Performance Evaluation of Virtual Laser-Based Surface-Guided Radiation Therapy Setup System Using Humanoid Head Phantom

Jeong-Woo Lee[1,2], Byoung-Moon Park[1], Yong-Ki Bae[1], Min-Young Kang[1] and Semie Hong[1,2]

[1]Department of Radiation Oncology, Konkuk University Medical Center, Seoul, Korea
[2]Department of Medical Physics Convergence, Graduate School of Engineering, Konkuk University, Seoul, Korea

Abstract : We aimed to verify patient setup accuracy using a combination of virtual laser-based SGRT systems (LUNA 3D, LAP, Germany). The experiments were divided into (1) skin-surface guidance with virtual laser and (2) mold-surface guidance with optical laser. The humanoid head phantom setups were analyzed into vertical (mm), lateral (mm), longitudinal (mm), and rotational (yaw in degree). In the virtual laser-based SGRT results, the displacement in the lateral direction is less than 0.5 mm, and the displacement in the longitudinal direction is more pronounced. In comparison, the vertical direction shows a difference of about 1 mm. The mold-based optical laser system showed vertical and longitudinal direction errors up to 2 mm. The SGRT system with the virtual laser can provide accurate alignment information of a large area and the area of interest set before treatment, providing accuracy of treatment and stable treatment setup.
Keywords: SGRT, virtual laser, optical laser, head phantom

1 Introduction

Radiotherapy technology has generally been developed along the two axes of efficient intensity modulation and image-guidance technologies.
In recent years, surface-guided radiation therapy (SGRT) has begun to replace traditional laser-based setups. It is even used as an alternative to patient motion management in image-guided radiation therapy (IGRT). Also, the installation of non-invasive and non-radiographic devices for managing patient setup posture before and during treatment using optical surface imaging technology has been expanding. Patients move against their will during treatment, which can lead to significant errors in high-precision treatments such as intensity-modulated radiation therapy (IMRT) or stereotactic body radiation therapy (SBRT).
Since the setup using an optical laser-based system uses ink or pen directly on the patient's skin to draw lines according to the laser projected from 3 directions (frontal & bilateral), the systemic error of the laser system itself and the random error of the radiotherapist still affect the quality of the patient's treatment. In addition, if a tattoo is applied to the patient's skin, it cannot be erased, and if the line drawn with ink is smeared or erased by sweat or water, CT simulation may have to be repeated.
One of the most popular treatment areas for SGRT is the breast, and studies have shown that tattoo-based treatments can reduce cosmetic and psychological burdens, as well as improve reproducibility and accuracy of patient positioning. These results have been confirmed by studies that have expanded the application to the chest, abdomen, pelvis, and head and neck.
In this study, we aimed to verify patient setup accuracy using a combination of virtual laser and optical camera using dicom information from the CT-based treatment plans.

2 Materials and Methods

The equipment used in the experiment was a C-arm type linear accelerator (iX, Varian, USA) and an SGRT system (LUNA 3D, LAP, Germany) with a virtual laser function. To realize accurate equipment performance, once the equipment was installed, calibration was performed using a cubic phantom and plate for calibration (Figure 1). The calibration of the virtual laser is crucial in the calibration process of SGRT equipment, especially in checking the agreement with the precisely calibrated CBCT.
To evaluate the performance of the LUNA 3D system, CT simulation was performed using a head phantom (Edward model 605, CIRS, USA) with and without a thermoplastic mask (Figure 2). CT scans (LB, Canon, Japan) were performed at 1 mm thickness to reconstruct 1 mm CT slices to minimize the effect of the resolution of the fine reference surface.

