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# Table of Contents

## Original Articles

**Weekly versus Three–Weekly Cisplatin–based Concurrent Chemoradiotherapy as definitive treatment in Head and Neck Cancer– Where do we stand?**

6

**Stereotactic Hypofractionated Accurate Radiotherapy of the Prostate (SHARP), 36.25 Gy in Five Fractions for Localized Disease: A Case Series Results from King Faisal Specialist Hospital, Saudi Arabia**
M.W. Hegazy, R. Mahmood

12

**FOLFOX as Perioperative Chemotherapy of localized Gastric Cancer: Efficacy and Tolerance**

17

**Evaluation of localization uncertainty of fiducial markers due to length and position variations induced by motion in CT imaging by measurement and modeling**

21

**Effect of Fractionated Dose of Radiotherapy on Oral Mucosa in Head and Neck Cancer Patients: A Cytological Assessment**
S. Khan, M. Jain, V. Mathur, SMA Feroz

30

**Change in the Quality of Life in Oropharyngeal, Laryngeal and Hypopharyngeal Cancer Patients treated with Volumetric Modulated Arc-Based Concomitant Boost Radiotherapy**
P. Kannan, A. Mukherji, K. Reddy, S. Vivekarandam, C. Shamsudheen, V. Santhosh

36

**Prostate biopsy handling: special tissue embedding technique with sponges affects the yield of prostatic tissue available for microscopic examination**
E. Salmo, K. Sitpura

46

**Expression of VEGF–A in Epithelial Ovarian Cancer: Correlation with Morphologic Types, Grade and Clinical Stage**
C.S. Premalata, K. Umadevi, K. Shobha, M. Anurekha, L. Krishnamoorthy

49

**Efficacy of Different Protocols in treatment of nephroblastoma: a revisit**
O.M. Zakaria, M.Y.I. Daoud, S.H. Farrag, MS Al Mulhim

55

## Case Reports

**Ectopic Intrathymic Parathyroid adenoma demonstrated on Tc–99m Sestamibi SPECT–CT**
S. Usmani, A. Javaid, F. Abu Huda, H.G. Amanguno

61

**Is cutaneous leishmaniasis a risk factor for basal cell carcinoma?**
M. Chiisti, R. Almasri, I. Hamadah

64

**Bilateral Choroidal Metastases from Prostate Cancer revealed in a patient under abiraterone – Fourteen years after diagnosis**
H.R. Kourie, J. Antoun, F. Bteich, A. Jalkh, M. Ghosn

67

**Spectrum of Presentation of anorectal Malignant Melanoma: experience of a tertiary Care Centre of north India**
A. Gupta, P. Prakash, A. Rattan, N. Wadhwa, S. Kumar, V. Rathi

70

## Review Articles

**Metaplastic carcinoma of breast: a case series of seven patients from a tertiary care center and review of literature**
R. Benson, R. Madan, P.K. Julka, G.K. Rath

74

**DNA methylation and Cancer: Identifying and targeting epigenetic modifications may be the future of cancer therapy?**
G. Maresca, P.S. Wismayer

77

**Novel agents in second–line therapy for EGFR wild–type Advanced Non–Small–Cell Lung Cancer**

84

## Conference Highlights/Scientific Contributions

- **News Notes**

89

- **Advertisements**

93

- **Scientific events in the GCC and the Arab World for 2016**

94
Original Article

Evaluation of localization uncertainty of fiducial markers due to length and position variations induced by motion in CT imaging by measurement and modeling

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Abstract

Purpose

To quantify the variations in the length and position of fiducial markers induced by motion in axial (ACT), helical (HCT) and cone-beam CT (CBCT) imaging and associated uncertainty in image-guided radiotherapy (IGRT) by measurement and modeling.

Methods

A mobile thorax phantom containing markers of various lengths was imaged using ACT, HCT and CBCT imaging. The phantom was imaged while stationary and moving where it was moved sinusoidally with different motion amplitudes and frequency. An analytical motion model was developed that predicts the localization accuracy of IGRT based on fiducial markers in mobile phantom with ACT, HCT and CBCT.

