PHYSICS CONTRIBUTION

COMPARISON OF LOCALIZATION PERFORMANCE WITH IMPLANTED FIDUCIAL MARKERS AND CONE-BEAM COMPUTED TOMOGRAPHY FOR ON-LINE IMAGE-GUIDED RADIOTHERAPY OF THE PROSTATE

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Purpose: The aim of this work was to assess the accuracy of kilovoltage (kV) cone-beam computed tomography (CBCT)–based setup corrections as compared with orthogonal megavoltage (MV) portal image-based corrections for patients undergoing external-beam radiotherapy of the prostate.

Methods and Materials: Daily cone-beam CT volumetric images were acquired after setup for patients with three intraprostatic fiducial markers. The estimated couch shifts were compared retrospectively to patient adjustments based on two orthogonal MV portal images (the current clinical standard of care in our institution). The CBCT soft-tissue based shifts were also estimated by digitally removing the gold markers in each projection to suppress the artifacts in the reconstructed volumes. A total of 256 volumetric images for 15 patients were analyzed.

Results: The Pearson coefficient of correlation for the patient position shifts using fiducial markers in MV vs. kV was \( R^2 = 0.95, 0.84, 0.81 \) in the left–right (LR), anterior–posterior (AP), and superior–inferior (SI) directions, respectively. The correlation using soft-tissue matching was as follows: \( R^2 = 0.90, 0.49, 0.51 \) in the LR, AP and SI directions. A Bland-Altman analysis showed no significant trends in the data. The percentage of shifts within a ±3-mm tolerance (the clinical action level) was 99.7%, 95.5%, 91.3% for fiducial marker matching and 99.5%, 70.3%, 78.4% for soft-tissue matching.

Conclusions: Cone-beam CT is an accurate and precise tool for image guidance. It provides an equivalent means of patient setup correction for prostate patients with implanted gold fiducial markers. Use of the additional information provided by the visualization of soft-tissue structures is an active area of research. © 2007 Elsevier Inc.

Cone-beam CT, Image-guided, Prostate radiotherapy, Fiducial markers, Surrogates.

INTRODUCTION

Highly conformal radiation therapy fields for the treatment of prostate cancer have been shown to reduce the risk of rectal toxicity compared with conventional radiation therapy (1, 2). This has permitted dose escalation, with Phase II and III trials showing improved biochemical relapse–free survival compared with standard dose radiation therapy (3, 4).

Conformal radiotherapy techniques require greater precision in treatment setup and delivery than conventional techniques if target coverage is to be assured. A geometric margin around the clinical target volume (CTV) is added to account for uncertainties in prostate position as a result of prostate motion and patient setup errors. However, additional steps in the planning and treatment process are required to minimize these potential sources of error to ensure the target is localized within this planning target volume.
(PTV). Daily localization of the gland or its surrogate before treatment allows this volume to be reduced and provides verification of target coverage. It has been recognized that the prostate is a moveable structure and the nature of its motion is well-documented (5–7). Bony anatomy is not a strong surrogate for daily prostate position, therefore portal imaging alone is not sufficient for substantial PTV reductions.

Various methods have been used to localize the gland. Three-dimensional localization of the prostate gland using ultrasound has been shown to be an efficient and accurate method (8, 9). However, some of the literature reports user difficulty because of poor image quality and there are concerns that the ultrasound probe itself may displace the prostate (10, 11). Acquiring CT images using the treatment beam, or megavoltage CT (MVCT), has been offered as another solution to the online imaging problem (12, 13). This permits soft-tissue visualization but at the cost of high imaging doses (5–15 cGy in MV CBCT (14) and 1.5–12 cGy in the case of helical MVCT (15)) and reduced image quality compared with conventional CT.

A common method is to implant fiducial markers, which can be visualized on megavoltage (MV) electronic portal images (EPIs), as a surrogate for prostate position (16–18). This technique has been used in an online fashion at our institution for more than 7 years and a reduction of post-treatment error to ≤3 mm in 99% of treatment setups has been demonstrated (5, 19). Disadvantages of marker implantation include; an invasive procedure with a potential for discomfort that requires an additional appointment, possible bleeding and infection, and the services of an interventional radiologist. Furthermore, markers provide little information on deformation of the target, localization of the seminal vesicles, or changes in the surrounding normal anatomy. There are data to suggest that the prostate may deform by up to 10 mm irrespective of seed location (20).

