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Daily patient geometry correction: application of NAL and eNAL protocols

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Abstract

Purpose: To test the NAL and eNAL correction protocols using daily patient setup displacements.

Methods and material: In total, the analysis was performed for 749 and 797 kV CBCT images for gynecological and prostate patients, respectively, each of 30 patients. After the planning procedure, patients were set up on the treatment table in the treatment position every day. The on-line correction protocol was applied. KV CBCT images were acquired by means of x-ray lamp mounted orthogonally on Linac. Patient setup displacement was assigned. NAL and eNAL corrections protocols were simulated using daily data from online corrections for these two groups of patients. The overall systematic error and random error were calculated for each direction.

Results: For the prostate group, the random errors for daily Raw data (no correction) in LAT, LONG, and VERT directions were 2.0 mm, 1.6 mm, and 3.2 mm, respectively. For NAL and eNAL protocols, they were in the range of 1.8 mm to 3.2 mm. For the gynecological group, the random errors were: for daily Raw data 2.2 mm, 1.7 mm, and 3.2 mm, respectively. For NAL and eNAL protocols, they were in the range of 2.0 to 3.4 mm.

For the prostate group, values of systematic errors 1.8 mm, 1.8 mm, and 3.3 mm, respectively for Raw data. For NAL and eNAL protocols, these values were less than 1.8 mm. For the gynecological group, the systematic errors were 2.6 mm, 2.3 mm, and 2.8 mm, respectively, for Raw data. For NAL and eNAL protocols less than 1.8 mm.

For the gynecological group, for Raw data, 45% of the total displacement vectors exceeded 5 mm, whereas only 25% did after the NAL procedure and 29% after the eNAL procedure. For the prostate group, for Raw data, 34% of the total displacement vectors exceeded 5 mm, whereas only 22% did after NAL procedure and 28% after eNAL procedure.

Conclusions: For gynecological and prostate cancer patients, the NAL and eNAL correction protocols can be safely applied to substantially reduce setup errors.

Key words: setup control; correction protocols; geometry errors.

Introduction

Accuracy in delivering dose to the patient treated with ionizing radiation is a crucial point in the whole process of radiotherapy. An accurate and repeatable patient setup is needed to achieve good reproducibility during the whole course of radiotherapy. The essential source of patient displacement is the process of realization of radiotherapy. Fractional therapy requires reproducible and controlled delivering treatment beams to the target during all treatment fractions. The large dose gradient is obtained in the volume of the target to protect healthy tissue and organ at risk. Therefore small changes between the planned and realized patient treatment geometry can significantly decrease the Tumor Control Probability (TCP) and increase the Normal Tissue Control Probability.

Patient setup displacements can be measured during radiotherapy treatment by comparing images acquired on the treatment machine to reference images. Patient's displacements are obtained in 3 orthogonal directions: Lateral (LAT), Longitudinal (Long), and Vertical (Vert) as a difference in position between treated and planned isocenter. Modern radiotherapy demands the patient setup shifts less than a few millimeters. The quality of treatment is inseparably connected with continuous monitoring of some parameters such as delivered dose and patient setup.¹ Today many correction strategies protocols are available to estimate patient's setup errors which can determine and correct systematic and random errors. A gantry mounted kV imaging systems and MV imaging systems enable us to acquire two dimensional (2D) portal images and three dimensional (3D) Cone Beam CT images.

In conventional radiotherapy, one can use an offline setup verification procedure to adjust the patient position on the treatment table. The result is acquired after the completion of the irradiated fraction. This procedure requires using some criteria for correcting the next patient setup or not. Offline procedure protocol is managed to reduce only systematic errors. Another type of procedure is the online setup verification procedure where the decision of correcting patient setup is performed prior to each daily irradiation. During this procedure the radiation is turned off after delivering a small dose, the images acquired on the accelerator are compared to reference images. The result is used to decide on the continuation of irradiation with or without correction patient setup. The last progress of the imaging systems enables us to perform on-line corrections during the current fraction and reduce both systematic and random errors.² To take a decision for off-line procedure require to apply some other correction protocols. One of them is “shrinking action level” (SAL), no action level (NAL), or extended action level (eNAL).^{3,4}

Daily imaging-guided radiotherapy (IGRT) was implemented to reduce patient setup errors more precisely prior to radiation delivery. The purpose of the present study was to test the NAL and eNAL correction protocols using daily patient setup displacements.

