Evaluation of the Relationship Between Positioning Accuracy and Scanning Volume Using Optical Surface Scanning System and Surface Image Features

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JULY 12–16 2020 VIRTUAL
JOINT AAPM | COMP MEETING
EASTERN TIME [GMT-4]

INTRODUCTION

An optical surface scanning (OSS) system registers reference and live surface images to calculate the displacement of an isocenter in six degrees of freedom for patient positioning and monitoring.

The time and accuracy of registration using the OSS system depend on the reference surface size (i.e., the scan volume). Increasing the reference surface size may reduce the time resolution of registration while decreasing it may reduce the positioning accuracy and precision. A pre-quantitative estimation of the optimal reference surface size could solve these problems.

AIM

This study aimed to evaluate the positioning accuracy of the OSS system by resizing the reference surface size of a head rigid phantom and to investigate the relationship between the three-dimensional features of the surface image and positioning accuracy. This is to determine the optimal surface reference size with high accuracy and time resolution.

METHODS

This study was performed using an ET Verification Head Phantom (The Phantom Laboratory, USA) with a Catalyst HD system (C-RAD Positioning AB, Sweden).

The external contour of a planning computed tomography (CT) was set as the reference surface of the head phantom. The plan isocenter was located at the volume center of the phantom. The area including the entire head was defined as the baseline of the reference surface size, and the scan volume lengths in the x-, y-, and z-axis directions were resized by one quarter of the baseline to crop the reference surface size (Fig. 1).

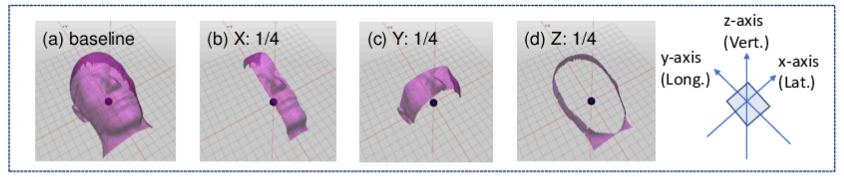

Fig. 1 The size of the reference surface image.
Image (a) is the baseline of the reference surface size.
The lengths of the scan volume are a quarter in (b) x-axis, (c) y-axis, (d) z-axis.

The phantom was positioned at the isocenter using each reference surface with the Catalyst HD. Cone beam CT images were acquired and the displacement of the isocenter in translations was defined as the residual error of positioning using the Catalyst HD. The mean absolute error (MAE) was calculated to determine the positioning accuracy by subtracting the residual error, obtained using the baseline, from the residual error, obtained using each reference surface size. We calculated the normal vector of each point in each reference surface image comprising a three-dimensional point cloud, and estimated the relationship histograms of the normal vector components using the residual error.

RESULTS

The MAE in translations for each reference size, which reflect the positioning accuracy, are shown in Fig. 2.

The MAE and standard deviation (SD) for the X: 1/4 (b) setting were **0.58 ± 0.39 mm**, 0.18 ± 0.10 mm, and 0.14 ± 0.10 mm in the lateral, longitudinal, and vertical directions, respectively.

Similarly, for the Y: 1/4 (c) setting, the values were 0.10 ± 0.11 mm, **0.59 ± 0.50 mm**, and 0.23 ± 0.16 mm in the lateral, longitudinal, and vertical directions, respectively.

For the Z: 1/4 (d) setting, the values were 0.15 ± 0.25 mm, 0.17 ± 0.09 mm, and **0.94 ± 0.75 mm** in the lateral, longitudinal, and vertical directions, respectively.

Cropping the reference surface size in the x-, y-, and z-axis directions significantly increased the MAE and SD for the lateral, longitudinal, and vertical directions, respectively.

The nominal positioning accuracy of the Catalyst HD, which C-RAD published on its company website[1)], was less than 0.5 mm; however, it was quantitatively suggested that excessive downsizing of the reference surface size may result in an accuracy of more than 0.5 mm. Optimizing the reference surface size proved to be important.

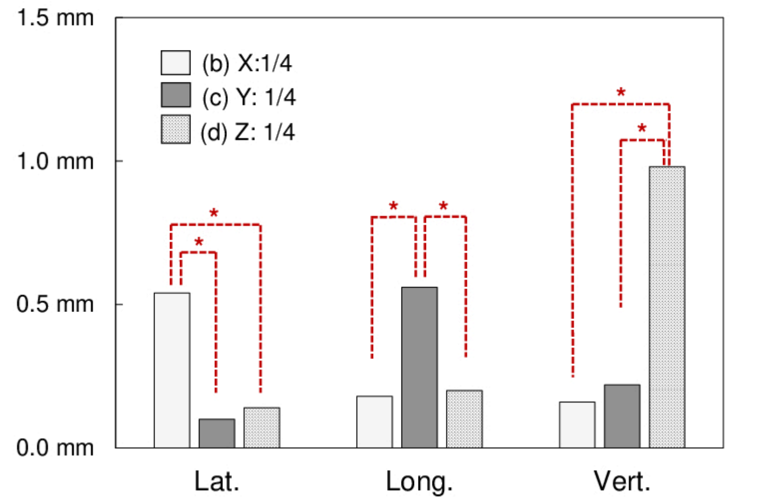

Fig. 2 The mean absolute error (MAE) of residual error for each reference size in the lateral, longitudinal, and vertical directions.
* : p<0.01 (Kruskal-Wallis test)