![Fig. 1. (a) Photograph of the medical linear accelerator imaging platform with portal imaging system marked in dotted line and volumetric imaging system in dashed line. Currently, implanted gold fiducial markers (b) are used to guide daily setup correction. The same markers appear distinctly using the kilovolt volumetric imaging system (c) as well as bone and soft-tissue structures.](image)
Cone beam computed tomography (CBCT) is a new technology that permits the acquisition of 3-dimensional (3D) volumetric images while the patient is in treatment position (21). These images are acquired using a flat panel detector by rotation of a kilovoltage (kV) X-ray source mounted on the accelerator gantry orthogonal to the primary treatment axis (Fig. 1a). Unlike conventional CT scanners, CBCT reconstructs an entire image volume from a single gantry rotation. The resulting image is of high spatial resolution (~0.6 mm (22)) and has a field of view (FOV) in excess of 40 cm in diameter and 26 cm in the SI extent. Daily visualization and localization of soft-tissue immediately before treatment delivery is now feasible and initial studies have highlighted the potential for this technology to improve the accuracy of treatment delivery (23).

The aim of this study was to compare CBCT guidance using soft-tissue (Fig. 1b) and MV EPI guidance using fiducial markers (Fig. 1c) and assess if they are equivalent methods of determining isocenter corrections. This was achieved by acquiring CBCT and MV EPI datasets within the same fraction, before isocenter correction. MV imaging was used to correct patient position, as per institutional protocol, and the CBCT data were stored for retrospective analysis. The design of this study provided the unique opportunity of acquiring information of daily prostate position over an entire treatment course using three different measurement tools: (1) MV EPIs localizing fiducial markers (MV-FM); (2) CBCT localizing fiducial markers (CBCT-FM); and (3) CBCT localizing soft-tissue (CBCT-ST). A

<table>
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<th>x (L/R) (mm)</th>
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<tbody>
<tr>
<td>MV(FM)</td>
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<td>M</td>
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<td>Σ</td>
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<td>σ</td>
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<td>CBCT(ST)</td>
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<td>M</td>
<td>−1.37</td>
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<td>Σ</td>
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<td>2.86</td>
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Reference value ("the truth") is chosen to be the 60% concordance between observers.

Cone beam computed tomography (CBCT) is a new technology that permits the acquisition of 3-dimensional (3D) volumetric images while the patient is in treatment position (21). These images are acquired using a flat panel detector by rotation of a kilovoltage (kV) X-ray source mounted on the accelerator gantry orthogonal to the primary...
summary of each imaging modality is detailed in Table 1. The required couch shift to correct the isocenter position was compared among these three methods and the level of correlation reported. Ambiguity in interpretation of the images generated by both MV EPIs and kV CBCT was quantified through interobserver variability studies.

**METHODS AND MATERIALS**

A total of 16 patients with low-risk to intermediate-risk prostate cancer provided their informed consent under an ethics approved protocol. This investigation was considered to be a descriptive feasibility study. A sample size of 16 was therefore deemed adequate to evaluate the study objectives and a statistical evaluation was not required. The treatment prescription was 79.8 Gy in 250 fractions using 3DCRT (5). Patients were treated on an Elekta Precise® linear accelerator equipped with cone-beam CT imaging. To target the prostate, three gold fiducial markers (24k, 0.8 mm) were implanted in the prostate under transrectal ultrasound (TRUS) guidance before radiation therapy planning (2).

**Positioning and EPI**

Patients were immobilized in a VacLoc™ bag (MedTec, Orange City, IA) and aligned to the treatment room isocenter using skin marks and a couch height specification. Before treatment delivery, orthogonal EPIs (10 cm × 10 cm field @ 6 MV, 3MUs per beam) were acquired and referenced to DRRs generated from the planning CT (voxels: 1 × 1 × 2 mm slice thickness). Template matching tools available in commercial electronic portal imaging software (iViewGT™, Elekta Ltd, Crawley, UK) were used to manually calculate the mismatch. Manual adjustments to the couch were performed if the recommended correction was >3 mm in any of the cardinal directions. If a shift was executed, a second set of images was acquired for verification. Changes to the initial setup isocenter position were made if a systematic trend was observed as described in Alasti et al. (2). The EPIs were analyzed offline for a second time by a single observer and all mismatches were recorded in a database for the purposes of this study.