Material

The study was performed for two groups, each of 30 patients, undergoing radical irradiation for gynecological and prostate tumors. Both groups of patients were treated with IMRT and VMAT techniques. We analyzed 749 and 797 kV CBCT images for gynecological and prostate patients, respectively. Patients were irradiated with isocentric technique, with 6 MeV and 15 MeV energy photon beams, the number of treatment fields were in the range 4 to 6 fields. CT images were made of the pelvic regions with the patients lying in the supine position before starting treatment. CT images were used to make treatment plans for each patient by means of Pinnacle treatment planning system. The position of isocenter was matched on every treatment plan. After the planning procedure, patients were set up on the treatment table in treatment position every day. The on-line correction protocol was applied. kV CBCT images were acquired by means of an orthogonal x-ray lamp, consisted of a conventional X-ray tube (kV source) and an a-Si flat panel detector, both mounted on the gantry of the LINAC.

kV CBCT images were matched to the treatment planning CT images and patient setup displacement was assigned. Finally, treatment couch was moved by these displacement values in proper orthogonal directions if the values of displacement were greater than 2 mm. The procedure was repeated every day before starting treatment delivery.

Methods

Patient setup displacement can be described in terms of systematic and random errors. The overall systematic error Σ and the random error σ were calculated for each direction as described in the literature.⁵⁻⁷ Calculations were performed for single patients and groups of patients. We tested NAL and eNAL corrections protocols using daily data (indicated as “Raw data”) for these groups of patients. We simulated the NAL protocol by calculating mean displacement over the first three treatment fractions. This mean displacement was applied to correct all subsequent fractions if the value of the mean displacement was greater than 2 mm. For the eNAL protocol, the initial step is the same, but additional weekly follow-up measurements were performed. A new setup correction was determined for 8,13,18,... fraction as described in the literature⁸ and it was used for the subsequent treatment fraction. This new correction factor is a value of a linear least-squares fit function calculated for additional measurement and it is used for the subsequent treatment fractions until a new correction, based on new data, is calculated. For example, 30 treatment fractions require eight measurements of corrections for this kind of protocol. Total displacement vectors were calculated for all prostate and gynecological patients.

Results

Table 1 shows the results of the systematic error Σ and the random error σ in three orthogonal directions LAT, LONG, and VERT for a group of patients treated with gynecological and prostate cancer for Raw Data, NAL and eNAL protocol, respectively.

Figure 1 shows the cumulative distribution of the total displacement vector length for patients treated with gynecological cancer. **Figure 2** shows the cumulative distribution of the total displacement vector length for patients treated with prostate cancer.

Table 1. Systematic error Σ and the random error σ for the gynecological and prostate group.

Localization	Protocol	Σ_{LAT} (mm)	Σ_{LONG} (mm)	Σ_{VERT} (mm)	σ_{LAT} (mm)	σ_{LONG} (mm)	σ_{VERT} (mm)
Prostate	Raw Data	1.8	1.8	3.3	2.0	1.6	3.2
	NAL	1.1	0.8	1.4	2.1	1.8	3.0
	eNAL	1.3	1.1	1.8	2.4	1.9	3.2
Gynecology	Raw Data	2.6	2.3	2.8	2.2	1.7	3.2
	NAL	1.3	1.0	2.0	2.8	2.0	3.4
	eNAL	1.5	1.4	2.1	2.6	2.0	3.2

Figure 1. Comparison of the total displacement vector length for Raw Data, NAL, and eNAL protocols for patients with gynecological cancer.

Discussion

The utilization of online procedure is very useful in modern radiotherapy. By comparing kV CBCT images with CT images one can get precise information about whether patient setup on treatment machine is equal to the intended setup and if not, correct patient position by the displacement shifts during each treatment session. But a possible drawback of this correction protocol is the increase in treatment time. When we have online daily patient displacements data we can try to simulate some offline procedure using this data. This test can help to answer the question about the workload of online procedure.

