

# Application of aSi-kVCBCT for Volume Assessment and Dose Estimation: An Offline Adaptive Study for Prostate Radiotherapy

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## Abstract

**Objective:** The purpose of this study is to develop a method to estimate the dose using amorphous silicon detector panel cone beam computed tomography (aSi-kVCBCT) for the OARs and targets in prostate radiotherapy and to compare with the actual planned dose. **Methods:** The aSi-kVCBCT is used widely in radiotherapy to verify the patient position before treatment. The advancement in aSi-kVCBCT combined with adaptive software allows us to verify the dose distribution in daily acquired CBCT images. CBCT images from 10 patients undergoing radical prostate radiotherapy were included in this study. Patients received total dose of 65Gy in 25 fractions using volumetric modulated arc therapy (VMAT). aSi-kVCBCT scans were acquired before daily treatment and exported to smart adapt software for image adaptation. The planning CT is adapted to daily aSi-kVCBCT images in terms of HU mapping. The primary VMAT plans were copied on to the adapted planning CT images and dose was calculated using Anisotropic Analytic Algorithm (AAA). The DVH is then used to evaluate the volume changes of organs at risk (OAR), the actual dose received by OARs, CTV and PTV during a single fraction. **Results:** The normalized volume of the bladder and rectum ranged from 0.70–1.66 and 0.70–1.16 respectively. The cumulative mean Sorensen–Dice coefficient values of bladder and rectum were 0.89±0.04 and 0.79±0.06 respectively. The maximum dose differences for CTV and PTV were 2.5% and -4.7% and minimum were 0.1% and 0.1% respectively. **Conclusion:** The adapted planning CT obtained from daily imaging using aSi-kVCBCT and SmartAdapt<sup>®</sup> can be used as an effective tool to estimate the volume changes and dose difference in prostate radiotherapy.

**Keywords:** aSi-kVCBCT- adapted planning CT- prostate radiotherapy- volume change- dose difference

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## Introduction

Multiple trials have shown that hypo fractionation can shorten treatment schedule for patients with prostate cancer and might also allow us to enhance the therapeutic ratio even further (Dearnaley et al., 2016). Recent technologic improvements have allowed hypo fractionated radiation treatment to be administered with greater precision, improved safety, and an enhanced potential for disease control. The treatment efficacy depends on the patient setup error and interfraction motion throughout the whole treatment. Volume changes in the bladder and rectum can cause prominent variations in the prescribed dose vs the actual dose received in prostate radiotherapy. Inter-fractional prostate motions are corrected through pre-treatment imaging during each fraction. Advancements in treatment delivery techniques like volumetric-modulated arc therapy have improved the

sparing of critical structures and reduced the treatment delivery time, thereby limiting intrafraction motion errors (Anantharaman et al., 2016). In this scenario, the development in adaptive algorithms enables us to execute adaptive radiotherapy in an efficient manner using daily CBCT images to account for the intrafraction volume changes of the critical organs in prostate patients.

In recent times, aSi-kVCBCT is a major tool to obtain the 3D image of the patient before treatment. These multidirectional images provide sufficient information to reconstruct patient anatomy in three dimensions, including cross-sectional, sagittal and coronal planes. There is a possibility of changes in the anatomy of bladder, rectum and bowel during the entire course of the treatment for prostate. Thus, position of the PTV may change due to anatomical changes of OARs. Several authors found that the volume change in prostate by an average of +/- 10% during the course of radiation therapy, while bladder and

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rectal volumes varied by +/- 30% (Roeske et al., 1995). The planning CT data are ideally not representative of the anatomy present during treatment. In principle, dose calculation should be done on aSi-kVCBCT image but the challenges posed due to the artifacts and non-standard HU values prevent us from using these images for dose calculation.

In the current situation, many systems are available to estimate the dose and assess the volume changes on adapted planning CT. Several authors had investigated the dose calculation accuracy on CBCT and compared with planning CT (Richter et al., 2008). CT number mapping is a well-known method to perform adaptive radiotherapy and the dose was calculated on CBCT (Hu et al., 2010). In this study, aSi-kVCBCT had been used to estimate the dose and assess the volume change during the prostate radiotherapy with the help of commercially available image adaptive system.