**Cone-beam CT imaging process**

**Data acquisition.** One CBCT dataset was acquired at every fraction for each patient, immediately after setup to skin marks and immediately before localization of the markers with MV EPIs. The kV source and detector rotate in a circular trajectory capturing approximately 320 2-D radiographs through 360°. This is achieved by slowing the gantry to 2 min to complete a full rotation. Each 2-D projection was captured on an amorphous silicon flat-panel detector (RID1640, Perkin-Elmer, Wiesbaden, Germany) with a 133 mg/cm²Gd₂O₂S:Tb scintillator. The detector has an active area of approximately 41 × 41 cm with a 1024 × 1024 image matrix and a pixel pitch of 0.4 mm. The X-ray generated image is digitized to a 16-bit depth. To generate a field of view (FOV) of sufficient size to image the entire pelvis, the detector is offset 10 cm laterally and a complete 360° of projection data need to be acquired. The FOV in the z-direction was symmetrically collimated to 10 cm, which reduces scatter and the dose applied to the patient. The imaging geometry consists of a 100 cm source-to-axis distance (SAD), and a 153-cm source-to-detector distance (SDD), which yields a magnification factor of 1.53. A technique of 120 kVp, 100 mA, 20 ms per exposure for a charge of 2 mAs per projection, was used. The imaging dose delivered was estimated to be 2.1 cGy to the center of the patient and 3.3 cGy at the periphery (depth, 2 cm) per scan (24). The reliability and geometric accuracy of the CBCT system has been reported previously (25). The geometric calibration of the kV cone-beam CT system was performed intermittently based on service to the kV imaging panel and X-ray tube changes. This totaled 12 calibrations over the course of this study.

The projection images are corrected for variations in pixel dark signal and gain. A filtered back-projection technique is used in the reconstruction (26). Flex in the mechanical structure of the gantry system is also corrected for. The reconstruction resolution was set at 1 mm³ for these investigations over a 40 × 40 × 25.6 cm FOV. All data were processed using a PowerEDGE 4 CPU server (Dell, Austin, TX) with 4 GB memory and 3 TB of RAID5 storage.

**MV-FM vs. CBCT-FM.** The targeting and geometric accuracy were evaluated offline by comparing the MV marker locations with the marker locations imaged via kV cone-beam CT (Fig. 2a). The kV markers were auto-segmented (Fig. 2b) and a center-of-mass (CoM) method was used to determine the translational shift. A high-resolution reconstruction on a small FOV centered about the isocenter was performed. The 250-μm voxel grid allowed for detailed positioning of the kV markers. A histogram-based threshold was applied to recover the marker voxels. These voxels were further segmented into the individual markers based on their slice.
The couch shift is computed as the displacement of the CoM of all three markers.

**MV-FM vs. CBCT-ST.** The markers in the prostate produce artifacts in the reconstructed CBCT image sets and can confound the localization of the prostate boundary. For this reason, the seeds were digitally removed from the images post acquisition using a novel approach (27). A 5 x 5 x 5 cm cube that encompasses all three of the gold markers was identified, and each seed was located in the reconstruction space. These locations were then projected on to each of the 320 projections and were digitally masked from the projection by replacing it with a regional average pixel value and noise. The corrected projections were then reconstructed again to provide the same CBCT dataset with theseeds suppressed (Fig. 2c).

The resulting “marker-less” cone-beam CT datasets were imported into a commercial treatment planning system (Pinnacle®3, Philips, Madison, WI) to perform a fusion using soft-tissue anatomy. The central voxel of the cone-beam CT datasets were loaded and placed onto the isocenter of the treatment plan according to the geometric calibration process (25). The CTV contour from the plan was overlaid upon the cone-beam CT data set. Observers (1 radiation therapist + 1 radiation oncologist) then performed a manual 3D registration, using translational shifts only, to align the prostate gland (as visualized on the cone-beam CT dataset) with the CTV contour. These shifts were recorded in a database for comparison to the results of the MV and kV marker approaches described in the previous sections.