Results

The apparent lengths of the markers varied with the different motion patterns and CT imaging modalities. In CBCT, the apparent length of the markers increased linearly with the motion amplitude for both half-fan and full-fan modes. In HCT and ACT, the apparent length of the markers increased or decreased non-linearly with motion parameters and speed of the imaging couch. When the marker moved opposed to couch motion the apparent lengths decreased, while they increased when the phantom moved along the direction of the imaging couch as predicted by the motion model. The position of marker centers did not shift and distance between makers did not change in CBCT images. However, in HCT and ACT, the position of marker center and distance between markers varied depending on motion parameters during imaging. The marker center could move superiorly or inferiorly and the distance between markers could increase or decrease depending on the phase of motion as predicted by the motion model.

Conclusions

The variations of marker length and position due to phantom motion were quantified by measurement and modeling. These variations may lead to large positioning uncertainties in patient setup and tumor localization based on IGRT with fiducial marker registration.

Key Words

fiducial marker, image-guided radiation therapy, motion artifacts, uncertainty, localization, CT imaging.

Introduction

In recent years, technological advancements in radiation therapy have led to more complex treatment planning and dose delivery techniques. These techniques allow the delivery of intensity-modulated radiation therapy (IMRT)¹ or volumetric-modulated arc therapy (VMAT)²,³ which conform doses more tightly to the planning target volumes. This has resulted in stringent requirement for more accurate target localization and patient setup techniques. The use of image guided radiation therapy (IGRT) has also become more popular in recent years⁴,⁵. Utilizing fiducial marker is a common clinical practice in IGRT where markers are implanted
Localization uncertainty of fiducial markers in CT imaging, I. Ali, et al.

within or in the vicinity of tumors in prostate (6–8), liver (8) and lung (10). A typical IGRT procedure includes acquisition of orthogonal radiographic pair or CT images of the patient prior to dose delivery that are compared with two-dimensional (2D) reference digitally-reconstructed radiographs (DRR) or three-dimensional (3D) simulation CT images, respectively. In IGRT with fiducial markers, the markers between the two sets of images are aligned, and the shifts of the treatment couch are determined and carried out prior to dose delivery. (11)

In IGRT, it is important that the fiducial markers do not shift or migrate after the treatment planning CT scan. This allows accurate patient setup using localization with the markers at each treatment prior to dose delivery. Marker migration has been evaluated by various works (10, 12, 13), and it is generally accepted that the likelihood of individual seed migration is low, especially if the treatment planning CT scan is not performed on the same day as the marker placement (14–16). Several works have demonstrated that image artifacts related to CT slice thickness (17), volume averaging (18), missing tissue effects (19) and patient motion (20, 21) may lead to uncertainties in tumor localization and patient setup for treatment. Patient motion induces image artifacts in CT imaging (21–23) which may affect specifically the accuracy of IGRT with fiducial markers. These artifacts involve variations in the apparent lengths of the markers and displacements of the markers in CT imaging. However, the uncertainties associated with the variations in marker length and position induced by patient motion on the localization accuracy of fiducial marker and variability between different CT imaging techniques that are used in IGRT have not been studied extensively.

In this work, the variations in the length of the markers, position of the marker center and distance between the markers were investigated quantitatively using three imaging modes ACT, HCT and CBCT. The variations in length and position of different markers that were inserted in a mobile thorax phantom were measured quantitatively. A motion model was developed that predicts the variations in marker position, distance between markers and apparent lengths and its dependence on motion parameters in the different CT imaging techniques.

Materials and Methods

A. Phantom Setup and Imaging

The localization of fiducial markers was studied using both stationary and mobile thorax phantom (Standard Imaging, Inc., Middleton, WI) shown in Fig. 1a. The phantom consists of solid water phantom slabs in the shape of a thorax. Styrofoam is used to emulate low-density tissue such as the lungs. Several fiducial markers with different lengths were embedded in the phantom along the Y-axis and scanned with different CT imaging techniques as shown in Fig. 1b. The fiducial markers were made from a Teflon wire with 2 mm diameter that provides high contrast without introducing large image artifacts in CT images. The markers #1 (42 mm), #2 (22 mm), #3 (12 mm), #4 (8 mm) and #5 (45 mm) as indicated in Fig. 1b were selected for data analysis because their lengths represent a wide range of clinical markers implanted in patients and used for setup with IGRT (6).