## Materials and Methods

### A. Patient selection

10 prostate cancer patients were included in this study with low, intermediate risk (stage T1-2N0M0) had radiotherapy (RT) with total prescribed dose of 65 Gy by 2.6 Gy per fraction. Patients were immobilized with vacuum cushion and thermoplastic mask. For planning CT simulation, the patients were asked to drink two glass of water about 20 mins before the acquisition CT and the same were maintained before each fractional treatment. Planning CT acquisition performed with the slice thickness of 3 mm along with Contrast enhanced CT for better delineation of anatomical structures. For all 10 patients, the clinical target volume (CTV) was defined as the prostate gland and seminal vesicle on the CT scan. The planned target volume (PTV) was defined as CTV plus 5 mm in the posterior direction and 8 mm for all other directions. The Bowel, rectum, bladder, femoral heads were also contoured for each patient. The VMAT plan optimization was performed with 6MV photon and dose calculation (Anisotropic Analytic Algorithm) was carried out on the planning CT in the Eclipse v.11 treatment planning system® (Varian Medical Systems, Palo Alto, CA) with the calculation grid size of 2.5 mm.

### B. aSi-kVCBCT Acquisition

The patient position verification consists of daily 2D Kv orthogonal imaging for bony landmark verification and aSi-kVCBCT for 3D anatomical verification. The following parameters of aSi-kVCBCT were used for 3D imaging: Kv: 125kVp, high-resolution reconstruction: 512 X 512 pixel, with a slice thickness of 3 mm; Gain mode: Dual gain; Filter: half fan bow tie filter. Detector: Amorphous silicon flat panel imager Active imaging area: 40 x 30 cm<sup>2</sup> Resolution: 1,024 x 768 pixels; Max frame acquisition rate: 9.574 frames/second; Energy range: 40 - 150 kVp; Spatial resolution: 0.19 mm. Daily aSi-kVCBCT imaging protocol were followed for prostate radiotherapy.

### C. Adaptive image registration

To estimate the changes in volume and daily dose to the bladder and rectum, the planning CT is rigidly auto-aligned and deformed to the aSi-kVCBCT. Image adaptation mainly relies on Deformable Image Registration (DIR) and the same have been discussed in many literatures (Hou et al., 2011). SmartAdapt® system (Varian Medical Systems, Palo Alto, CA) system has the ability to perform DIR and map the HU values from planning CT to CBCT for better dose calculation accuracy (Anantharaman et al., 2016) which uses accelerated demons algorithm proposed by Wang et al., (2005).

The adaptive image registration consists of two steps: 1) possible bony landmark registration of CBCT with planning CT through a rigid registration algorithm. 2) Deformable image registration of planning CT to aSi-kVCBCT to deform the contours using the deformation vector field determined by the SmartAdapt® system. The deformed structures were checked carefully for its changes in adapted planning CT. The adapted planning CTs along with contours were exported to Eclipse planning system for contour evaluation and dose calculation.

### D. Volume assessment and Dose estimation

The Sorensen–Dice coefficient (SDC) is used to compare the similarity of two contoured sets. The volume changes in adapted planning CT were compared with initial planning contours. In this study SDC is used as a volume-based similarity index to evaluate the volume changes quantitatively. The SDC is calculated as follows, where Vp and Va represents initial planned volume and adapted volume respectively.

$$SDC = \frac{2 * |Vp \cap Va|}{|Vp| + |Va|}$$

To estimate the “dose of the day” all planning parameters were kept the same, including field size, beam arrangement, dose fluence map, planned monitor units and dose calculations were performed. AAA algorithm was used to calculate the dose on adapted planning CT with the calculation grid size of 2.5mm. Dose estimation was computed in dose volume histogram option in Eclipse. The dose-volume parameters were calculated in terms of dose received by 15% of volume (V15%), 25 % (V25%), 35 % (V35%) and 50 % (V50%) (RTOG report no: 0126) for rectum and bladder. DVH analysis of Clinical Target Volume (CTV) and Planning Target Volume (PTV) were performed using doses received by 99% (D99%), 95% (D95%) and 1% (D1%) of volume.

