OPTO-ELECTRONIC GUIDED PATIENT POSITIONING IN THE CONFORMAL RADIOTHERAPY OF PROSTATE CANCER

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Abstract: In the management of prostate cancer, external beam radiotherapy represents a valuable therapeutic approach. Nevertheless, treatment optimization entails the definition of reliable methodologies and technologies for the evaluation and compensation of patient set-up errors. Opto-electronic guidance was investigated as a way to detect patient misalignments and to suggest adequate strategies for increasing positioning accuracy. The daily treatment fractions of 10 patients undergoing conformal radiotherapy for prostate cancer were monitored through an opto-electronic localizer. External IR-reflective markers were placed on the abdomen for the frameless stereotactic reconstruction of prostate localization. The accuracy of manual laser alignment was compared to opto-electronic guided patient positioning. The results show that 6 degrees of freedom (6DOF) are needed for the effective reduction of systematic and random patient set-up errors, in order to adequately compensate translational and rotational misalignments. The implemented 6DOF correction ensured the reduction of the 3-D systematic error from 5.1 mm (laser alignment) to 1.2 mm. The corresponding 3-D random set-up error was decreased from 2.2 mm to 0.6 mm.

Introduction

The treatment of prostate cancer patients with external beam radiotherapy proved comparable results with respect to surgery, in terms of clinical and biochemical control probability [1]. The dose released to the target over the course of treatment is highly correlated to local control [2]. Nevertheless, the maximum dose is limited by the risks related to the over-exposure of the surrounding healthy structures.

Conformal irradiation techniques can be exploited for the release of high doses to the target, with the maximum sparing of organs at risk. The physiological variability in patient anatomy, and the geometrical uncertainties in patient set-up, hinder the actual conformation of dose distribution around the clinical target volume (CTV). Additional margins of healthy tissues are commonly used in clinical practice as a way to account for these uncertainties in the definition of the irradiation target [3,4].

In the field of external beam radiotherapy applied to prostate cancer, the reduction of set-up errors play a decisive role in the effective minimization of treatment margins [3,4] and rectal toxicity [5]. The performance of opto-electronic localization in the guidance of patient set-up was assessed, aiming at the definition of the optimal protocol for the correction of patient set-up.

Materials and Methods

Ten patients undergoing conformal radiotherapy for prostate cancer were enrolled in the study. The abdomen was fitted with *n*=5-7 IR-reflective radio-opaque fiducials placed on selected skin landmarks (Figure 1). Treatment planning was performed on 3 mm-thickness CT slices: 76 Gy were delivered in 38 daily fractions in a double dynamic arc, conformed to the target through a micro-multileaf collimator (m3, BrainLab AG, Heimstetten, Germany).

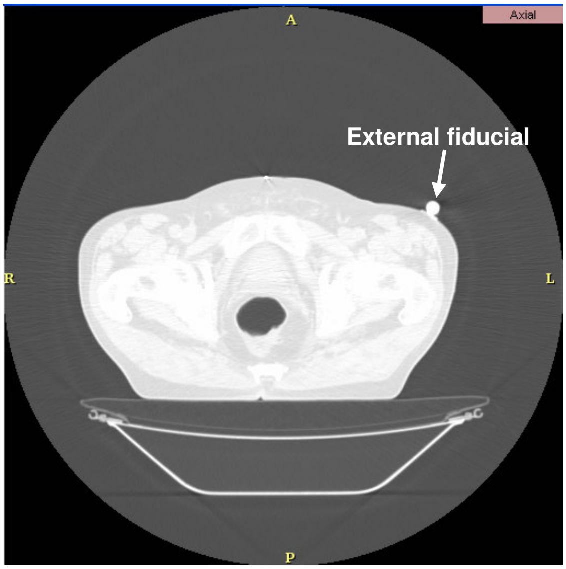

Figure 1: Axial CT slice for patient 1, showing one of the external fiducials used for set-up monitoring

