Temporal Dependence of Intra-fraction Motion of the Prostate

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Introduction

The prostate location can change systematically during the treatment course while fluctuating randomly around its mean daily position, a process termed inter-fraction motion. Systematic and random variations in prostate location can also occur during daily treatment fractions, a process termed intra-fraction motion. While patient setup with imaging systems such as cone-beam computed tomography (CBCT) may account for errors caused by inter-fraction motion, they do not correct for errors as a result of intra-fraction motion. Not accounting for the uncertainty due to intra-fraction motion may cause inaccuracies in the daily external beam prostate radiotherapy (RT). With the availability of electromagnetic transponders that can be implanted into the prostate gland for clinical use, intra-fraction motion can be assessed in real-time and its errors corrected for, if necessary. The purpose of our study is to quantify and describe prostate intra-fraction motion using real-time electromagnetic transponder detection in a cohort of patients treated with classic intensity-modulated radiotherapy (IMRT) and a cohort of patients treated with volumetric modulated arc therapy (VMAT). The ultimate goal of our study is to identify intra-fraction time trends, if any, in the prostate motion.

Hypothesis:
Based on the information collected from clinical procedures, we hypothesize that the longer the duration of the treatment, the greater the magnitude of errors that are caused by intra-fraction motion of the prostate gland during external beam prostate radiotherapy.

Materials & Methods

Seventy-six prostate cancer patients treated with the IMRT technique and eighty-two prostate cancer patients treated with the VMAT technique formed the basis of our study. Each patient was implanted with three electromagnetic transponders and underwent a treatment course of either 28 or 39 fractions. Each patient had at least one CBCT a week and daily electromagnetic transponder detections for inter-fraction error correction. Furthermore, each patient had daily real-time electromagnetic transponder tracking for intra-fraction error correction. The patient population was thus divided into four groups: IMRT_C; corresponding to days when patients subjected to IMRT were setup with the electromagnetic transponders only, IMRT_CC; corresponding to days when patients subjected to IMRT were setup with the electromagnetic transponders and verified with CBCT, VMAT_C; corresponding to days when patients subjected to VMAT were setup with the electromagnetic transponders only, and VMAT_CC; corresponding to days when patients subjected to VMAT were setup with the electromagnetic transponders and verified with CBCT.

Materials & Methods

To statistically analyze the data sets that were derived from these population groups, average and standard deviation (STD) were calculated. The calculated averages and STDs were used to determine the values of the systematic and random errors introduced by intra-fraction motion of the prostate gland in three dimensions (left-right or **LR**, head-to-toe or **IS**, and back-to-front or **AP** directions). Based on the Van Herk *et al.* formula **[2.5∑ + 0.7σ]**, the planning target volume (PTV) margin needed to insure above 90% of the patients will receive ≥98% uniform distribution was calculated.

Results

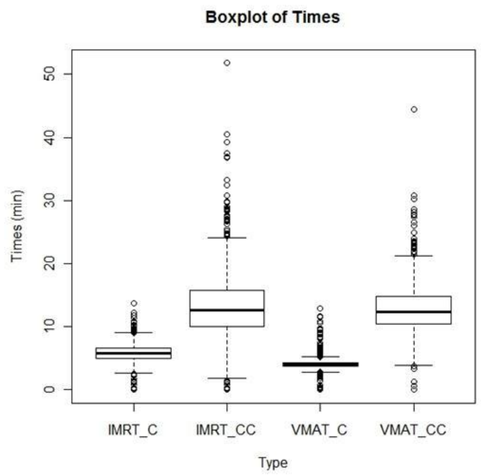

Figure 1: Boxplot showing the distribution of treatment times for each population group.

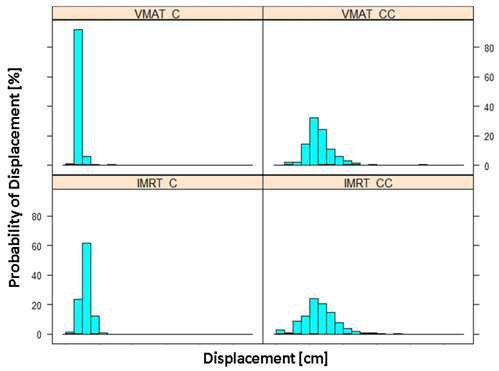

Figure 2: Probability of increase in displacement as a function of treatment technique.

Results

		LR			IS			AP		
	Time (min)	$\sum_{Intra}$	σ_{Intra}	Margin (±)	$\sum_{Intra}$	σ_{Intra}	Margin (±)	$\sum_{Intra}$	σ_{Intra}	Margin (±)
VMAT_C	4.15	0.0253	0.444	0.374	0.0321	0.399	0.360	0.0351	0.411	0.376
IMRT_C	6.00	0.0254	0.112	0.142	0.0295	0.392	0.348	0.0303	0.379	0.341
VMAT_CC	13.1	0.0584	1.925	1.45	0.0435	1.41	1.097	0.0455	1.15	0.918
IMRT_CC	13.5	0.0817	2.592	2.02	0.0530	1.85	1.42	0.0504	1.53	1.20

Table 1. Population statistics including systematic errors, random errors, and PTV margins for each population group. The values in red indicates calculations with inconsistencies and will be addressed subsequently. *Abbreviations:* LR _ left–right; AP _ anterior–posterior; IS _inferior–superior, standard deviation (STD)

Figure 1 is a box plot that shows the distribution treatment times for each population group. The time variation for each population group is also presented in Table 1, along with the corresponding population statistics. The probability of intra-fraction motion increased with treatment duration (Table 1 and Figure 2).

Conclusion

Intra-fraction motion was found to be patient-specific suggesting individualized management approaches. The chances of prostate displacement increased with elapsed treatment time, indicating the relevance of prompt initiation of dose administration after the patient is setup. Furthermore, the dependency of intra-fraction uncertainties on the duration of treatment must be accounted for in order to avoid bias in generating corrective PTV margins. Finally, contrary to our expectations, the dependence of intra-fraction motion on the duration of treatment was found to be much more significant in the LR direction; we are currently taking another look at our analyses in order to address this inconsistency.

In the future, more research needs to be done to help us understand the most effective treatment for patients with prostate cancer. In today's treatments, there are no specific instructions given to patients on what to do prior to treatment. Instructions that would be given include explicit life styles, such as diet. These patients can then be studied to see the effect of diet on the position of the prostate during treatment. Other factors such as having a full bladder or rectum vs. standardizing bladder or rectum as well as flatulence, could also play a significant role in the uncertainty of the location of the prostate. We could also segregate patients by body mass index (BMI), age, or body size which differentiates variations of the random and systematic errors. The ultimate goal is to make radiation treatment be more effective, more accurate, and safer.

Literature

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