## Results

### A. Volume assessment

Weekly aSi-kVCBCT images for 10 patients were first analyzed and later adapted to planning CT. For each patient the volumes of bladder and rectum were assessed. Figure 1 shows the volume projection in an axial section of bladder and rectum on the weekly adapted planning CT for a patient. Volumes of bladder and rectum were normalized corresponding to initial planning volumes as shown in

Table 1. The SDC Values for Bladder and Rectum

P. No	SDC									
	1	2	3	4	5	6	7	8	9	10
B	0.88± 0.023	0.82± 0.071	0.91± 0.021	0.89± 0.015	0.93± 0.010	0.94± 0.020	0.91± 0.035	0.84± 0.063	0.85± 0.021	0.95± 0.035
R	0.76± 0.012	0.80± 0.017	0.64± 0.010	0.77± 0.002	0.85± 0.019	0.88± 0.020	0.78± 0.041	0.86± 0.012	0.76± 0.017	0.79± 0.024

SDC, Sorensen–Dice coefficient; P.No, Patient number; B, Bladder; R, Rectum

Table 2. The Average Cumulative Dose Differences for CTV

Patient No	CTV								
	D <sub>95%</sub>			D <sub>99%</sub>			D <sub>1%</sub>		
	Planned (cGy)	Calculated (cGy)	Variation (%)	Planned (cGy)	Calculated (cGy)	Variation (%)	Planned (cGy)	Calculated (cGy)	Variation (%)
1	63.6	63.8	0.3	63.1	63.2	0.1	66.7	67.0	0.4
2	65.2	66.4	1.8	64.7	65.7	1.6	67.6	69.3	2.5
3	65.9	66.0	0.2	65.6	65.5	-0.2	69.1	69.4	0.4
4	63.9	64.3	0.7	63.4	63.6	0.3	66.6	67.1	0.8
5	64.0	64.4	0.6	63.4	63.1	-0.5	66.7	66.3	-0.6
6	66.2	66.0	-0.3	63.2	63.8	0.9	69.2	69.7	0.7
7	66.5	66.0	-0.8	63.4	63.1	-0.5	69.9	69.7	-0.3
8	65.3	64.4	-1.4	64.6	64.0	-0.9	67.8	66.9	-1.3
9	66.4	66.8	0.6	63	62.5	-0.8	66.9	67.4	0.7
10	66.3	66.4	0.2	64.2	63.3	-1.4	67.0	66.8	-0.3

CTV, Clinical target volume; D95%, D99%, D1%, dose received by 95%, 99%, 1% of volume

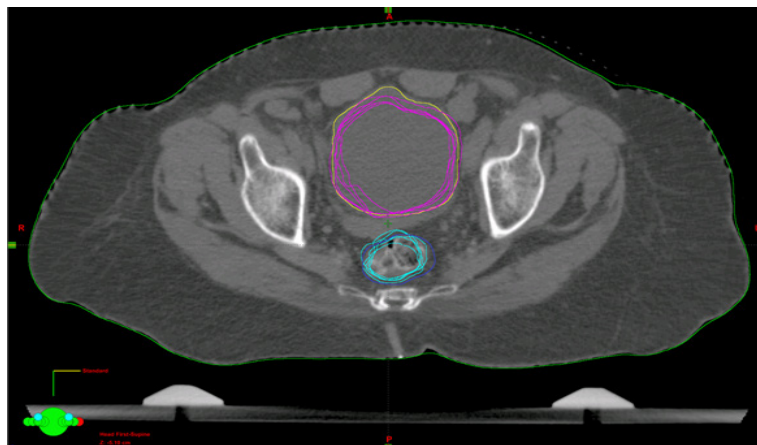


Figure 1. The Volume Projection in an Axial Section of Bladder and Rectum on the Weekly Adapted Planning CT