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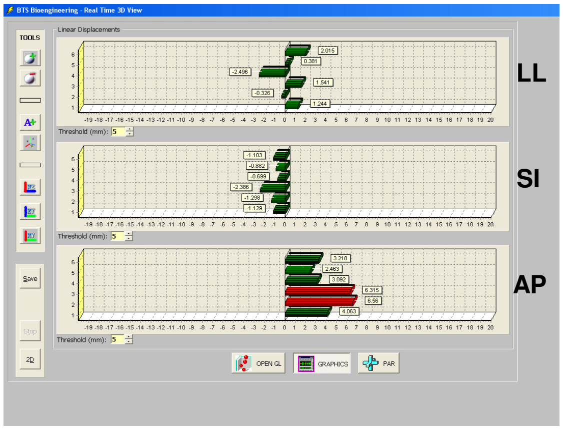
At each irradiation session, patients were manually aligned on the basis of skin tattoos and laser reference lines: an opto-electronic localizer (EL.I.TE., BTS Spa, Milano, Italy) recorded the 3-D coordinates of the external fiducials after laser alignment. Once a week, real-time visual feedback of residual marker displacements (Figure 2) was provided to an instructed operator, who performed 3 degrees of freedom (3DOF) optimization of patient set-up by means of the treatment couch movements along the latero-lateral (LL), superior-inferior (SI) and antero-posterior (AP) directions.



Threshold (mm): 5

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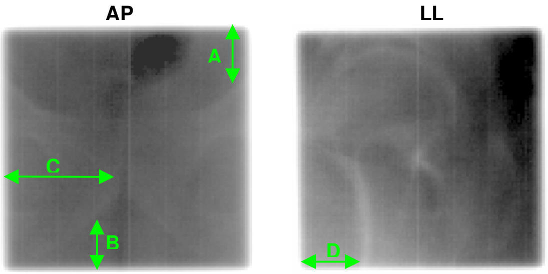
Figure 2: Example of the graphic user interface used as real-time visual feedback; the colored bars depict the linear marker displacements in each direction (LL, SI and AP), where green or red colors denote under or lower threshold errors, respectively

Following 3DOF correction, marker positions were acquired and electronic portal imaging (EPID) was used for checking patient set-up relying on bony anatomy (Figure 3).

Raw data were processed in order to obtain the off-line 3-D stereotactic reconstruction of PTV centre of mass from the fiducials coordinates. The implemented stereotactic reconstruction algorithm was based on a weighted strategy, in order to exploit redundancy in the 3-D reconstruction of tumor position (Figure 4).

Stereotactic localization relies on a rigid-body assumption, assuming that the geometrical configuration of the external fiducials is not significantly altered over the course of treatment. The application of stereotactic localization techniques when the fiducials are placed on skin surface (frameless approach) must adequately account for the effects of physiological deformations.



A = field edge – ischiopubic ramus
B = field edge – pubic symphysis inferior limit
C = field edge – pubic symphysis
D = field edge – femur anterior limit

Figure 3: Example of AP (left panel) and LL (right panel) portal images acquired for set-up check, where the distances used for comparison with the planning DRR are highlighted

The original set of external fiducials was decomposed in different subsets $S_{i,k}$, each of them corresponding to one of the possible combinations featuring k markers, with k ranging from 4 to n. PTV localization was performed for each subset, and the final isocenter localization was obtained as the weighted mean, being the weight $W_{i,k}$ defined as a function of the non-rigid deformation $D_{i,k}$ (1):

$$W_{i,k} = \frac{1}{\sum\limits_{i,k} W_{i,k}} \cdot \frac{k}{D_{i,k}} \qquad (1)$$

The amount of deformation $D_{i,k}$ for each subset was evaluated as the root mean square difference of the local coordinates of the markers comprising subset $S_{i,k}$. The weighted procedure adopted in this work ensured a minimal sensitivity to non-rigid deformations in frameless stereotactic localization.

The IR-based localization of PTV was exploited to evaluate systematic (mean) and random (1SD) set-up errors [4], and to compare laser vs. opto-electronic guided alignment. A roto-translation minimizing the measured marker displacements was used to simulate the 6 degrees of freedom (6DOF) correction of manual alignment, including patient rotations. Systematic and random residual set-up errors following 6DOF optimization were quantified.