Figure 1: (a) Thorax phantom with fiducial markers and mobile platform, (b) Markers (1–5) with different lengths and the imaging reference frame with motion along Y–axis.
B. Marker Length and Position Measurements

All imaging studies were imported into the Eclipse (Varian Medical Systems, Inc., Palo Alto, CA) treatment planning software. Three marker parameters were measured that include: (a) apparent length of the markers, (b) position of the center of each marker and (c) the distance between markers. The apparent length of each fiducial marker (#1, #2, #3, and #4) was measured in the CT images by considering the distance between the visible edges of each marker. Similarly, the position of the center of each marker was calculated by locating the ends of each marker using coronal and axial image views using the distance and position measurement tools in the Eclipse treatment planning system. The window and level of CT values of the markers was set appropriately to consider blurring and spread out of CT values induced by motion artifacts. The distance between markers was measured by considering the distance between the centers of two markers.

C. Motion Model

The localization accuracy of IGRT with fiducial markers is affected by several factors that include: (a) displacement of the center of a maker, (b) variations in the distance between markers and (c) variations in the length of a marker induced by motion in CBCT, ACT and HCT imaging. The following represents a mathematical formulation of these factors.

C.1 CBCT Marker Localization Model

Considering a phantom that includes several markers and moves sinusoidally with an amplitude, $A$, and a frequency, $f$, in the superior-inferior direction ($Y$-axis) during imaging, the position of the center of marker varies with time, $t$, as given by the following equation:

$$ Y_i(t) = Y_i^0 + A \sin(\omega t + \phi) $$

where $Y_i^0$ is position of the center of marker $i$ in the stationary phantom, $\omega = 2\pi f$ is angular frequency and $\phi$ represents the phase angle. The second term in equation (1) represents the displacement of the center of marker due to phantom motion. The difference in the distance between the second and first marker centers in the stationary phantom is given by the following:

$$ \Delta Y_{21} = Y_2^0 - Y_1^0 $$

The difference in the distance between the centers of the first and second markers in the mobile phantom is given by the following:

$$ \Delta Y_{21}(t) = \Delta Y_{21}^0 + A[\sin(\omega t + \phi_2) - \sin(\omega t + \phi_1)] $$

The second term in equation (3) represents the difference of the distance between the centers of the two markers due to phantom motion which could lead to uncertainty in the localization of the markers relative to each other.

Assuming the points at the superior and inferior ends of a marker move with the same speed and phase and using equation (1), the maximal length of marker in CBCT is obtained by the following equation:

$$ L_i = L_i^0 + 2A $$

where $L_i^0$ is the actual length of the marker in stationary phantom. The second term represents marker elongation in CBCT images which could lead to positioning uncertainty of the marker using image registration with the reference image.

C.2 HCT and ACT Marker Localization Model

In ACT and HCT, the imaging couch move in steps or continuously in contrast with the couch in CBCT from on-board imager which remains stationary during scanning. The imaging couch moves with a constant speed, $V_c$, during scanning and the phantom moves with $V_p$ along the $Y$-axis. Although the couch motion in ACT is indexed, it is considered here continuous to simplify the mathematical modeling. If marker $i$ is stationary then the length of the marker is given by:

$$ L_i^0 = V_c \Delta t_i $$

Where $\Delta t_i$ is the time that the marker stays in the imaging view. If the marker is moving with a long $Y$-axis, then the speed of the mobile marker in the imaging frame is given by the following:

$$ V = V_c + V_p $$

Thus the net speed of the marker increases in the imaging frame, if the marker moves along the direction of motion of the imaging couch. While the net speed of the marker moving opposite to the couch motion decreases. Considering sinusoidal marker motion, $V_p$ can be obtained by taking the first derivative of equation (1) that gives the position of the first marker as follows:

$$ V_p = \frac{dY_p}{dt} = \omega A \cos(\omega t + \phi) $$

The apparent marker length in the imaging frame, $L_i'$, is obtained by integrating equation (6) and using variated speed of the marker as given in equation (7). $L_i'$ is given by the following:

$$ L_i' = V_p (t_2 - t_1) + \int_{t_1}^{t_2} A \omega \cos(\omega t + \phi) \, dt $$

$$ L_i' = V_p \Delta t_i' + A\{\sin(\omega t_2 + \phi_2) - \sin(\omega t_1 + \phi_1)\} $$

where $\Delta t_i'$ is the time that the marker stays in the imaging view starting from $t_1$ and exiting at $t_2$. This time depends on the relative speed between the couch and
 Localization uncertainty of fiducial markers in CT imaging, I. Ali, et. al.

