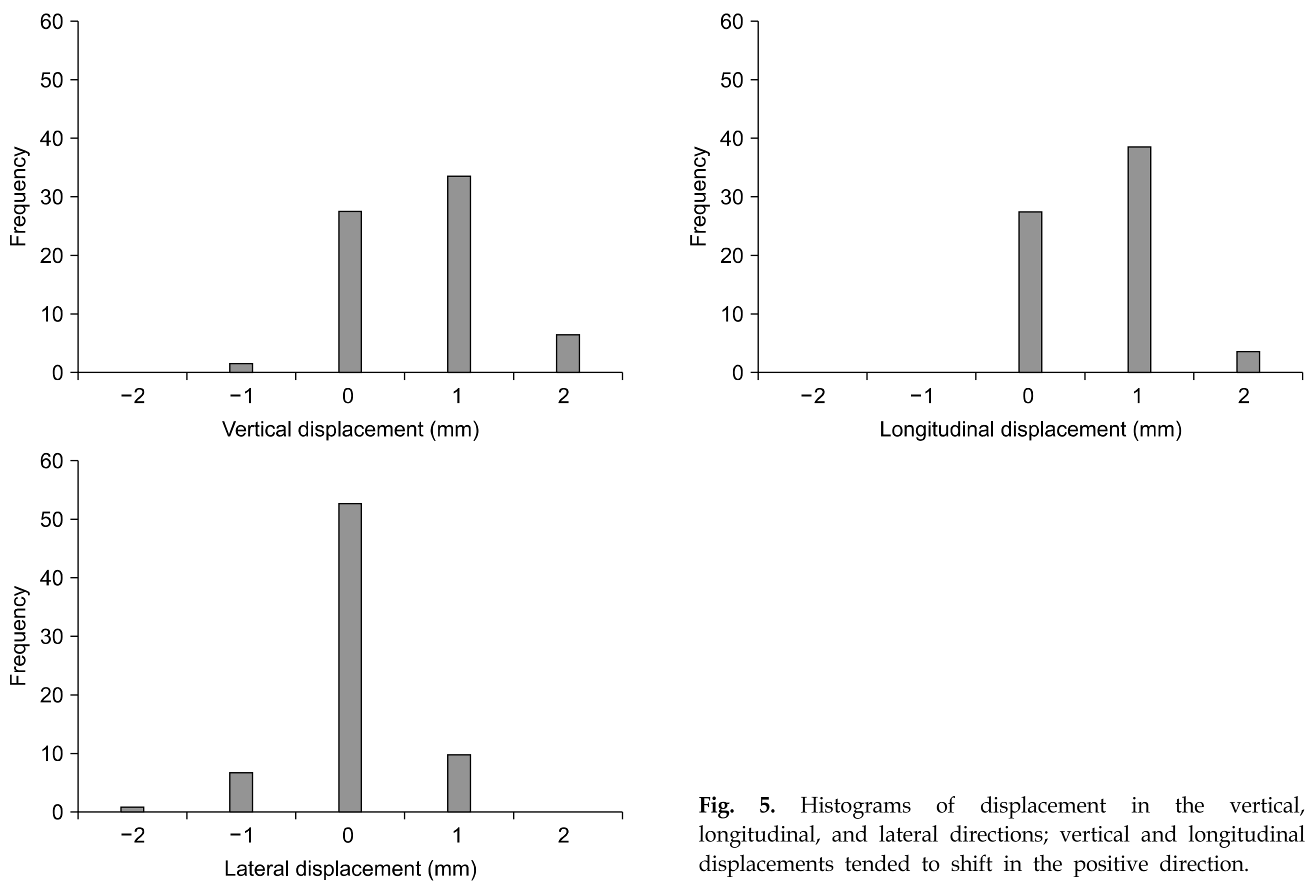


Fig. 5. Histograms of displacement in the vertical, longitudinal, and lateral directions; vertical and longitudinal displacements tended to shift in the positive direction.

up system, i.e., the combined output quality of the laser, gantry, OBI, and technical operation. This evaluation of overall setup is practical and easy to perform on a daily basis; however, a daily QA for laser and OBI alignment are also needed to minimize the systematic error. The results of this study will be applied to the daily patients' setup data and evaluate the patients' setup accuracy.

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온-보드 영상장치를 이용한 총체적 셋업의 정확성 분석

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본 연구에서는 방사선사를 포함한 레이저, 갠트리 및 온-보드 영상장치의 총체적 셋업의 정확성을 평가하고자 하였다. 경험이 많은 방사선사에게 매일 아침 마커블록을 카우치의 Lock bar 시스템에 고정하고 마커블록을 레이저 중심에 맞추도록 하였다. 71일간 마커블록을 2D/2D 정합으로 위치를 보정하기 위하여 0^o and 270^o 각도에서 한 쌍의 kV 영상을 획득하였다. 정합이 되었을 때 원격으로 카우치를 조정하여 셋업에러를 보정하고 보정 값은 저장하였다. 상하방향(vertical)과 앞뒤방향(longitudinal) 평균오차를 분석한 결과 상하방향은 0.65, 앞뒤방향은 0.66으로 나타났으며 반면에 좌우방향(lateral)은 0.01으로 나타났다. 상하방향과 앞뒤방향의 p 값은 모두 0.00으로 통계적으로 유의하게 나타났으며, 좌우방향에서는 p 값이 0.829로 나타나 계통오차를 발견하기 어려웠다. 총체적 셋업평가방법은 일간으로 시행하기에 유용하고 편리하였다. 그러나 계통오차를 줄이기 위해서 여전히 레이저와 OBI의 일간 점검은 필요하다.

중심단어: 온-보드 영상장치, 이차원정합, 셋업에러