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A comparison of three dimensional and two dimensional imaging in a busy radiotherapy department

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Abstract

Aim: The purpose of the study is to determine the advantage of three dimensional volume imaging over conventional two dimensional orthogonal imaging.

Materials and methods: For the study, 16 patients were selected for each of brain, head and neck, thorax, abdomen and pelvis sites. For all patients 2-D kilovoltage (kV) orthogonal images and 3-D volumetric cone beam images (CBCT) were acquired as a part of setup verification. The set up correction shift applied in all three coordinates for both the imaging techniques were noted down.

Results: The cumulative mean couch applied shifts for all the patients for CBCT imaging modality was 3.1 mm in lateral, 3.3 mm in vertical and 4.2 mm in longitudinal direction. The cumulative mean couch applied shifts for all patients for kV imaging modality was 2.5 mm in lateral, 2.7 mm in vertical and 3.2 mm in longitudinal direction.

Conclusion: From the study, we found that CBCT imaging was superior to orthogonal 2-D imaging for all sites, although CBCT imaging took longer duration. 2-D imaging is fast and widely used but only bony matching can be done. The main advantage of CBCT is 3-D volume informations.

Keywords: setup error, kV image, CBCT

Introduction

The use of ionizing radiation to cause the cell death is the basis of radiotherapy. Conventional radiotherapy is not accurate enough to damage the cancer cells only, so healthy tissues are also irradiated. This causes unwanted normal tissue complications or side-effects. Now a day, high energy linear accelerators capable of producing high energy X-rays and electrons of different energies are available. MLCs led to the wide spread use of three dimensional conformal radiotherapy (3DCRT). 3DCRT uses multiple beam angles to deliver conformal dose distribution, thereby reducing dose to critical structures. 3DCRT is based on forward planning where the treatment delivery parameters are optimized manually to achieve a desired dose distribution and the quality of the plan is highly planner dependant. With the introduction of Intensity modulated Radiation therapy (IMRT), dose to Organ at risks (OARs) were significantly less and dose escalation to tumors was viable. This also led to simultaneous integrated boost treatments which are especially useful in head and neck cancers. IMRT paints the dose on to the tumor precisely with the help of MLCs. It guides the beams of radiation to the tumor from many different angles. At each of these angles, the intensity of the radiation is modulated and the shape of the beam is changed to match the shape of the tumor. These adjustments enable the prescribed amount of dose to be delivered to each part of the tumor at the same time minimizing exposure to the surrounding healthy tissue.

These advantages can only be achieved if there is accurate dose delivery to the patient. Because of that reason verification of patient position in treatment unit should be part of the treatment procedure. In telecobalt machines no images were taken for set up verification. With early linear accelerators it is possible to take 2-D orthogonal images. These images are acquired in treatment position and compared with the corresponding treatment planning images. Nowadays, a variety of image techniques are available such as planar MV images, planar kV images, CBCT, in the state of art advance linear accelerators like True beam machine. Since the opening of our new radiotherapy true beam linear accelerators equipped with On-Board Imager (Varian Medical Systems, Palo Alto, USA) [1], it is possible to acquire planar kilovoltage (kV) and cone beam computed tomography (CBCT) images of the patient in the treatment position.

The kV images are faster to acquire and deliver lower exposure to the patient but, they have low contrast for soft tissues. So we can see only bony landmarks clearly. Whereas in CBCT, we can see the 3-D images of the patient as in CT scan. CBCT just as a diagnostic CT scanner which uses kilovoltage x-ray transmission principles for image generation [9, 6]. The CBCT using a kV imaging system mounted on a linear accelerator has also become an important technique for analyzing patient's setup errors. In this paper we have analyzed if there is significant differences in setup errors detected between the two techniques (planar kV vs. CBCT) for different sites in radiotherapy