Mobile marker. If the marker is moving opposite to the couch then it stays long time in the imaging view. The marker can stay forever hypothetically if it has equal and opposite speed to the couch speed. If the marker is moving in the same direction where the couch is moving, then the marker remains shorter time in the imaging view.

In order to simplify the above formulation, assume that the marker is moving with a constant or an average speed which can be used to simplify equation (8). The use of constant or average speed is valid considering that the mobile phantom or patient speed is nearly constant within certain respiratory phase. For example, the speed of the mobile phantom does not vary much and can be approximated to be constant taking narrow respiratory phases such as start, middle and end of inhale or exhale.

Considering a marker \( i \) with a length of \( L_i \) along the \( Y \)-direction moving with a constant speed, \( V_p \), then the time, \( \Delta t_i ' \), that the marker remains in the imaging view, is obtained by the following:

\[
\Delta t_i ' = \frac{L_i}{V_c + V_p} \tag{9}
\]

Using equation (9) and assuming the points at the superior and inferior ends of a marker move with the same constant speed and phase, the apparent length of marker \( L_i ' \) during scanning with HCT and ACT can be obtained by the following equation:

\[
L_i ' = \frac{V_c}{(V_p + V_c)} L_i \tag{10}
\]

The apparent length of a mobile marker depends on motion parameters according to above equation which could increase or decrease depending on the phase.

Figure 2: The first row shows coronal views from HCT images with a motion period of 4 seconds and different motion amplitudes: (a) represents 0 mm, (b) represents 5 mm, (c) represents 10 mm, and (d) represents 20 mm. The second row shows coronal views from ACT images where (e) represents 2.5 mm amplitude and 6 sec period, (f) represents 10 mm amplitude and 6 sec period, (g) represents 20 mm amplitude and 6 sec period, and (h) represents 20 mm amplitude and 2 sec period. The third row shows coronal views from CBCT images where (i−l) represent 2.5 mm, 7.5 mm, 15 mm, and 20 mm amplitudes, respectively.
during ACT or HCT imaging. The term with dependence on the velocity of phantom and couch may cause uncertainty in marker localization due to motion.

The difference in the displacement of the centers of second and first markers is given by the following:

$$\Delta Y_{21} = \Delta Y'_{21} + \frac{E_{1}}{2} \left( \frac{L_{2} - L_{1}}{v_{p} + v_{C}} \right)$$  \hspace{1cm} (11)$$

where $L_{1}$ and $L_{2}$ are the actual lengths of first and second markers, respectively. The second term represents the difference in the displacement between centers of the second and first markers due to phantom motion which may lead to errors in positioning of the markers relative to each other.

**Results**

**A. Marker Displacement**

The marker centers did not shift from their initial position in CBCT (Figs. 3a–b). This can be explained by equation (1) for a phantom moving with cyclic motion, where it moves back and forth around the initial position for a long time that includes several motion cycles during CBCT imaging. While the marker elongates along the direction of motion, the average position of the marker center remains at the same place. However, in HCT and ACT images, the centers of some markers were displaced from initial position in the stationary images as shown in Fig.3 (c–f). The displacement of marker’s center exceeded sometimes the motion amplitude of the phantom. This is in agreement with the predictions of the motion model in equation (7), where the position of the marker center depends nonlinearly on the phantom speed. For a sinusoidal motion, the phantom speed in its turn depends on the motion amplitude, frequency and phase as shown in equation (8). Figure 3c–f show the variations of the position of the center of markers 1–4 with motion amplitude and frequency as indicated for helical and axial CT. The position of marker center varied with the imaging modality. The marker center can shift superiorly or inferiorly depending on the motion phase during imaging as predicted by equation (7).