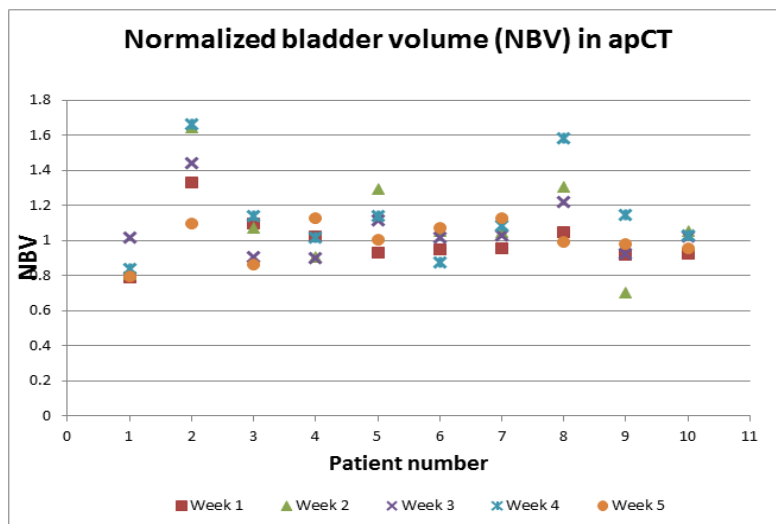


Figure 2. Normalized Bladder Volume Corresponding to Initial Planning Volumes

Table 3. The Average Cumulative Dose Differences for PTV

Patient No	PTV								
	D95%			D99%			D1%		
	Planned (cGy)	Calculated (cGy)	Variation (%)	Planned (cGy)	Calculated (cGy)	Variation (%)	Planned (cGy)	Calculated (cGy)	Variation (%)
1	63.1	62.8	-0.5	61.8	60.1	-2.7	66.9	67.1	0.3
2	63.4	63.1	-0.5	61.9	60.5	-2.3	67.7	69.5	2.7
3	63.9	63.3	-1	59	59.4	0.7	69.3	69.4	0.1
4	62.8	61.3	-2.5	61.4	58.5	-4.7	66.7	67.4	1
5	62.7	62.9	0.3	61.4	60.2	-2	66.5	66.8	0.5
6	64.0	63.5	-0.8	62	62.2	0.3	69.9	68.7	-1.7
7	63.0	64.0	1.6	60.7	60.3	-0.7	68.9	66.7	-3.2
8	63.3	64.2	1.4	61.7	60.8	-1.5	67.4	67.1	-0.4
9	63.0	64.9	3	60.2	59.5	-1.2	66.9	69.2	3.4
10	64.2	63.0	-1.9	61.7	60.0	-2.8	67.1	66.5	-0.9

PTV, Planning target volume

Table 4. Dose Difference of Bladder Due to the Volume Change

Patient No		Bladder									
		1	2	3	4	5	6	7	8	9	10
V <sub>15%</sub>	Planned (cGy)	42.5	65.1	58.5	52	52.6	56.7	63.2	52.3	58.7	60.6
	Calculated (cGy)	47.6	59.5	58	54.3	53.2	52.8	58.9	61.2	60.4	64.2
	Dose Difference (%)	12.1	-8.6	-0.9	4.5	1.1	-6.9	-6.8	17.0	2.9	5.9
V <sub>25%</sub>	Planned (cGy)	26.8	59.6	43.0	44.9	44.3	42.5	49.7	49.8	42.6	45.8
	Calculated (cGy)	31.9	46.4	41.9	46.3	42.2	44.2	50.3	56.5	47.8	39.4
	Dose Difference (%)	19.1	-22.1	-2.5	3.0	-4.7	4.0	1.2	13.5	12.2	-14
V <sub>35%</sub>	Planned (cGy)	16.2	47.6	31.2	39.5	35.1	30.2	40.2	42.1	28.7	30.7
	Calculated (cGy)	20.5	39.4	29.5	40.7	38.2	32.3	37.4	40.7	33.5	31.8
	Dose Difference (%)	26.3	-17.2	-5.3	3.0	8.8	7.0	-7.0	-3.3	16.7	3.6
V <sub>50%</sub>	Planned (cGy)	7.2	36.6	19.3	32.5	32.6	16.8	32.1	24.1	15.5	19.2
	Calculated (cGy)	9.5	32.8	18.2	33.9	30.5	15.6	27.5	33.6	16.2	22.5
	Dose Difference (%)	31.4	-10.5	-5.9	4.3	-6.4	-7.1	-14.3	39.4	4.5	17.2

Figures 2 and 3. The normalized volume of the bladder and rectum ranged from 0.70–1.66 and 0.70–1.16 respectively. From this study we found that the bladder volume changes

were comparatively more than the rectum. The SDC between the adapted and primarily delineated contours were determined for bladder and rectum shown in Table

