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Analysis of electromagnetic transponders tracking data to quantify intrafraction prostate motion during radiotherapy treatments

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Abstract. The Calypso tracking system (Varian, Palo Alto, CA, USA) is used to track the prostate isocenter on patients undergoing prostate radiotherapy after implantation of electromagnetic transponders. Aim of this study was to assign 226 recorded prostate tracks to different patterns of prostate intrafraction motion (i.e. stable target (ST), continuous target drift (CTD) and irregular wave motion (IWM)) and excursion (i.e. transient excursion (TE), persistent excursion (PE) and high-frequency excursion (HFE)). Relative frequencies of STs, CTDs and IWMs were 51.8%, 44.6% and 3.6%, respectively. TEs, PEs and HFEs were revealed in 9.4%, 5.4% and 14.3% cases, respectively, with maximum values of 8.0 mm, 8.7 mm and 15.5 mm, respectively. The equation $D(t) = 8.0 \times 10^{-3}$ mm/s * t + 0.93 mm was established to calculate the average prostate drift D with time t. Intrafraction prostate motion and excursions can be significant and should be in particular taken into account with treatment deliveries that require a prolonged treatment time, as for instance stereotactic body radiotherapy (SBRT) or hadrontherapy.

1. Introduction

The dose escalation achievable with intensity modulated radiotherapy (RT) techniques can nowadays significantly enhance the local control of prostate cancer [1, 2]. Nevertheless, even when patients are managed with appropriate external immobilization techniques during dose delivery, a possible intrafraction target motion can lead to irreversible blurring of the dose distribution as well as to hot or cold spots to the target and organs at risk (interplay effect) [3-7][kyme ref]. This can constitute a serious concern in highly hypo-fractionated RT or hadrontherapy prostate treatments, where delivery times can be prolonged if compared to standard fractionated RT [8]. In this work, intrafraction prostate motion was analysed in patients undergoing radical RT after transrectal implantation of electromagnetic transponders used for prostate localization and tracking [9]. Aim of the study was to identify different

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patterns of prostate intra-fraction motion and excursion and to classify the analysed sampled tracks according to these patterns.

2. Materials and Methods

By means of the Calypso tracking system (Varian, Palo Alto, CA, USA) coordinates of the target isocenter were recorded continuously over full radiotherapy fractions on 10 patients (i.e. 226 treatment fractions) undergoing radical radiotherapy after transrectal implantation of the Beacon transponders. The sampling frequency was of 10 Hz. In analogy to Kupelian *et al* [10], the following three different motion patterns were associated to the tracking data: stable target at baseline (ST), continuous target drift (CTD) and irregular wave motion (IWM). An example of each one of these patterns is provided in figure 1.

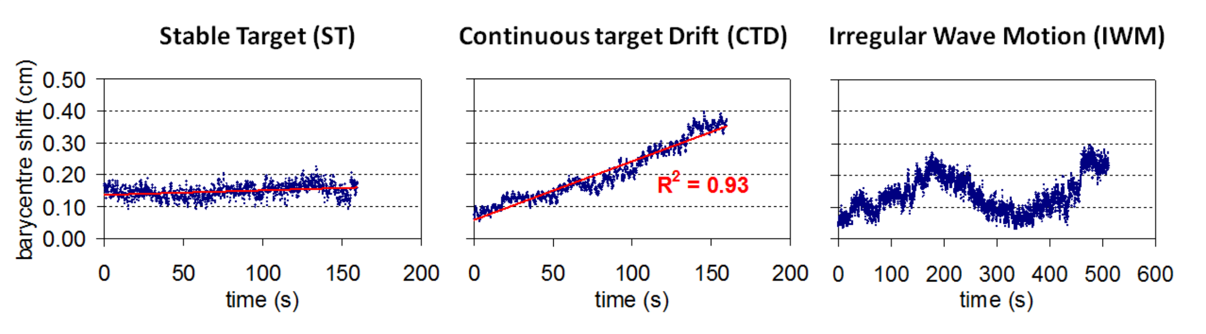

Figure 1. Examples of prostate motion patterns associated to the intrafraction tracking data.

In particular, for each CTD case, a linear regression $D(t) = v_D * t + p$ was calculated to evaluate the correlation between the prostate drift D and the time t. v_D represents the drift speed of the prostate isocenter. p indicates the prostate position at t = 0 s, which is not exactly 0 (i.e. the exact isocenter) due to a small localization uncertainty and a possible initial rotation of the target. Associated to the overall prostate trajectory within the RT treatment fraction, further three type of prostate excursions were investigated and classified: transient excursion (TE), persistent excursion (PE) and high-frequency excursion (HFE). An example of each one of these excursion patterns is provided in figure 2.

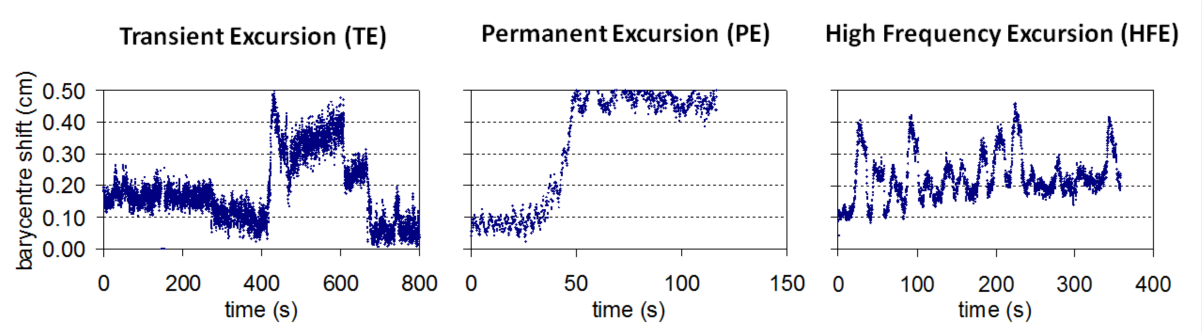

Figure 2. Examples of prostate excursion patterns associated to the intrafraction tracking data.