For example, in Fig. 3c, the center of marker #1 shifted nearly 9 mm inferior to its initial position at 15 mm motion amplitude and by about 3 mm superior to its initial position at 5 mm motion amplitude using HCT. Figure 3f shows that the center of the same marker #1 shifted superiorly by 7.5 mm at $A = 20$ mm and inferiorly by 1.3 mm at $A = 5$ mm using ACT. The accuracy of distance or length measurements is determined by half a slice thickness (mm for HCT and ACT and mm for CBCT).

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Figure 3 (a–b) Variations in the position of the marker center with motion amplitude in CBCT for the different frequencies as indicated. Variations in the position of the center of marker #1–4 with actual lengths of 42, 22, 12 and 8 mm, respectively, inserted in the mobile phantom as a function of motion amplitude and periods in HCT in (c–e) and axial CT in (f) as indicated.
B. Distance between Markers

In the mobile phantom, the distance between the centers of the markers did not change in CBCT imaging (Figs. 4a–b). As predicted by the model according to equation (3), the position of the centers of markers have the same phase during imaging considering rigid motion of the phantom and thus the distance between the centers would not change in CBCT. However, in ACT and HCT, the distance between the centers of the markers decreased or increased where the second term in equation (9) accounts for the variations in the distance between two markers and its dependence on the phantom motion parameters (amplitude, frequency and phase). For example, the distance between markers #1 and #5 increased by nearly 24 mm at motion amplitude of 15 mm and period of 4 sec and decreased by 6.7 mm at motion amplitude of 20 mm and period of 4 sec as show in Fig. 4c for HCT. In ACT, the distance decreased by 9.3 mm and 14.1 mm at amplitudes of 10 and 20 mm, respectively, for a motion period of 2 sec. as shown in Fig. 4f.

C. Variations of Marker Length

Figure 5 shows the variations in the measured apparent length of markers 1–4 with motion amplitude and frequency for CBCT, HCT and ACT. In the case of CBCT, the measured apparent length of the markers increased linearly with motion amplitude as shown in Fig. 5a–b as predicted by equation (4). In HCT and ACT, the measured marker lengths varied non–linearly with motion parameters as predicted by equation (10). For example, the measured apparent length of marker #1 (initial length of 42 mm) decreased to nearly 25 mm at motion amplitude of 10 mm and period of 4 sec, while its length increased to 56.3 mm at motion amplitude of 20 mm using HCT as shown in Fig. 5c. The apparent length of the same marker increased to 65 mm and 72 mm at motion amplitudes of 10 mm and 20 mm, respectively, with a period of 6 sec for ACT as shown in Fig. 5f.

D. Simulation of Apparent Target Length

Figure 6a shows a simulation of the apparent length of markers 1–4 with lengths of 42, 22, 12 and 8 mm, respectively, along Y-axis which increases linearly with the motion amplitude of the phantom using CBCT imaging according to equation (4). Figure 6b shows the variations in the length of the different markers as a function of the phantom speed along and opposed to the imaging couch motion in HCT or ACT as predicted by equation (10). The imaging couch speed was considered to move with a constant speed of 10 mm/sec along the superior–inferior direction. When the phantom moves in the same direction as the couch, the lengths of the different markers shrink with increasing phantom speed as shown in Fig. 6b. While the markers elongated as the phantom speed increased in the opposite direction approaching the speed of the

Figure 4: Variation of the distance between the marker centers (1–4) relative to 5 for different motion amplitudes and periods in CBCT (a–b), HCT (c–e) and ACT (f).
The motion model predicted that as the phantom speed approaches a speed that is nearly equal and opposed to the imaging couch speed, then the marker length increases significantly because the marker stays for a long time in the imaging view. At $V_p = -V_c$, the apparent length of the marker will be infinite because the marker stays all the time in front of the imaging detectors. When the phantom is moving with a speed larger than the couch speed in the opposite direction, then the marker remains long times in the imaging view and thus the marker will be elongated. As the phantom speed increases in the opposite direction to couch motion ($< -2V_c$), the marker length decreases. At large phantom speeds opposed to couch motion, the marker length approaches zero where it moves quickly out of the HCT or ACT imaging view. Considering a constant or average speed for the mobile marker is valid in two situations. First, short mobile markers imaged with a fast scanner where the markers moving with a sinusoidal

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**Figure 5:** Apparent marker length variations with motion amplitude and periods for different markers (1,2,3,4) with actual lengths (42 mm, 22 mm, 12 mm, 8 mm), respectively, for CBCT (a–b), HCT (c–e) and ACT (f).