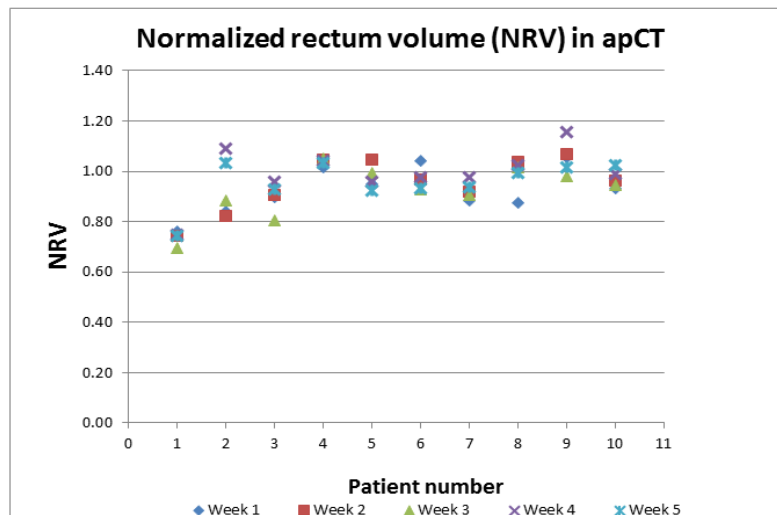


Figure 3. Normalized Rectum Volume Corresponding to Initial Planning Volumes

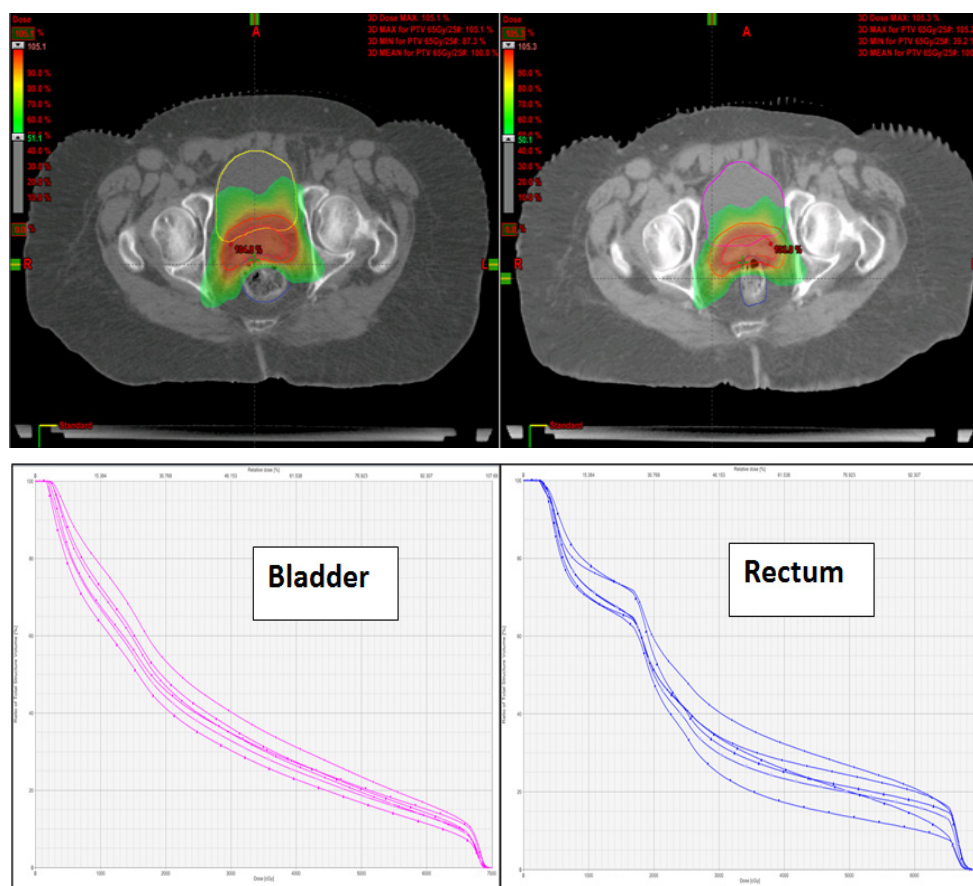


Figure 4. Dose Distribution and DVH Spread on Planning CT and Adapted Planning CT of a Prostate Patient

Table 5. Dose Difference of Rectum due to the Volume Change

Patient No		Rectum									
		1	2	3	4	5	6	7	8	9	10
V <sub>15%</sub>	Planned (cGy)	53.3	56.6	58.4	55.9	56	52.5	58.2	50.7	45.2	50.1
	Calculated (cGy)	56.7	61.2	60.9	48.7	55.2	58.2	54.5	45.6	49.7	46.5
	Dose Difference (%)	6.3	8.1	4.3	-12.9	-1.4	10.9	-6.4	-10.1	10	-7.2
V <sub>25%</sub>	Planned (cGy)	38.6	42	40.8	43.7	35.8	41.5	48.7	44.8	38.2	39.8
	Calculated (cGy)	40.6	43.8	41.7	37.3	30.9	42.3	46.8	40.2	36.5	36.7
	Dose Difference (%)	5.2	4.2	2.3	-14.7	-13.7	1.9	-3.9	-10.3	-4.5	-7.8
V <sub>35%</sub>	Planned (cGy)	29.2	28.7	29	35.1	27.5	36.6	30.2	34.7	21.6	25.2
	Calculated (cGy)	29.9	28.3	28.9	32.5	28.4	33.2	27.5	29.8	25.6	21.8
	Dose Difference (%)	2.5	-1.5	-0.5	-7.5	3.3	-9.3	-8.9	-14.1	18.5	-13.5
V <sub>50%</sub>	Planned (cGy)	18.7	16.8	20.3	27.6	25.1	20.8	15.6	20.9	18.7	14.6
	Calculated (cGy)	18.4	16.7	21	21.7	25.6	18.6	17.8	16.5	19.6	16.3
	Dose Difference (%)	-1.4	-0.7	3.3	-21.5	2	-10.6	14.1	-21.1	4.8	11.6