3. Results and Discussion

A total of 224 fractions were categorized in at least one of the three motion patterns, i.e. ST, CTD and IWM. In two cases, motion patterns were too irregular and impossible to categorize. In 21 cases, two different patterns were discernible within the same RT fraction, both were therefore separately taken into account. Figure 3 shows the observed frequencies for ST, CTD and IWM prostate motions and the observed frequencies for TE, PE and HFE prostate excursions. Maximum transient, persistent and high-frequency excursions were of 8.0 mm, 8.7 mm and 15.5 mm, respectively.

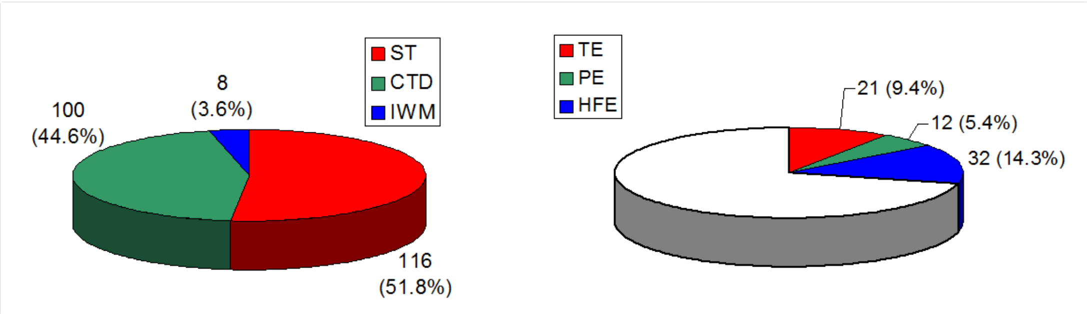

Figure 3. Relative frequencies of prostate patterns of motion (i.e. ST, CTD and IWM) and excursion (i.e. TE, PE and HFE) over 224 analysed fractions.

Analysing only the CTD cases (i.e., 44.6%), the average (median) values of v_D and p resulted to be $8.0*10^{-3}$ mm/s ($6.4*10^{-3}$ mm/s) and 0.93 mm (0.80 mm), respectively. Distribution of all the obtained v_D is shown in figure 4. Splitting the average drift speed in its main components, it resulted to be $3.0*10^{-3}$ mm/s towards the posterior direction, $2.2*10^{-3}$ mm/s towards the inferior direction, and less than $1*10^{-3}$ mm/s in left-right direction. Bladder and rectum morphological changes are most likely the causes for this shift.

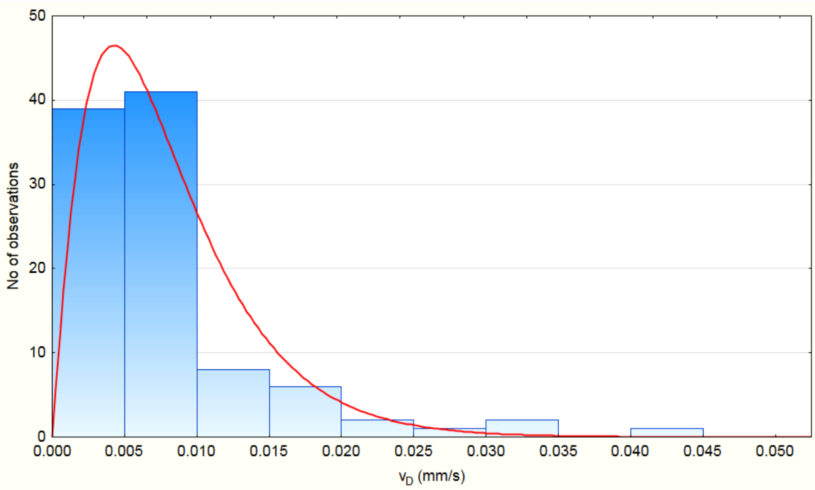

Figure 4. Distribution of all obtained prostate drift speeds over 100 CTDs events. Data were fitted with a gamma-distribution which is shown in red with the histogram.

In light of this result, assuming a reasonable time of 360 s for a prostate SBRT treatment performed with volumetric modulated arc therapy (VMAT) delivered with two full arcs (as it is the current experience at our institution), an average prostate drift of 3.8 mm would be expected at the end of the treatment. Moreover, if the v_D and p values encompassing the 95% of the observed cases were considered (i.e., v_D = $15.1*10^{-3}$ mm/s and p = 1.54 mm), the prostate drift expected at the end of a 360 s treatment would be of 7 mm.

5. Conclusions

Although not directly sampled on patients treated with prostate SBRT, results are of particular interest for SBRT cases where the CTV→PTV margins should be in principle chosen as small as possible to reduce the risk of toxicities to rectum and bladder [11]. Results are also important in hadrontherapy, where treatment time might be significantly increased with respect to conventional RT. In light of the resulting frequency and entities of intrafraction prostate drifts or excursions, the use of a RT facility provided with a real time tracking system results to be of primary importance for an accurate SBRT delivery. In hadrontherapy, adequate CTV→PTV margins should be planned to take also into account intrafraction motion, in particular if no means for intrafraction prostate localization are available.

6. Acknowledgments
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7. References
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