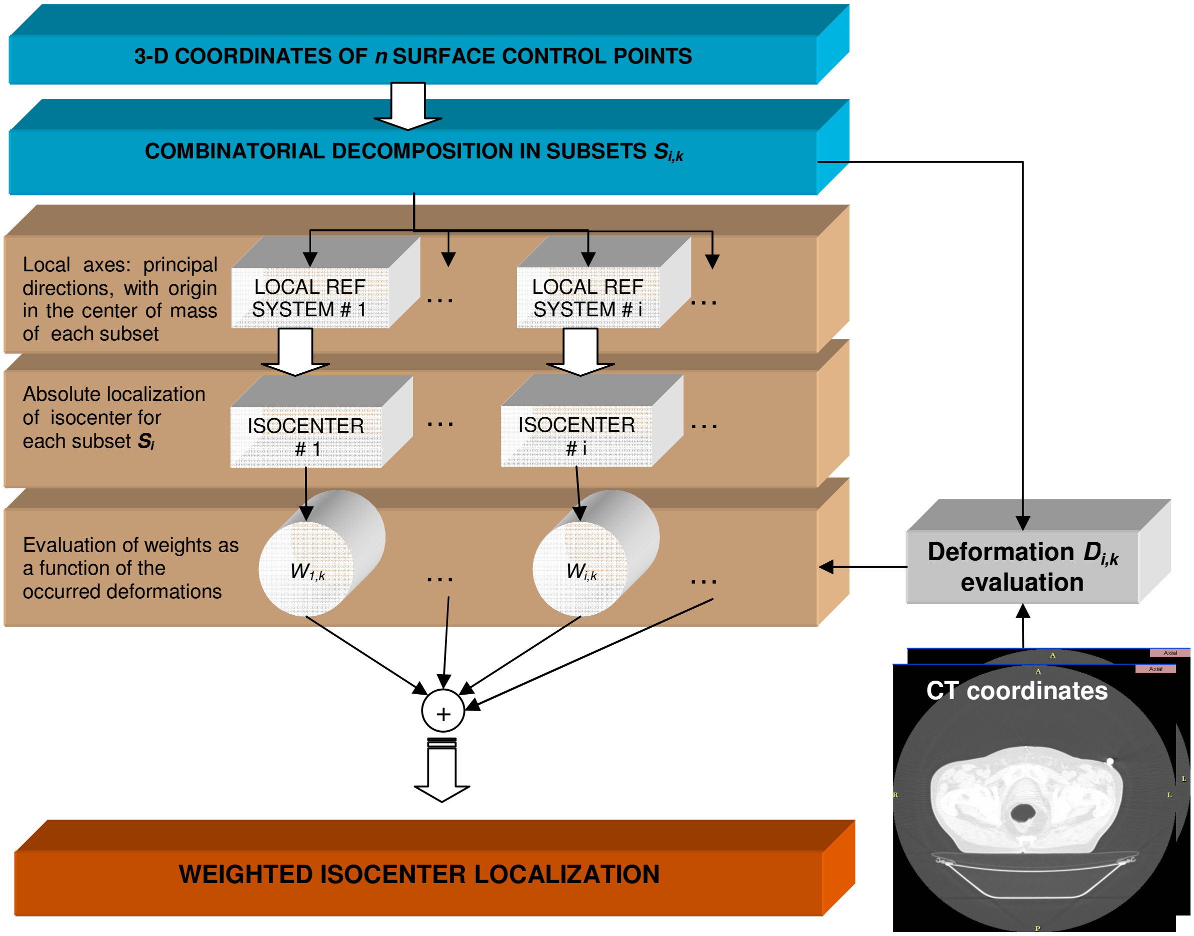


Figure 4: Flow-chart of the stereotactic reconstruction algorithm used for the 3-D localization of the PTV centre of mass

Results

No statistical significant difference (Mann-Whitney test, p=0.05) in IR-based PTV localization was highlighted between the daily manual laser alignment and the weekly controls, indicating equivalent accuracy in laser manual positioning (Figure 5).

The evaluated systematic and random patient set-up errors are depicted in Figure 6. The laser alignment and the 3DOF correction conditions revealed comparable values for group systematic errors. Statistical significant differences (Wilcoxon matched pair test, p=0.05) were found for random errors along the SI direction, with a reduction from manual alignment to 3DOF optimization measuring 0.9 mm. More consistent improvements were obtained through the application of the 6DOF correction: the 3-D systematic error was decreased from 5.1 mm (laser alignment) to 1.2 mm; linear random errors along the LL, SI and AP directions were reduced down to 0.3 mm, 0.8 mm and 0.2 mm, respectively (Figure 6).