Materials and methods

10 patients for different sites including brain, head and neck (H&N), thorax, abdomen and pelvis were retrospectively selected. The Varian True Beam machine was used for the study. The machine has both kV orthogonal imaging and CBCT systems. The kV imaging system consists of X-ray tube, and an amorphous silicon detector [8] as the image generation and recording system. The detector is taken out remotely to a preset image acquisition position. This system is robust and the image acquisition is faster. KV images were obtained with preset values already present in the On-board Imager (OBI) system. The preset kV and mAs values for each site were not changed manually to acquire images. The CBCT also uses a kV imaging system to acquire 3-D images. The machine rotates around the patient with the kV imager and detector in position. The CBCT uses the same principle as the CT scanner. There are two modes of operation. Half fan and full fan mode. Full fan mode is used in brain and head & neck sites. Half fan mode is used in thorax, abdomen and pelvis sites. The Varian OBI systems are very robust and have been tested in literature [2].

During the course of the treatment, each patient underwent a twice weekly kV and CBCT scanning before radiotherapy. The kV and CBCT images were taken on the same day before the treatment delivery. Imaging was done on two days per week and not daily. Images were not acquired on a daily basis due to workload on the treatment machine. We analyzed all the acquired images online using OBI software. We compared the setup deviation of kV and CBCT image with the planning CT image collected in different regions and recorded the figures of setup errors of three translational directions [10, 11]. Couch shifts in X (lateral), Y (vertical) and Z (longitudinal) directions were corrected before treatment delivery and noted [3-5]. The mean couch shifts in all directions for all sites were determined for both the imaging techniques. Values of couch shifts are available in offline review platform of eclipse software (version 13.1). Setup corrections were made before treatment if the translational setup error was greater than 2 mm in any direction.

Results

The cumulative mean couch shifts for all patients for each particular site for both imaging modalities was also found out and tabulated in table 1. The mean couch shift correction applied for each patient for different sites in each imaging modality is presented as figures. Figure 1 represents the mean shift for brain cases in kV and CBCT imaging. Figure 2 represents the mean shift for head and neck cases in kV and CBCT imaging. Figure 3 represents the mean shift for thorax cases in kV and CBCT imaging. Figure 4 represents the mean shift for abdomen cases in kV and CBCT imaging. Figure 5 represents the mean shift for pelvis cases in kV and CBCT imaging.

Table 1: Cumulative mean couch shifts for sites studied

Site	Cumulative Mean shift for CBCT Imaging(mm ± SD)			Cumulative Mean shift for kV Imaging (mm ± SD)		
	X	Y	Z	X	Y	Z
Brain	2.1±1.3	1.5±1.2	2.2±1.7	1.9±1.0	1.4±1.2	2.0±1.3
H&N	2.7±1.7	2.8±1.5	3.0±1.4	2.1±1.1	2.3±0.8	2.4±1.0
Thorax	3.3±1.1	2.5±1.1	3.0±0.9	2.7±0.6	2.1±0.6	2.6±0.7
Abdomen	3.2±1.3	3.4±1.4	3.6±1.5	2.5±1.1	2.6±0.8	2.9±1.3
Pelvis	3.5±1.4	3.7±1.5	4.2±1.2	2.5±0.8	3.4±0.8	3.8±0.9

