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CBCT MOTION TRACKING INTERNAL MOTION TRACKING AND VALIDATION FOR ABDOMINAL RADIATION THERAPY

Health care

Gopal Subramanian Frontier Health Care, Chennai, India

ABSTRACT

Purpose To demonstrate that during pretreatment Cone-Beam CT (CBCT) can accurately measure tumor motion and that this method should be used to validate margins during treatment.

Methods and Materials For 26 patients with abdominal tumors and implanted fiducial markers, tumor motion was measured daily with CBCT and fluoroscopy for 186 treatment fractions. Fiducial tracking and maximum-likelihood algorithms extracted 3-dimensional fiducial trajectories from CBCT projections. The daily internal margin (IM) (ie, range of fiducial motion) was calculated for CBCT and fluoroscopy as the 5th-95th percentiles of displacement in each cardinal direction. We validated CBCT fiducial tracking as an accurate predictive measure of intrafraction motion by comparing the daily measured IM CBCT with the daily IM.

Results Four-dimensional CT could not accurately predict intrafractional tumor motion for ≥84% of fractions in 96% (IMCBCT), 94% (IM pre-fluoro), and 100% (IM fluoro) of patients. For patients with median treatment time t < 7.6 minutes, IM CBCT was in agreement with IM fluoro for 94% of fractions (superior–inferior), compared with 67% for the t > 7.8 minutes group, demonstrating the need for patient-specific intratreatment imaging.

Conclusions Cone-beam CT could replace fluoroscopy for pretreatment verification of simulation IM, reducing patient setup time and imaging dose. Patients with treatment time t > 7.6 minutes could benefit from the addition of intratreatment imaging.

KEYWORDS

CBCT, Radiotherapy, Marker, Quality Assurance

INTRODUCTION

Highly conformal intensity modulated radiation therapy and stereotactic body radiation therapy (SBRT) are effective methods of treating abdominal cancers while minimizing radiation damage to healthy tissue (1). For abdominal sites, tumor motion is due to a combination of respiratory and gastrointestinal movement and is typically on the order of 10-30 mm (2) . Historically, a uniform margin was added to the clinical target volume (CTV) to account for internal motion and patient setup errors (3). However, it has been shown that 4DCT can fail to accurately estimate daily intrafractional tumor motion, owing to irregular breathing captured during simulation, short 4DCT acquisition time, and/or functional or anatomic changes between simulation and treatment (4).

For abdominal cancer, cone-beam computed tomography (CBCT) (5) may be used for target localization before each treatment fraction, in combination with implanted radio-opaque fiducial markers. Recently, Poulsen *et al.*(6) demonstrated a method for extracting tumor motion (4D fiducial coordinates) from a single CBCT. Yadav et al demonstrated that CT to density curve over time is important for dosimetric integrity (7). Unlike retrospectively binned 4D-CBCT, this method does not require additional scanning time or suffer from artifacts due to irregularities in internal motion and limited projection data (8).

We propose that tumor motion can be accurately measured, and the planned margin for internal motion can be verified, by using the projection data from the localization CBCT based on existing evidence of its acceptability in adaptive planning (7). In this work we have confirmed that simulation 4DCT does not adequately predict daily tumor motion. Furthermore, we have demonstrated that internal motion measurements using CBCT are in good agreement with on-table kilovoltage (kV) taken immediately before and after treatment.

METHODS AND MATERIALS

Twenty six patients with various abdominal tumors treated over a 2-and-a-half year period were included in this study under an institutional review board–approved retrospective protocol. Patient tumor locations and treatment modalities consisted of: 10 pancreatic and 3 abdominal tumor sites receiving conventionally fractionated radiation therapy in 25 fractions; and 10 liver, 1 abdominal, and 1 lower lung tumor site(s) receiving SBRT in 5 fractions. Of these potential 425 treatment fractions, we successfully recorded all daily imaging necessary for this study for 216 treatment fractions. All patients had single or multiple radio-opaque fiducial markers implanted endoscopically or percutaneously in or near the tumor.

A 4DCT-derived planning internal margin (IM 4DCT) was measured along each axis for each clinically used fiducial marker. The EOE phase of the 4DCT was defined as the phase with the most superior marker location. The 3-dimensional (3D) marker position in this phase was arbitrarily defined as the zero position. The IM 4DCTwas defined as the extent of motion over the 10 phases of the 4DCT in the superior–inferior (SI), anterior–posterior (AP), and left–right (LR) directions.

We used Trilogy due to its onboard Imager feature as suggested in existing literature (7). The stability of CT to electron density calibration is a validation of CT number integrity and is a precondition for dosimetric calculations (7). We acquired CBCT scans with onboard scanner with 640 projections over 360 degrees. Scans were imported to Pinnacle for image value measurements. Regions of interest were contoured with the center of each of the phantom plugs and mean HU values within the contours were recorded. This analysis was done for 06 months as per guidelines of Yadav et al (7).