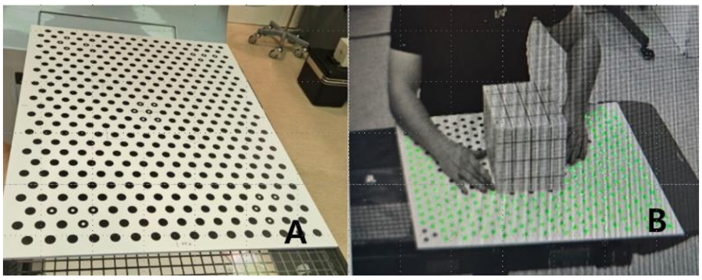

Figure 1: LUNA 3D system calibration (A) SGRT calibration plate (B) cubic phantom for SGRT calibration

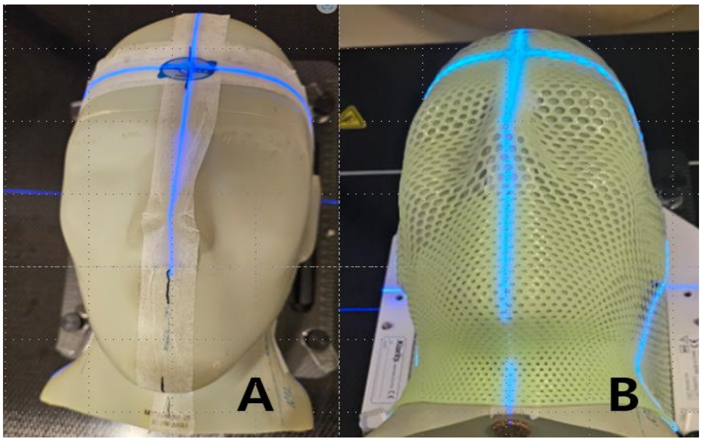

Figure 2: CT simulation using a head phantom (Edward model 605, CIRS, USA) without (A) and with (B) a thermoplastic mask

A volumetric modulated arc therapy (VMAT) treatment plan was established for the phantom plan, and the dicom

RT plan and dicom RS files were generated and imported into the LUNA 3D server.
The experiments were divided into (1) skin-surface guidance with virtual laser and (2) mold-surface guidance with optical laser. The phantom setups were analyzed into vertical (mm), lateral (mm), longitudinal (mm), and rotational (yaw in degree). The calibrated cone beam CT (CBCT) was used as a baseline to analyze the errors. The CBCTs were acquired in half fan mode with a scan condition of 512 x 512 pixels and a slice distance of 2 mm (Figures 3 and 4). Each setup was performed three times; the average and deviation were calculated, and the magnitude was analyzed by calculating the composite value of the error. The region of interest (ROI) of the skin surface was set to the whole frontal surface of the phantom. The virtual laser was referenced to the setup by matching the coordinate axis of the isocenter set during calibration with the value provided by the SGRT system based on the dicom information of the CT image (Figure 5).

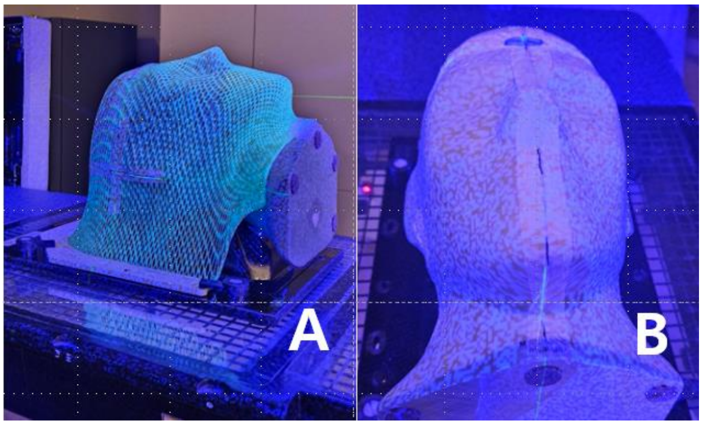

Figure 3: SGRT setup with the optical and the virtual lasers (A) mold-surface guidance with the optical laser vs. (B) skin-surface guidance with the virtual laser using humanoid phantom