For the prostate group, the random errors for daily Raw data in LAT, LONG, and VERT directions were 2.0 mm, 1.6 mm, and 3.2 mm, respectively. When we adapted the NAL protocol the random errors in LAT, LONG, and VERT directions were 2.1 mm, 1.8 mm, and 3.0 mm, respectively. We cannot observe a significant increase in these values. When we adapted the eNAL protocol the random errors in LAT, LONG, and VERT directions were 2.4 mm, 1.9 mm, and 3.2 mm, respectively. NAL and eNAL data are comparable between each other and they are smaller than daily Raw data.

For the gynecological group, the random errors for daily Raw data in LAT, LONG, and VERT directions were 2.2 mm, 1.7 mm and 3.2 mm, respectively. When we adapted the NAL protocol the random errors in LAT, LONG, and VERT directions were 2.8 mm, 2.0 mm, and 3.4 mm, respectively. We cannot observe a significant increase in these values. When we adapted the eNAL protocol the random errors in LAT, LONG, and VERT directions were 2.6 mm, 2.0 mm, and 3.2 mm, respectively. The random errors for both groups were found to be larger in the VERT direction than in LAT and LONG directions and they were about equal for the last two directions.

For the prostate group, the systematic errors were about equal for Raw data in LAT and LONG directions (1.8 mm and 1.8 mm, respectively) and considerably larger in VERT

Figure 2. Comparison of the total displacement vector length for Raw Data, NAL, and eNAL protocols for patients with prostate cancer.

direction (3.3 mm). For a NAL protocol, the systematic errors were smaller in all directions than Raw data and they were about all equal. For an eNAL protocol, there was not a significant growth of systematic errors for all directions (1.3 mm, 1.1 mm, and 1.8 mm, respectively).

For the gynecological group, the systematic errors were about equal for Raw data in LAT, LONG, and VERT directions (2.6 mm, 2.3 mm, and 2.8 mm, respectively) and considerably larger in the VERT direction (3.3 mm). For a NAL protocol, the systematic errors were smaller in all directions than Raw data and they were about all equal. For an eNAL protocol, there was a significant growth of systematic errors for all directions (1.5 mm, 1.4 mm, and 2.1 mm, respectively).

Figure 1 shows the relative frequencies of different magnitudes of total displacement vectors for gynecological groups. For Raw data, 45% of the total displacement vectors exceeded 5 mm, whereas only 25% did after the NAL procedure and 29% after the eNAL procedure. Twenty-three percent of total displacement vectors exceeded 7 mm for a Raw data, and that was reduced to 9% after the NAL correction procedure and 14% after the eNAL correction procedure.

Figure 2 shows the relative frequencies of different magnitudes of total displacement vectors for the prostate group. For Raw data, 34% of the total displacement vectors exceeded 5 mm, whereas only 22% did after the NAL procedure and 28% after the eNAL procedure. Fifteen percent of total displacement vectors exceeded 7 mm for a Raw data, and that was reduced to 7% after the NAL correction procedure and 12% after the eNAL correction procedure.

There is a significant growth of total displacement vectors exceeded 5 mm and 7 mm after the eNAL correction procedure both for the gynecological and prostate group.

Precise patient setup reproducibility in the pelvic region can cause particular difficulties. Patient skin movability (as well as

skin markers) with respect to internal bone structures effects on a different patient setup from planning one. Larger values of random errors were obtained in vertical (VERT) direction. Hurkman's at all. reported random errors for gynecological patients in LAT, LONG, VERT directions as 2.8 mm, 2.6 mm, and 3.0 mm, respectively.⁹ H. El-Gayed at all. published random errors for prostate patients in LAT, LONG, VERT directions as 1.7 mm, 1.2 mm, and 1.9 mm, respectively.¹⁰ This data are similar to data obtained by the authors.

Conclusions

Patient setup geometry control is a very important part of modern radiotherapy. Application of NAL and eNAL protocols reduced values of total displacement vectors in comparison to Raw data for gynecological and prostate cancer patients. The NAL and the eNAL correction protocols can be safely applied to substantially reduce setup errors in these groups of patients.

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