**Figure 6:** (a) Apparent marker length as a function of phantom motion amplitude using CBCT imaging. (b) Apparent marker length variations as a function of phantom speed considering along and opposed phantom motion relative to the imaging couch motion using HCT and ACT imaging for the indicated markers. Couch speed was considered to be equal to 10 mm/sec.
motion pattern have nearly constant speed for a short time in the imaging view. It is also valid considering imaging of the mobile marker within a certain respiratory phase for a short period of time. The speed of a mobile marker does not change much and can be approximated by a constant within the time window of narrow respiratory phases such as start, middle and end of inhale or exhale using four-dimensional CT (4D-CT) imaging.

Discussion

The marker length, shape, position and number are important parameters that determine the accuracy of patient setup and tumor localization using IGRT based on implanted fiducial marker image registration as reported in previous studies (6–11, 24). Both length and position of the markers have to be reproducible between reference CT images or DRR’s created in the treatment planning system and CBCT images or radiographic projections acquired from the kV on-board imager for patient setup. Motion affects the apparent length, position of the marker center, and distance between markers in different ways in CBCT, ACT and HCT. For example, the markers elongate in CBCT because of motion artifacts, while the marker center position and distance between the markers remain the same and they are not affected. Large errors can be introduced in patient setup that uses fiducial marker matching due to elongation of the markers which increased linearly with the phantom motion amplitude in CBCT as predicted by equation (4). In HCT and ACT, the apparent lengths varied non-linearly with time the mobile marker remains in the imaging view where they can increase or decrease depending on the motion parameters such as amplitude, frequency and phase as predicted by the motion model in equation (8). The position of the marker centers imaged in CBCT did not change despite of marker elongation along the motion direction and thus the distance between the markers did not change in contrast to HCT and ACT.

Instead of using CBCT images which are acquired over long time nearly one minute with significant motion artifacts, 2D–radiographic images that are matched with DRR’s can be used for IGRT with marker matching. The effects of marker elongation induced by motion can be eliminated because the radiographs from the kV on-board imager are acquired as snapshots in a very short time. However, the position of a marker will be displaced in the radiographs that are captured at a certain time during patient motion which will limit the accuracy of 2D image registration. Furthermore, both marker elongation and center displacement effects persist in DRR’s obtained from simulation ACT or HCT images in radiotherapy. When the markers are close to each other, then they are acquired nearly at one motion phase and thus the lengths and distances between the markers does not change significantly as shown by the model in equation (9) considering a sinusoidal motion. If the markers used in IGRT are far away from each other, then they will be acquired at different motion phases in the same CT imaging set and thus the distance between the markers will vary in the same imaging study as well as in the setup and reference images.

Conclusion

In this work, the localization uncertainty of fiducial markers in a mobile phantom have been evaluated quantitatively both by measurement and modeling. A motion model was developed in this work that predicts the displacement of the center of the markers, variation in the distance between markers and elongation of markers induced by motion in CBCT, ACT and HCT imaging techniques. The predictions of the model were tested by measurement of these three parameters for markers that were inserted in stationary and mobile phantoms and imaged with different CT techniques. In mobile phantoms, the position of the marker center and distance between markers did not change in CBCT, while larger and irregular displacements of the marker center were measured in ACT and HCT. The marker’s elongation was proportional to the motion amplitude in CBCT, while it varied non-linearly in ACT and HCT and depended on motion amplitude, frequency and phase. The variations in apparent lengths and position of the markers in CT images affect the accuracy of patient setup and tumor localization and have to be considered in IGRT based on fiducial makers.

References

4 S.P. Robertson, E. Weiss, G.D. Hugo, “Localization accuracy
from automatic and semi-automatic rigid registration of locally–advanced lung cancer targets during image–

5 AAPM TG–104, “The role of in–room kV x–ray imaging for
patient setup and target localization,” Report of AAPM Task
Group 104(2009).