**Interobserver study.** An observer study was performed to evaluate the influence of interobserver variation for CTV matching on the CBCT image sets. An image set was randomly chosen from 5 patients. These patients were selected from the 16 study patients and represented a cross-section of patient size. In the intended image-guidance model for cone-beam CT, fraction-by-fraction repositioning will be achieved by therapist-driven registration of the CBCT image to the CT-defined CTV (prostate volume). Five radiation therapists with experience using the planning system alignment tools and who are involved in the image-guidance program participated. The observers were given technical instructions with regard to the process but were free to window and level and manipulate the display of the cone-beam CT images as desired. Access to the planning CT images was not permitted in the alignment process. Observers performed a 3D registration, using translational shifts only, to align the prostate gland as visualized on the CBCT dataset with the CTV contour. The resulting isocenter

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**Fig. 4.** Two-dimensional correlations of the applied megavoltage (MV) shifts vs. the predicted kilovoltage cone-beam computed tomography (CBCT) shifts (a–c), the soft-tissue (ST)–based shifts (d, e) for all 15 patients. The cone-beam–only shifts (fiducial markers vs. soft-tissue) are shown in (g–i). The shift directions were in the (a, d, g) left–right (L/R), (b, e, h) anterior–posterior (A/P), and (c, f, i) superior–inferior (S/I) directions.
shift was computed and recorded for each observer and for each dataset.

**Statistical analysis**

The Pearson product–moment correlation coefficient was used to measure the correlation in couch shifts between CBCT (FM or ST) and MV EPI results. The difference between the measured couch shifts was then plotted against the average couch shift as recommended by Bland and Altman (28) when a new method of measurement is to be compared against a gold standard. If the two measures are equivalent, the difference should show a zero mean and no significant trends. The 95% confidence interval of the error distribution is also reported.

The random ($\sigma$), systematic ($\Sigma$), and group systematic (M) errors for each guidance method were also calculated (29). The distribution of the systematic error was estimated by taking the standard deviation of the mean values for each patient. Interobserver variation was measured using the same technique for 5 observers over 5 different CBCT images. The difficulty with interobserver studies using patient data are that there is no ground truth. To overcome this pitfall, the 60% concordance of the shift value for MV marker observations was defined as the truth.

**RESULTS**

The study was well tolerated by all participants with no adverse events. The total elapsed time for participant accrual was 6 months. Treatment appointment times were extended from the normal 15 min to 30 min to allow for the additional imaging. The clinical workflow was evaluated to measure efficiency and the total time necessary for each...
fraction was approximately 25 min. When compared with the current clinical workflow using EPI, the time for image acquisition was 1.5 min longer for CBCT and for reconstruction of the CBCT images an additional 1 min. The matching of the images, however, took on average the same amount of time for both the MV-FM and CBCT-ST methods (2 min).

One patient was excluded from the analysis because of migration of the posterior gold marker during the treatment course. The data from 15 patients were therefore analyzed, rendering a possible 630 image datasets (15 patients × 42 fractions). Of these, 83 datasets (~13%) were lost because of either down time of the linear accelerator or the kV imaging system, or rendered unusable because of poor image quality caused by incorrect imaging technique or patient movement during acquisition. The remaining 547 CBCT datasets were deemed useful for the purposes of this study. Overall, a total of 1,098 GB of data were collected and stored online.

The elapsed time for data analysis was approximately 9 months. Because of the prohibitive number of man-hours involved in the digital removal of the markers from each dataset, only one was analyzed every 1 s, resulting in a total of 256 datasets being used in the analysis reported here. Figure 3 contains a trace of the couch shifts for all fractions for 1 patient as measured by MV-FM, CBCT-FM, and CBCT-ST in each of the cardinal directions. This patient was selected for being typical of those seen in the study.

**MV-FM vs. CBCT-FM**

The two-dimensional correlation plots are shown in Fig. 4. Here, the couch shifts measured by the markers from the MV EPIs and by the markers from the volumetric cone-beam CT images for all 15 patients (256 data points) are plotted (x’s). A linear regression analysis finds a Pearson’s correlation coefficient (R²) of 0.95, 0.84, and 0.81 in the left–right (LR) (Fig. 4a), anterior–posterior (AP) (Fig. 4b), and superior–inferior (SI) (Fig. 4c) directions, respectively. To discern trends, a Bland-Altman analysis is shown in Figure 5. The 95% CI is (−0.22, +2.5) LR, (−3.57, +2.43) AP, and (−3.85, +1.86) SI. In our current clinical practice, shifts of ≥3 mm are considered to be significant and the computed shift is implemented. The percentage of couch shift agreements within ±3 mm was 99.7, 95.5, and 91.3 in the LR, AP, and SI directions respectively.