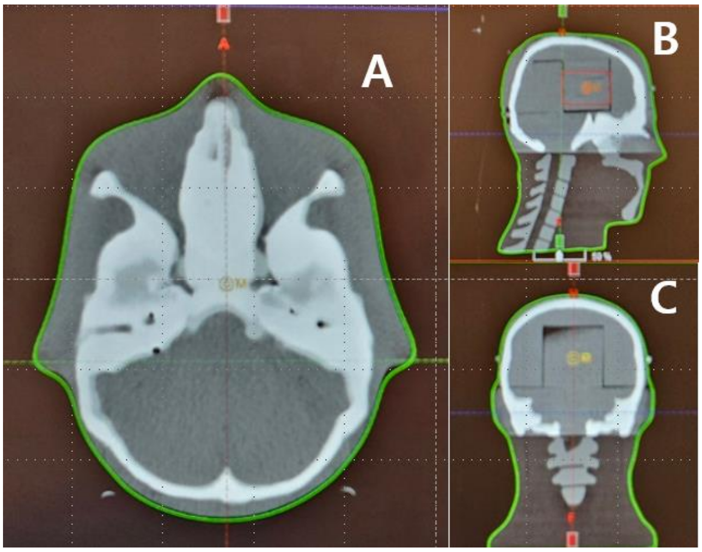

Figure 4: CBCT imaging to analyze the setup error. (A) axial CT image, (B) sagittal CT image, and (C) the coronal image

3 Results

Table 1 shows the results of calculating the displacement by taking a CBCT after setting up the humanoid phantom based on the virtual laser-based skin-surface guidance. As you can see from the results, the displacement in the lateral direction is less than 0.5 mm, and the displacement in the longitudinal direction is more pronounced. In comparison, the vertical direction shows a difference of about 1 mm. The magnitude of the three directions showed results in the range of 1 to 1.5 mm. In all three measurements, the displacement in the yaw direction was less than 0.1 degrees.

SG+VL*	Vt[1] (mm)	Lt[2] (mm)	Lg[3] (mm)	Mg[4] (mm)	Yw[5] (°)
1st	0.3	0.5	1.4	1.5	-0.1
2nd	-0.6	-0.3	-1.0	1.2	0
3rd	-1.0	0	-0.2	1.0	-0.1

Table 1: Skin-surface guided setup using the virtual laser (SG+VL). The acquired CBCT images were used to analyze the deviations: Vt[1] (vertical), Lt[2] (lateral), Lg[3] (longitudinal), Mg[4] (magnitude), and Yw[5] (yaw). Table 1 shows the results of calculating the displacement using an SGRT system after CBCT imaging correction.*

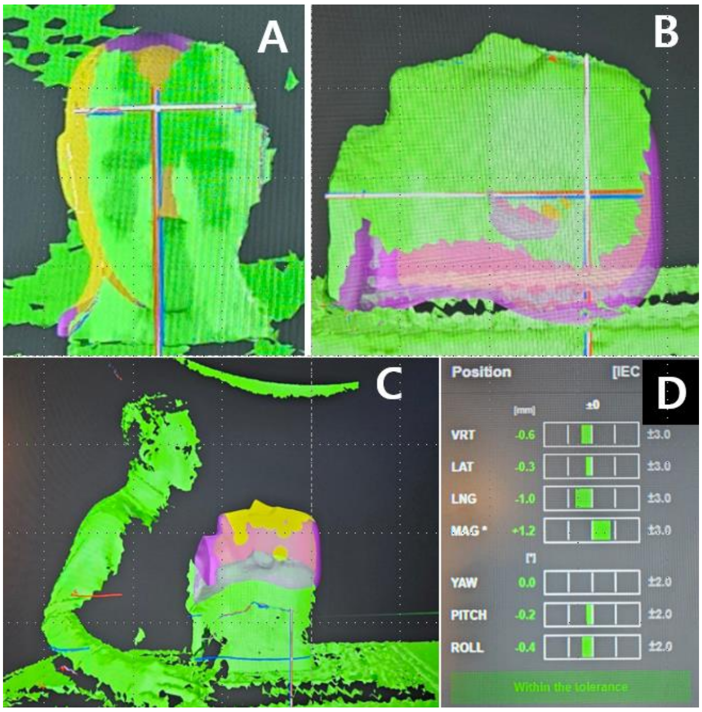

Figure 5: SGRT setup screen with the virtual lasers(blue lines) and patient dicom center (red lines) (A) frontal view, (B) left lateral view, (C) red crosslines to blue crosslines matching operation, and (D) mismatching results based on the virtual lasers and the phantom's dicom center

MG+OL*	Vt[1] (mm)	Lt[2] (mm)	Lg[3] (mm)	Mg[4] (mm)	Yw[5] (°)
1st	0.0	0.0	2.0	2.0	-0.1
2nd	2.0	0.0	1.0	2.2	-0.6
3rd	1.0	0.0	2.0	2.2	0.0

