Quantitative Evaluation of Setup Error for Whole Body Stereotactic Radiosurgery by Image Registration Technique

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ABSTRCT

Whole body stereotactic radiosurgery (WBSRS) technique is believed to be useful for the metastatic lesions as well as relatively small primary tumors in the trunk. Unlike stereotactic radiosurgery to intracranial lesion, inherent limitation on immobilization of whole body makes it difficult to achieve the reliable setup reproducibility. For this reason, it is essential to develop an objective and quantitative method of evaluating setup error for WBSRS. An evaluation technique using image registration has been developed for this purpose. Point pair image registrations with WBSRS frame coordinates were performed between two sets of CT images acquired before each treatment. Positional displacements could be determined by means of volumetric planning target volume (PTV) comparison between the reference and the registered image sets. Twenty eight sets of CT images from 19 WBSRS patients treated in Asan Medical Center have been analyzed by this method for determination of setup random error of each treatment. It is objective and clinically useful to analyze setup error quantitatively by image registration technique with WBSRS frame coordinates.

Keywords: Image registration, whole body stereotactic radiosurgery

1. INTRODUCTION

The stereotactic radiosurgery (SRS) has been widely used for the metastatic intracranial neoplasm as well as the primary lesion [1-3] since the first introduction of this technique introduced in the treatment of arteriovenous malformation (AVM) by Leksell in 1951 [4]. SRS resulted in favorable clinical outcomes in the treatment of the relatively radioresistant and/or small sized intracranial malignancies by deliver high dose per fraction. However, internal movements such as respiration, peristalsis make it difficult to apply this method to extracranial tumor. Lax *et al* developed a stereotactic frame for body and started to treat extracranial diseases by SRS in 1990's [5,6]. Whole body stereotactic radiosurgery (WBSRS) using stereotactic body frame (Elekta, Sweden) has been performed in Asan Medical Center, Seoul, Korea since December 1997, and Ahn *et al* reported preliminary results [7]. It has been used as an evaluation of setup error to overlap developed films of two sets of repeated CT simulation image manually and measure the difference in two directions (X, Y axis). This method has an inherent weak point due to inter- and/or intra-clinician difference and somewhat subjective. To overcome the drawbacks of the evaluation method, we applied image registration technique to quantitative analysis of the difference between two sets of CT image. The objectives of the study are to determine the feasibility and accuracy of evaluation method using image registration technique.

2. MATERIALS AND METHODS

Nineteen patients treated with WBSRS with 28 sets of CT image were entered on this study. Each patient was immobilized in either the supine or the prone position with a vacuum mold using a stereotactic body frame with shallow respiration during CT simulation and radiation treatment. Setup marking was checked on stereotactic body frame using a chest marker and leg marker. Target motion range due to pulmonary and cardiac movement was determined fluoroscopically. In order to keep acceptable movement tolerance level, a diaphragm compressor was used to reduce respiratory movement when necessary. The diaphragm movement was evaluated by fluoroscopy with/without diaphragm compressor. Axial CT images were obtained from the mid neck to the level of the 2nd lumber vertebrae. To assess the accuracy of patient positioning, we repeated CT scanning and selected anatomically similar image to reference on the treatment day 1 and 3. The developed films of selected two image sets were overlapped and analyzed displacement with standard for the PTV. In case of the difference of both X, Y scale less than 5 mm, the conventional

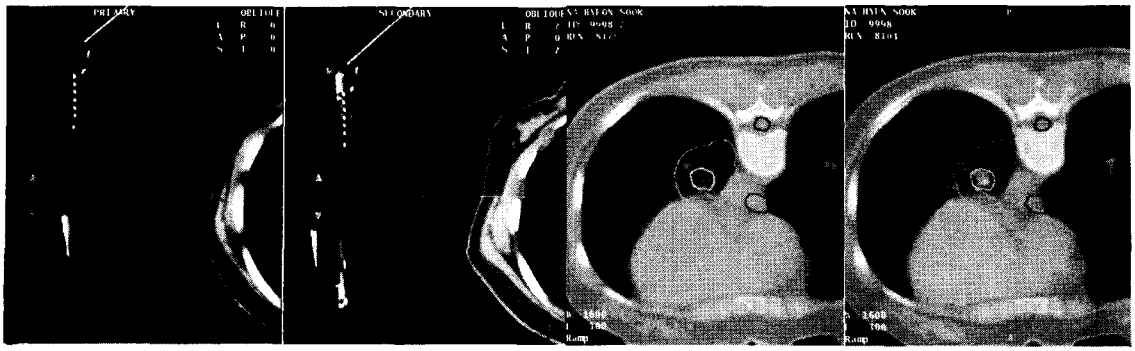

Fig. 1. Point pair registration and registered images.