Figure 6a plots the computed shift differences between these two modalities in 3D. The ellipsoid represents the 95% CI. Ideally, this ellipsoid should be small (random error), centered on the origin (group systematic error), and...
its principal components should be aligned with the coordinate axis (data independence). The frequency histograms, Figures 6b, 6c, and 6d indicate the ensemble mean and SD for the distribution of couch shift differences between MV-FM and CBCT-FM. These are $-1.1$ mm (SD 0.7), 0.6 mm (SD 1.5), and 1.0 mm (SD 1.5) in the LR, AP, and SI directions respectively.

**MV-FM vs. CBCT-ST**

The methods are repeated for comparison of the MV fiducial markers to the CBCT soft-tissue. Here the Pearson correlations are as follows: $R^2 = 0.90, 0.49, 0.51$ (Fig. 4d to 4f). The Bland-Altman analysis reveals that the 95% CI of shift-differences is ($-1.14$, $+2.79$), ($-5.57$, $+6.07$), ($-3.95$, $+5.57$) in LR, AP, and SI respectively (Fig. 5d–f). The percentage of agreement within ±3 mm was 99.6, 70.3, and 78.4% for LR, AP, and SI. The mean shift differences between MV markers and soft-tissue matching are $-0.8$ mm (SD 1.0), $-0.2$ mm (SD 3.0), and $-0.8$ mm (SD 2.5) in the LR, AP, and SI directions, respectively (Fig. 7b–d).

**CBCT-FM vs. CBCT-ST**

The same results are presented for CBCT fiducial markers vs. CBCT soft-tissue. Here, the shift proposed by the kV fiducial marker is considered to be ground truth. This comparison removes possible uncertainties between the two imaging modalities and the temporal uncertainties since the CBCT and EPIs were taken approximately 2 min apart. The Pearson’s correlations are: $R^2 = 0.90, 0.55, 0.41$ (Fig. 4g–i), whereas the Bland-Altman analysis shows the 95% CI of shift differences as the following: ($-2.15$, $+1.63$), ($-4.56$, $+6.31$), and ($-3.74$, $+7.30$) in LR, AP, and SI respectively (Fig. 5g–i). The percentage of agreement within ±3 mm was 90.8%, 63.7%, and 64.1% for LR, AP, and SI. Mean couch shift discrepancies of 0.3 mm (SD 1.0), $-0.9$ mm (SD 2.8), and $-1.8$ mm (SD 2.8) in the LR, AP, and SI directions (Fig. 7b–d).

**Interobserver results**

The group systematic error, systematic error, and random error for the 5 observers over five different datasets for MV marker and soft-tissue matching are reported in Table 2. The systematic error was higher for soft-tissue matching using the CTV $(0.61, 1.61, 2.21)$ [mm] than for MV marker matching, which was $(0.09, 0.36, 0.28)$ [mm] in the LR, AP, and SI directions, respectively. The random error
was also higher for the kV soft-tissue matching \( \sigma = (1.50, 2.86, 2.85) \) [mm] as compared with the random error in the MV matching \( \sigma = (0.26, 0.95, 0.47) \) [mm] in the LR, AP, and SI directions, respectively.

Table 3 presents a summary of the mean (M), random (\( \sigma \)), and systematic errors (\( \bar{\sigma} \)) based on the residual differences for MV-FM:CBCT-FM, MV-FM:CBCT(ST), and CBCT-FM:CBCT-ST. The largest value in systematic error is seen in the A/P direction for fiducial markers vs. soft-tissue. Overall, the systematic error for fiducial markers is less than that for soft-tissue. Also, the random errors for soft-tissue matching are greater than corresponding systematic errors.

### DISCUSSION

This study has shown that CBCT can successfully acquire daily volumetric images for the purposes of online assessment for image-guidance. The high correlation for the measured isocenter shifts between MV markers and kV markers demonstrates that the CBCT system is capable of submillimeter precision and accuracy when localizing unambiguous objects such as fiducial markers. It is also indicative of the geometric accuracy and robustness of the complete guidance system. The rotated ellipsoidal shape of the 95% CI cloud indicates that the shift differences in AP and SI directions are not independent and this could be attributed to the known rotational motion of the gland about the LR axis.