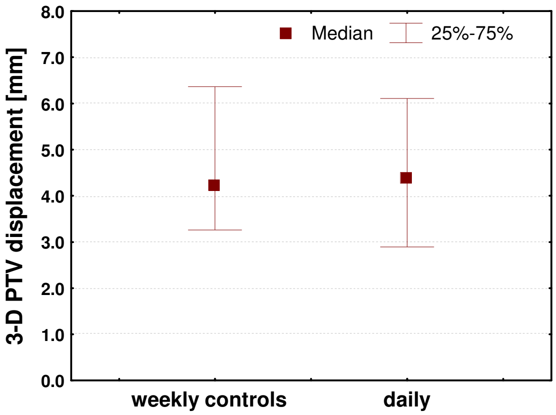


Figure 5: Median±quartile values of the three-dimensional PTV displacements measured daily and during the weekly controls for the manual laser alignment technique

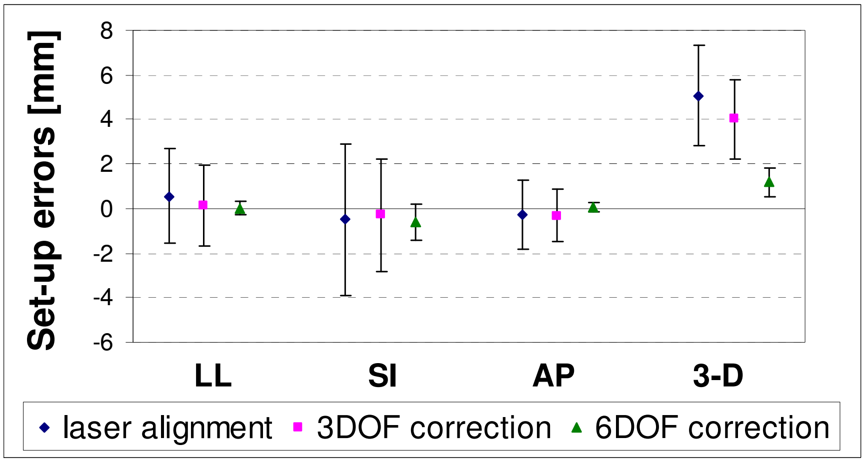


Figure 6: Linear and 3-D systematic±random set-up errors for laser alignment, 3DOF and 6DOF correction

Discussion

In the frame of external beam radiotherapy, the uncertainties in patient set-up have a negative impact on treatment optimization. When considering prostate cancer irradiation, the availability of appropriate techniques for compensating translational and rotational misalignments yield the actual reduction of systematic and random set-up errors.

Further studies are needed in order to asses the effect of physiological deformations on inter and intra-fractional tumor localization variability (organ motion).

Conclusions

The minimization of patient set-up errors and organ motion effects represent a valuable strategy towards the reduction of treatment margins and treatment optimization. The guidance of an opto-electronic localizer for patient positioning in prostate radiotherapy proved consistent results with portal imaging verification. Experimental activities showed that 6DOF correction of patient set-up is necessary in order to make the most of opto-electronic guidance for the effective reduction of systematic and random set-up errors.

References

[1] ROACH M., LU J., PILEPICH M.V., ASBELL S.O., MOHIUDDIN M., TERRY R., and GRIGNON D. (1999): 'Long-term survival after radiotherapy alone: Radiation therapy oncology group prostate cancer trials', *J. Urol.*, **161**, pp. 864-868

[2] HANKS G.E., HANLON A.L., SCHULTHEISS T.E., PINOVER W.H., MOVSAS B., EPSTEIN B.E., and HUNT M.A. (1998): 'Dose escalation with 3D conformal treatment: five year outcomes, treatment optimization, and future directions', *Int. J. Radiat. Oncol. Biol. Phys.*, **41**, pp. 501-510

[3] ICRU (1999): 'International Commission on Radiation Units and Measurements, Prescribing, Recording, and Reporting Photon Beam Therapy', Supplement to ICRU Report 50, ICRU Report 62 - International Commission on Radiation Units and Measurements, Bethesda, Maryland

[4] VAN HERK M. (2004): 'Errors and margins in radiotherapy', *Semin. Radiat. Oncol.*, **14**, pp. 52-64

[5] SOETE G., VAN DE STEENE J., VERELLEN D., VINH-HUNG V., VAN DEN BERGE D., MICHIELSEN D., KEUPPENS F., DE ROOVER P., and STORME G. (2002): 'Initial clinical experience with infrared-reflecting skin markers in the positioning of patients treated by conformal radiotherapy for prostate cancer', *Int. J. Radiat. Oncol. Biol. Phys.*, **52**, pp. 694-698