WBSRS were performed. Instead of developing and printing the two sets of anatomically similar images and evaluating manually, the image registration by the point pair technique was used for the volumetric evaluation of the setup error (Fig. 1).

The WBSRS frame coordinates were set a new standard for the image registration. After registering new image sets with the reference, the displacement between PTVs in all direction (X, Y, Z axis) were calculated by AcQSim software (Marconi, USA). To set golden standard for comparing registration technique to conventional method, a phantom containing PTV was designed and CT scanning was performed. After getting the initial CT image sets, the phantom were intentionally moved 4 mm in all direction and additional CT scanning was done. We analyzed the differences between two PTVs by both conventional and new methods and investigated which one could show an approximate value to known 4 mm.

3. RESULTS

The setup variation between the initial setup and the treatment setup were evaluated as the function of each axis and the distance, with two methods. The variance distance is defined by the geometric average of three axes. The average of the X-axis setup variation difference between the variation from the conventional method (CM) and the image registration method (IRM) was 1.45mm and those of the Y-axis and the Z-axis were 1.60 and 1.76 mm, respectively. The geometric average of the values were 2.79 mm, while the average of the variance distance was 1.4 mm. The range and standard deviation of displacement were shown in table 1.

Table 1. The differences of the evaluated setup deviations between the conventional method (CM) and the image registration method (IRM) for each axis. Unit : mm

	X axis (CM-IRM)	Y axis (CM-IRM)	Z axis (CM-IRM)
Average	1.45	1.60	1.76
Standard deviation	0.89	1.13	1.27
Minimum	0.09	0.04	0.18
Maximum	3.03	4.41	4.97

The differences between two sets of the phantom CT images were evaluated by both methods. When using the conventional method, the resulting values were 1.18, 1.76 and 6.45 mm in X, Y and Z axis, respectively. The results were 2.24, 1.51 and 1.22 mm by the image registration method, respectively. The expected values were 4,4 and 4 mm.

4. DISCUSSIONS AND CONCLUSION

As one knows from phantom study, the evaluation of setup error by image registration method was more reliable than conventional method although the difference were still small. Moreover the average differences between two sets of CT image by the conventional and by the image registration method were not more than 2.5 mm. Because PTV has 5 mm margin from clinical target volume, any methods were not unacceptable in clinical setting. Compared to conventional method affected by clinician's decision to select anatomically similar axial CT image, the new developed method has some advantages. First of all, it gives more precise results. And it has the capability to perform the volumetric comparison between two registered images. Assuming the PTV shape shown in Fig. 2, the setup error (the reproducibility) from a point A to a point A', one might be able to determine the X and the Y axis deviation, but not the Z axis with the conventional 2 dimensional method. However, the Z axis deviation was able to be found through the image registration method because of volumetric comparison between two PTV before and after movement.

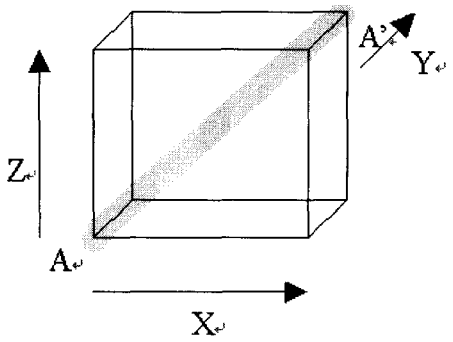

Fig. 2. Inter-treatment setup error for a point A to a point A'.

Both evaluation techniques, the conventional and the image registration method, have generally acceptable accuracy. The phantom study showed that the registration technique is more accurate although the difference was small. We could show that the new evaluation method using registration technique is more objective and can find more minute displacement. Also this volumetric study based image registration method has an advantage in case of evaluating extraordinarily shaped PTV. The dedicated software for the image registration method is needed since the fusion function in the AcQSim is not convenient enough for the routine clinic.

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