There is also a correlation between MV markers and kV soft-tissue although it is less strong. One possible explanation for this is the fact that 2D projection data are being compared with 3D volumetric data, which could render differing results. Another is that although both the MV and kV data were acquired within the same treatment fraction, there was a time lapse of approximately 2 min between the two acquisitions. During this time period it is possible that the prostate could have undergone a displacement, rotation, or deformation resulting in a difference in position or shape.

Both of these arguments can be dismissed when examining the correlations between kV markers and kV soft-tissue. These results are derived from exactly the same dataset; therefore both are volumetric and acquired at precisely the same time. Yet, the correlations are similar to those for MV markers to kV soft-tissue and certainly not as strong as those for MV markers to kV markers. It was therefore concluded that the predominant reason for weaker...
correlations for soft-tissue registration is because of the uncertainty in locating soft-tissue organs from CT data, which is well documented in the literature for conventional CT (30). The interobserver results from this study show that there is more uncertainty when locating the prostate on CBCT images than when manually registering the markers on the MV EPIs. Contouring of the prostate from the CBCT images was not a component of this study, and therefore the interobserver variability was not fully evaluated. It can be assumed, however, that it would be at the very best comparable to results reported for conventional CT images of the prostate. It may be possible to reduce this uncertainty by using automatic gray-value registration for the prostate, which is currently being investigated (31, 32).

It was also observed that the correlation data for all modalities were best in the LR direction compared with the AP and SI directions. This is in concordance with the literature with regard to observers having difficulty in locating the prostate–bladder interface and the prostate apex on conventional CT. The LR positioning is also supported by the clear symmetry in the pelvic anatomy in this region.

The small population-wide systematic errors within the data could be explained by errors in the geometric coordination of the various software tools and calibrations that are embedded within the system. At the level of precision achieved in this investigation (submm) it is possible to detect systematic errors on the order of 1 mm (as demonstrated in the comparison of MV and kV markers). For example, a 1-mm discrepancy could be because of deviations in the interpretation of a coordinate to be the edge or center of a voxel, errors in the location of line drawing in graphic overlay, or mechanical calibrations at the edge of acceptability. Patient-specific systematic errors can be attributed to the comparisons involving CTV contours and markers, which are also subject to interobserver uncertainties. An error occurring at this stage would therefore influence all subsequent treatment fractions if a contour-based alignment were to be implemented (33). Court et al. (34) conclude that the interobserver uncertainties for a contour-based method of alignment are sufficiently small to permit its use. However, Langen et al. (35) suggest that this may not be the best method of registration for volumetric data and that anatomy-based registrations are more accurate. Their study, however, also assumes that the CoM for the fiducial markers represents the true prostate position. Recent investigations in our facility have highlighted the imperfect correlation between implanted marker and MR-defined gland position (36).

The use of online image-guidance is intended to reduce random and systematic errors. According to certain margin “recipes,” systematic errors have the largest impact on the size of PTV margins (29). Craig et al. (37) relate the effects of errors to tumor control probability (TCP) and state that systematic errors can strongly influence TCP. Our results have shown that systematic errors are very small for the CBCT online localization of the prostate without markers 0.35, 0.99, and 0.98 [mm] and LR, AP, SI, assuming that MV markers can be taken as the ground truth. Currently, the PTV margins used for patients on this protocol are 10 mm from the CTV isotropically, with the exception of 7 mm on the posterior border. These are considered to be generous for the daily online guidance model in operation here. It is therefore feasible to move to online cone-beam CT guidance for soft-tissue localization without the use of fidu-
cial markers, provided that current PTV margins are maintained.

CONCLUSION

This investigation has shown that cone-beam CT is feasible for daily online image guidance of the prostate. The methodology of this study was designed to compare a new technology (cone-beam CT) to an existing standard of care (EP1 localization of markers). However, markers may not be the best method to test cone-beam CT against, as they are a surrogate for daily prostate position. The wealth of additional information provided by cone-beam CT images such as target visualization, critical organ avoidance, and assessment of treatment response, offers many potential benefits to radiation therapy delivery that require investigation.

The hardware and software components of cone-beam CT technology are constantly evolving to improve image quality, efficiency, and data analysis tools. Further studies have been initiated at our institution to investigate the interobserver error for prostate delineation on cone-beam CT images and to evaluate the workflow in terms of efficiency to explore further the merits of this online guidance system.

REFERENCES