6 J. de Boer, J. de Bois, M. van Herk, J.J. Sonke, “Influence
of the number of elongated fiducial markers on the
localization accuracy of the prostate,” Phys Med Biol. 57,
6211–6226 (2012).

7 T.F. Mutanga, H.C. de Boer, G.J. van der Wielen, D. Wentzlter,
J. Barnhoorn, L. Incroci, B.J. Heijmen, “Stereographic
targeting in prostate radiotherapy: speed and precision by
daily automatic positioning corrections using kilovoltage/

8 D. L’etourneau, A.A. Martinez, D. Lockman, D. Yan, C.
Vargas, G. Ivaldi, J. Wong, “Assessment of residual error
for online cone–beam CT–guided treatment of prostate
cancer patients,” Int J Radiat Oncol Biol Phys 62, 1239–
1246 (2005).

9 E. Berthelet, M. Liu, P. Truong, P. Czyzynski, N. Kalach,
C. Yu, K. Patterson, T. Currie, S. Kristensen, W. Dwan, V.
Moravan, “CT slice index and thickness: impact on organ
contouring in radiation treatment planning for prostate

10 J. Balter, R. Ten Haken, T. Lawrence, K. Lam, J. Robertson,
“Uncertainties in CT–based radiation therapy treatment
planning associated with patient breathing,” Int J Radiat

11 W. Watkins, R. Li, J. Lewis, J. Park, A. Sandhu, S. Jiang,
W. Song, “Patient–specific motion artifacts in 4DCT,” Med
Phys 37, 2855–2861 (2010).

12 E. Berthelet, M. Liu, P. Truong, P. Czyzynski, N. Kalach,
C. Yu, K. Patterson, T. Currie, S. Kristensen, W. Dwan, V.
Moravan, “CT slice index and thickness: impact on organ
contouring in radiation treatment planning for prostate

13 J. Balter, R. Ten Haken, T. Lawrence, K. Lam, J. Robertson,
“Uncertainties in CT–based radiation therapy treatment
planning associated with patient breathing,” Int J Radiat

tomography scanning of moving objects,” Semin Radiat

15 M. Nakamura, Y. Narita, A. Sawada, K. Matsumi, M. Nakata,
Y. Matsuo, T. Mizowaki, M. Hiraoka, “Impact of motion
velocity on four–dimensional target volumes: a phantom

16 R.J. Kudchadker, A.K. Lee, Yu, Z.H., J.L. Johnson, L. Zhang,
Y. Zhang, R.A. Amos, H. Nakanishi, A. Ochiai, L. Dong,
“Effectiveness of using fewer implanted fiducial markers
for prostate target alignment,” Int J Radiat Oncol Biol Phys
74, 1283–1289 (2009).

patient registration using volumetric true 3D ultrasound

18 D. Tiberi, J. Carrier, M. Beauchemin, T. Nguyen, D.
Beliveau–Nadeau, D. Taussky, “Impact of concurrent
androgen deprivation on fiducial marker migration in
external–beam radiation therapy for prostate cancer,” Int

19 S. Lalouell, S. Sohaib, I. Castellano, D. Mears, R.
Huddart, V. Khoo, “Investigating the relationship between
virtual cystoscopy image quality and CT slice thickness,”

20 J. Barrett, N. Keat, “Artifacts in CT: Recognition and

tomography scanning of moving objects,” Semin Radiat

22 M. Nakamura, Y. Narita, A. Sawada, K. Matsumi, M. Nakata,
Y. Matsuo, T. Mizowaki, M. Hiraoka, “Impact of motion
velocity on four–dimensional target volumes: a phantom

23 R.J. Kudchadker, A.K. Lee, Yu, Z.H., J.L. Johnson, L. Zhang,
Y. Zhang, R.A. Amos, H. Nakanishi, A. Ochiai, L. Dong,
“Effectiveness of using fewer implanted fiducial markers
for prostate target alignment,” Int J Radiat Oncol Biol Phys
74, 1283–1289 (2009).

patient registration using volumetric true 3D ultrasound

25 D.D. Sharma, P. Dongre, V. Mhatre, M. Heigrujam,
“Evaluation of automated image registration algorithm for
image–guided radiotherapy (IGRT),” Australas Phys Eng