1. The cumulative mean SDC values of bladder and rectum were  $0.89 \pm 0.04$  and  $0.79 \pm 0.06$  respectively.

#### B. Dose estimation

Figure 4 represents the dose distribution and DVH comparison on planning CT and adapted planning CT of a single patient. The average cumulative dose differences in DVH parameters for CTV and PTV are shown in Tables 2 and 3. The maximum dose differences for CTV and PTV were 2.5% and -4.7% and minimum were 0.1% and 0.1% respectively. Tables 4 and 5 represent the dose difference of bladder and rectum due to the volume change. The

average cumulative dose differences were found to be  $2.9\% \pm 12.9$  for bladder and  $-2.3\% \pm 9.5$  for rectum.

#### Discussion

This study is intended to analyze the application of aSi-kVCBCT for volume changes of bladder and rectum and dose estimation for the same for prostate radiotherapy. Many literatures showed that the volume, position and shape of the bladder and rectum vary throughout the course of prostate radiotherapy treatment (Li et al., 2011). The



SmartAdapt® system is already validated for deformable image registration by (Ramadaan et al., 2015). Pre-treatment bladder and rectum protocol helps to maintain the volume as per planning CT. However, from our results we observed that the changes in volume of bladder are found to be more compared with rectum volume changes. For some patients the bladder filling protocol have been changed during the course of treatment itself after analyzing the volume changes on daily aSi-kVCBCT to maintain as per planning CT. Patients are being advised to stay in the waiting room for a prescribed time after drinking prescribed amount of water wherein the ambient temperature is maintained every day. This practice is useful to maintain the bladder filling changes due to room temperature setting. When the rectum of patient is filled with gas and feces, it enlarges and encroach the PTV which elevates the dose to rectum and reduces the dose to PTV. The same have been observed by Padhani et al., (1999) in a study and they concluded that the patients should be advised to clear their rectum prior to radiotherapy to reduce rectal distension. If rectum and bladder filling are not sufficient or too filled, the treatment delivery should be aborted.

Table 1 show that the SDC fluctuate for each patient and indicates that there is volume changes of OARs. The minimum and maximum SDC for bladder is  $0.82 \pm 0.071$ ,  $0.95 \pm 0.035$  and for rectum is  $0.64 \pm 0.010$ ,  $0.88 \pm 0.020$  respectively. In our study, changes in CTV dose coverage for most patients were not prominent and for PTV it is within  $\pm 3.5\%$ . This is because the dose to PTV is more influenced by the volume changes of OARs than CTV. Even though the patient position error can be corrected, deformation of bladder and rectum and its consequences on dose distribution should be considered. The standard deviation of dose difference for bladder and rectum is high because of the dose difference in smaller dose range of V50%.

However, this approach is laborious to estimate the volume changes and dose difference every day because of the time taken for image registration, image adaptation, verification, dose calculation and analysis. That is the reason, this study limits itself to check the dose and volume changes weekly once rather than daily. Our results suggest that 3 dimensional imaging is a necessary tool to evaluate the OAR volumes although the filling protocol followed for bladder and rectum.

In Conclusion, this study was performed using aSi-kVCBCT to estimate the volume changes and dose difference in prostate radiotherapy. The adapted planning CT resulted from aSi-kVCBCT and SmartAdapt® system is an effective tool to estimate the volume changes and dose difference. Daily adaptive planning CT can estimate the cumulative dose variation during the entire course of treatment. Faster aSi-kVCBCT acquisition and enhanced reconstruction algorithm can estimate the dose difference with high accuracy.

#### Statement conflict of Interest

Authors have no conflict of Interest.

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