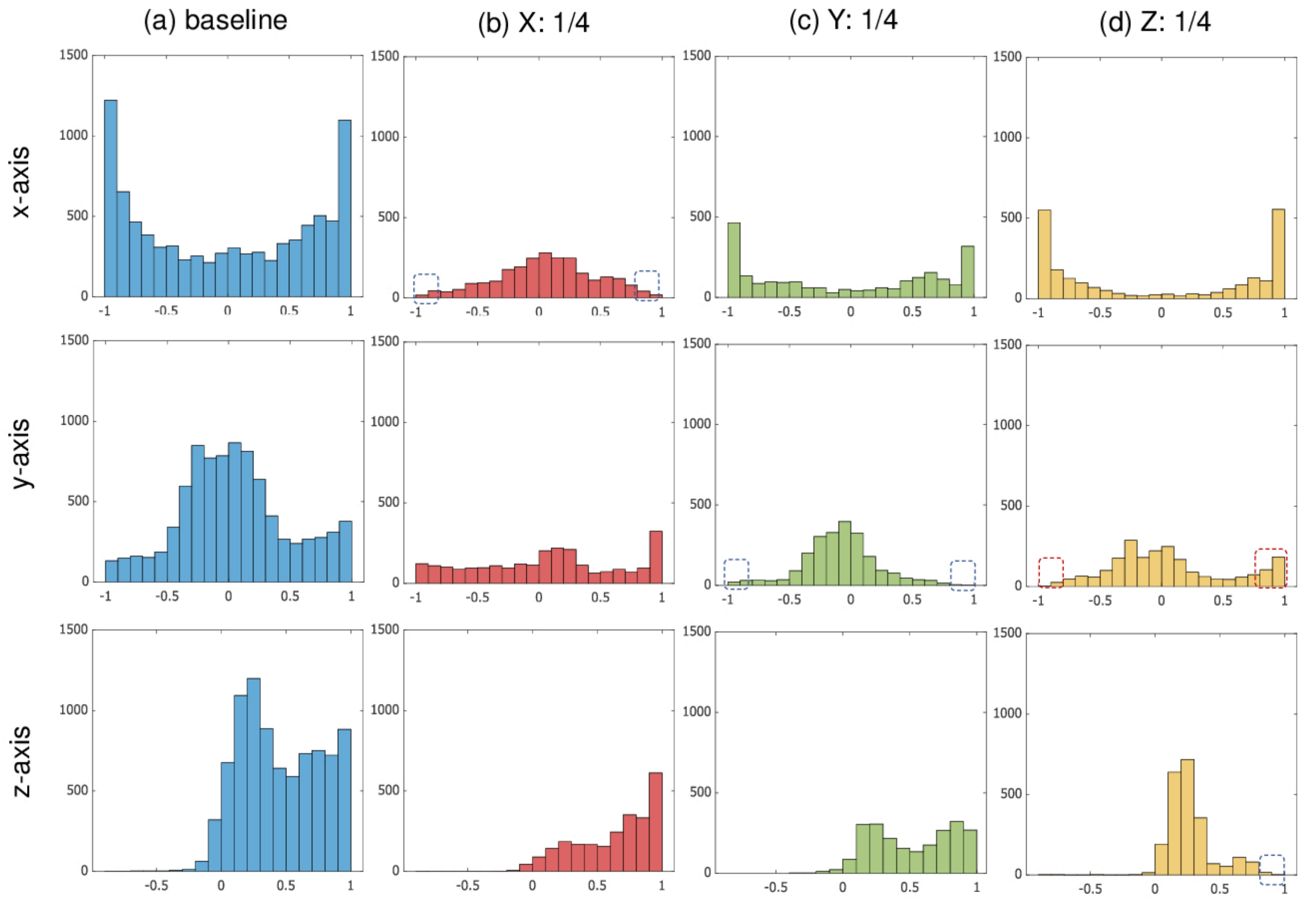

Fig. 3 Histograms of the normal vector components for each reference surface size.

The normal vectors were calculated at all points of each reference surface. They were directed outward from the surface.

Histograms of the normal vector components are shown in Fig. 3.

For the X: 1/4 (b) setting, with a large residual error in the lateral direction, the x-axis component number of the normal vectors with an absolute value greater than 0.8 was 126 points. This number tended to be relatively less compared to that of the baseline (a) setting. This result indicates that the area of the reference surface perpendicular to the x-axis was reduced.

Similarly, for the Y: 1/4 (c) and Z: 1/4 (d) settings, the y-axis and z-axis component numbers of the normal vectors with absolute values greater than 0.8 were 56 and 17 points, respectively. These values tended to be relatively less than that of the baseline.

The minimum value of the normal vector to ensure positioning accuracy was 318 points of the y-axis component for the Z: 1/4 (d) setting.

This result suggests that normal vector analysis can be used to set the optimal reference surface size.

In addition, to maintain the positioning accuracy of the OSS system, it was considered that vectors of at least 300 points were necessary.

CONCLUSIONS

In this study, we evaluated the positioning accuracy by cropping the reference surface size of the head rigid phantom.

It was found that cropping the reference surface size in the x-, y-, and z-axis directions significantly decreased the positioning accuracy of the lateral, longitudinal, and vertical directions, respectively.

In addition, we investigated the relationship between the normal vectors of surface points and positioning accuracy. We found that pre-evaluating the number of normal vectors with an absolute value greater than 0.8 can help determine the optimal reference surface size.

However, further studies on the differences in isocenter locations, target organs, additional reference surface sizes and validity of 0.8 as the threshold for normal vector are needed.

ACKNOWLEDGEMENTS

We thank radiation therapy technologists: Naoki Isomura, Shinsuke Hanaoka, Saori Watanabe, and Hiroshi Ueta (Kanazawa University Hospital, Kanazawa, Japan) for their technological support.

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