The median treatment time, defined as the time gap between pre- and posttreatment fluoroscopy, was 8.8 minutes (6.5-12 minutes) for conventionally fractionated patients and 17 minutes (11-25 minutes) for SBRT patients. For each fluoroscopy session, fiducial markers were tracked in 2D over the duration of the movie using a combination of DP and template matching, as first described by Wan *et al.* (8) . In total, 534 fluoroscopy movies were recorded and analyzed; occasionally posttreatment fluoroscopy was not recorded owing to day-to-day workflow of a busy clinic—these fractions were excluded from analysis.

The EOE positions in the other directions were defined as the fiducial locations in the AP and LR directions averaged over the times along the 3D trajectory where the fiducial was at EOE in the SI direction. This 3D EOE position was defined as the zero position in fluoroscopy, and the fluoroscopy-derived IM for pretreatment and pre-+posttreatment data ($IM_{pre\text{-}fluoro}$ or IM_{fluoro}) was in each direction defined as displacement from EOE to the 5th and 95th percentile motion locations.

We tested day-to-day variability of the on-treatment imaging modalities: CBCT and fluoroscopy. In cases of dose recomputations, we compared to the changes in dose volume histograms and dose distribution profiles due to variation in CT to density (7).The CBCT 2D-to-3D algorithm (9) uses maximum-likelihood-estimation to estimate the LR/AP locations at times when the kV source is not orthogonal to that motion axis. In addition, the CBCT tracking algorithm uses DP alone, whereas the fluoroscopy tracking uses a combination of DP and template matching (8). Therefore, we expected slightly higher variance in the LR/AP directions from the CBCT data

compared with fluoroscopy, and subsequently tested this using a paired Pitman-Morgan test for variance.

RESULTS

For our patient population, the average fiducial motion (±standard deviation) as measured by pretreatment fluoroscopy was 9.6 ± 4.9 mm, 3.6 ± 2.4 mm, and 2.1 ± 1.3 mm in the SI, AP, and LR directions, respectively. According to our criteria, on a per-patient basis the planning 4DCT was not an adequate representation of the daily motion in ≥80% of fractions for 97% (IM_{CBCT}), 94% ($IM_{pre\text{-}flouro}$), and 100% (IM_{flouro}) of patients. Examining all fractions from all patients combined, according to the same criteria, the planning 4DCT was not an adequate representation of the daily motion in 75% (IM_{CBCT}), 70% ($IM_{pre\text{-}flouro}$), and 75% (IM_{flouro}) of fractions. There was no distinct correlation between the difference in IM and the number of days between simulation and a particular treatment fraction.

Paired Pitman-Morgan test for variance

The paired Pitman-Morgan test showed that the difference in variance between the CBCT and pretreatment fluoroscopy IMs in the AP direction was not significantly different (P =.8), whereas in the LR direction the variance of IM_{CBCT} (3.9 mm) was significantly higher (P <.01) than the variance of $IM_{pre\text{-}fluoro}$ (1.7 mm). For comparison, the variance of the IM_{4DCT} in the LR direction over all patients was 3.1 mm.

DISCUSSION

The need for on-treatment verification of planning IM has been shown in previous patient studies. Our results confirmed that 4DCT less accurately predicts the daily IM in abdominal patients, compared with CBCT. Graphic and statistical analysis showed that both systematic differences between simulation and treatment and day-to-day variation of patient breathing contribute to this disagreement. This study does not distinguish whether differences between simulation and treatment are caused by the different imaging modalities or by changes in patient breathing pattern. Slice thickness of the 4DCT may be a limiting factor; as CT and data storage technology increases, 4DCT with 1mm slice thickness could become the clinical standard. Future investigations could compare the internal motion measured from simultaneous 3mm and 1mm 4DCT reconstructions. CBCT imaging should be preferred over MVCT images wherever possible especially in the cases of adaptive planning for over all workflow improvement (7).

Although our study used IM as an effective way to compare motion across time points and modalities, the same on-treatment CBCT data could be used with other treatment margin generation methods (eg, gated-ITV, MidP). Both gated-ITV and MidP margins use 4DCT data that must still be validated on-treatment before irradiation, and CBCT tracking could be used to aid in this verification.

There are anomalies in abdomen due to large daily variations in such anatomy. In such cases large margin of PTV can help for compensating setup errors (7). We propose that, in place of both a CBCT and fluoroscopy at every treatment fraction, IM could be verified via fiducial tracking on projection data from the localizing CBCT.

The PTV margin must also account for errors in contouring, daily localization, and patient setup. Therefore, our recommendation remains to verify the planning motion on the treatment table before treatment rather than using a generic expansion.

CONCLUSION

Simulation 4DCT-derived IMs must be verified on treatment and CT to density curve should be analyzed for appropriate treatment time. For anatomical variation adjustment there should be adaptive planning using CBCT (7). We established CBCT fiducial tracking as an accurate method of pretreatment IM verification for abdominal radiation therapy patients with implanted fiducials. Patients with treatment time ≥7.5 minutes could benefit from intratreatment imaging or more secure immobilization.

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