Table 2: Mold-surface guided setup using the optical laser (MG+OL). The acquired CBCT images were used to analyze the deviations: Vt[1] (vertical), Lt[2] (lateral), Lg[3] (longitudinal), Mg[4] (magnitude), and Yw[5] (yaw). Table 2 shows the results of calculating the displacement using the CBCT system after a mold-based surface-guided setup.*

On the other hand, the results of the optical laser-based mold-surface guided setup error are shown in Table 2. As shown in Table 2, the error in the lateral direction was zero in all three cases, but the errors in the vertical and longitudinal directions were up to 2 mm. The magnitude was about 2 mm, and the vertical and longitudinal directions were complementary, just like the virtual laser-based setup.

4 Discussion

In radiotherapy, stable patient positioning is more fundamental than any other technique, but it is common to all modalities and is essential for successful treatment.
In recent years, this has been the subject of active research, particularly in the breast deep-inspiration breath hold (DIBH) technique, which is synchronized with breathing, and patient motion management interfaces for high-precision radiotherapy such as frameless stereotactic radiosurgery. Traditional vendors in this SGRT market include VisionRT's AlignRT, C-RAD's Catalyst, and Varian's IDENTIFY, and their use is expected to expand as insurance coverage becomes available. Technically, many variables are utilized to evaluate the quality of an instrument, including data compatibility with the instrument, surface information acquisition and processing speed (CPU, GPU, etc.), treatment area, accuracy and reproducibility, and image resolution. Therefore, when introducing SGRT equipment, the equipment's characterization and quality evaluation are essential, and validation of new functions is necessary before use.

In this study, the functions of LAP's virtual laser with new functions were analyzed compared to the general optical laser system, and the significance of the research process was described.
1) After hardware installation of the SGRT solution and virtual laser calibration, cross-validation with a well-commissioned CBCT is necessary.
2) Comparison and verification of surface generation according to the resolution of dicom CT images is necessary.
3) Verify the correlation between the response speed of the patient's interfractional motion and the drive of the treatment device.
In the initial process of this study, we found a systematic error in the calibration of the virtual laser, which showed a difference of 1.7 mm in the same direction as CBCT, which was corrected. In addition, we found a slight difference in the 3D surface generated depending on the resolution of the reconstructed CT image, which may be important to note when using dicom images as a direct reference surface, and we believe that further research is needed. Finally, we found a delay in positional detection during the setup process based on the virtual laser, and sufficient research is needed for treatments based on real-time monitoring, such as motion tracking. This study aimed to compare the effectiveness of surface guidance based on a virtual laser to the mask molding surface guidance of an optical laser. We confirmed its usefulness with CBCT as a baseline.

5 Conclusion

In this study, the usefulness of the virtual laser-based SGRT system was compared to the conventional SGRT with the optical laser system to check the accuracy and reproducibility. By utilizing the virtual laser system, which is not adopted in the conventional SGRT system, it was possible to improve the accuracy of the setup through the information of the alignment during the patient setup, which suggested the possibility of reducing the setup time and additional imaging dose. We believe that the SGRT system, with the function of the virtual laser, can provide accurate alignment information of a large area and the area of interest set before treatment, which can provide accuracy of treatment and stable treatment setup.

References

[1] H.A. AI-Hallaq, L. Cervino, A. N. Gutierrez, et al. “AAPM task group 302: Surface-guided radiotherapy”. Med Phys 49 (2022), e82-e112. DOI: 10.1002/mp.15532.
[2] J. Rigley, P. Robertson, L. Scattergood. “Radiotherapy without tattoos: Could this work?”. Radiography 26 (2020), pp. 288-293. DOI: 10.1016/j.radi.2020.02.008
[3] P. Freislederer, M. Kügele, M. Ö llers, et al. “Recent advances in Surface Guided Radiation Therapy”. Rad Oncol 15:187 (2020),. DOI: 10.1186/s13014-020-01629-w.
[4] Z. Li, Q. Xiao, G. Li, et al. “Performance assessment of surface-guided radiation therapy and patient setup in head-and-neck and breast cancer patients based on statistical process control”. Phys Med 89 (2021), pp. 243-249. DOI: 10.1016/j.ejmp.2021.08.007