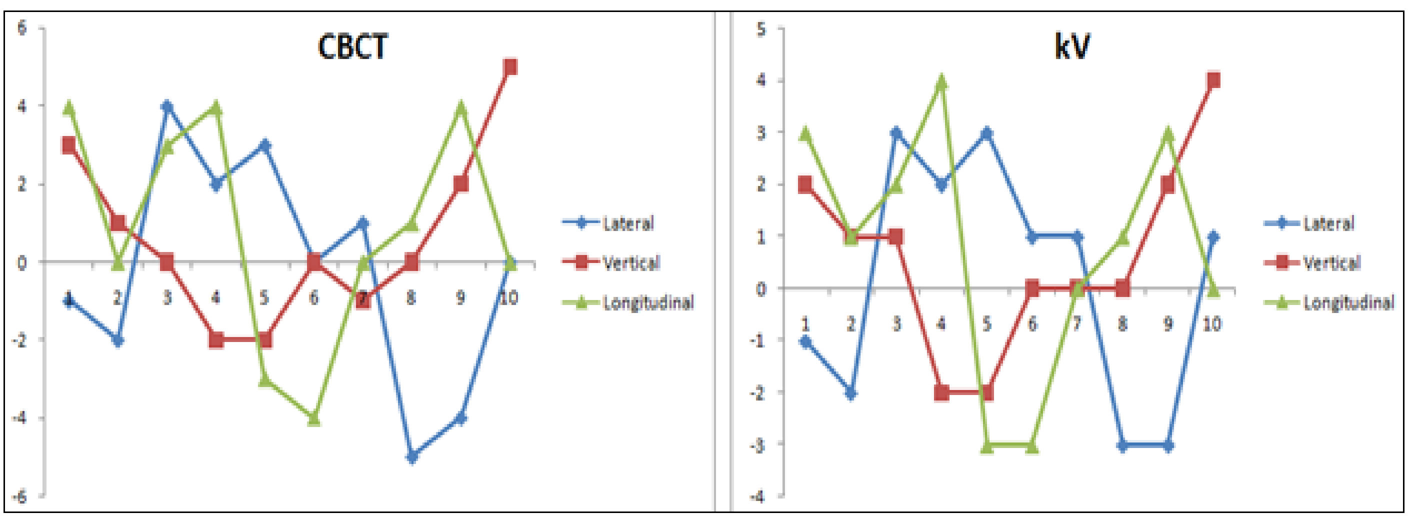

Fig 1: Mean couch shifts for Brain

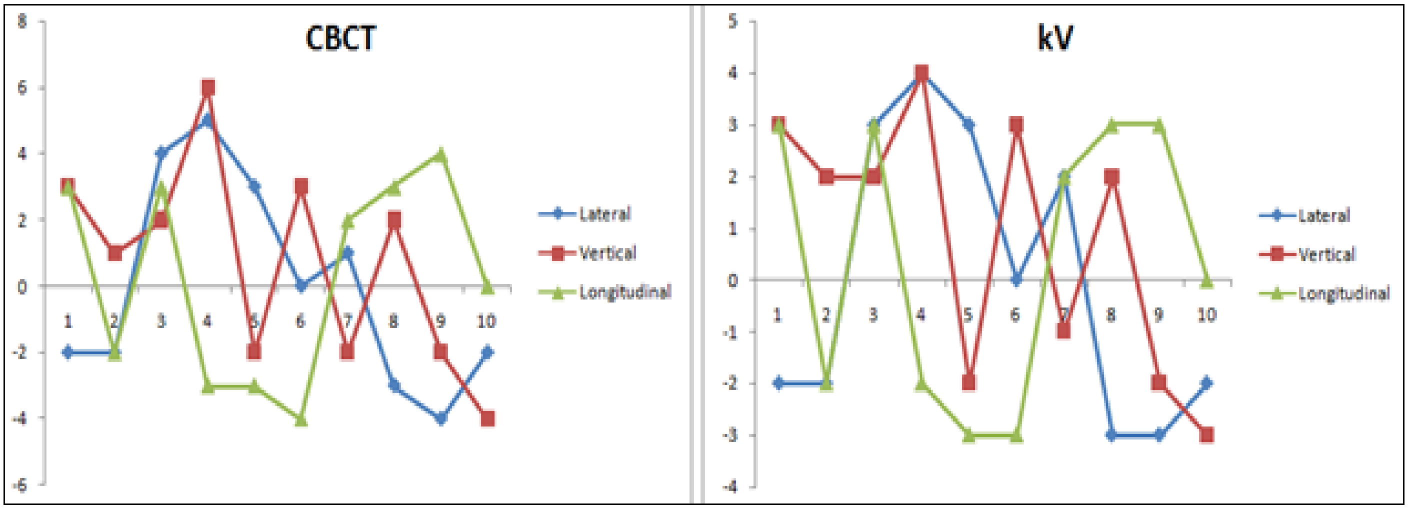

Fig 2: Mean couch shifts for Head and Neck

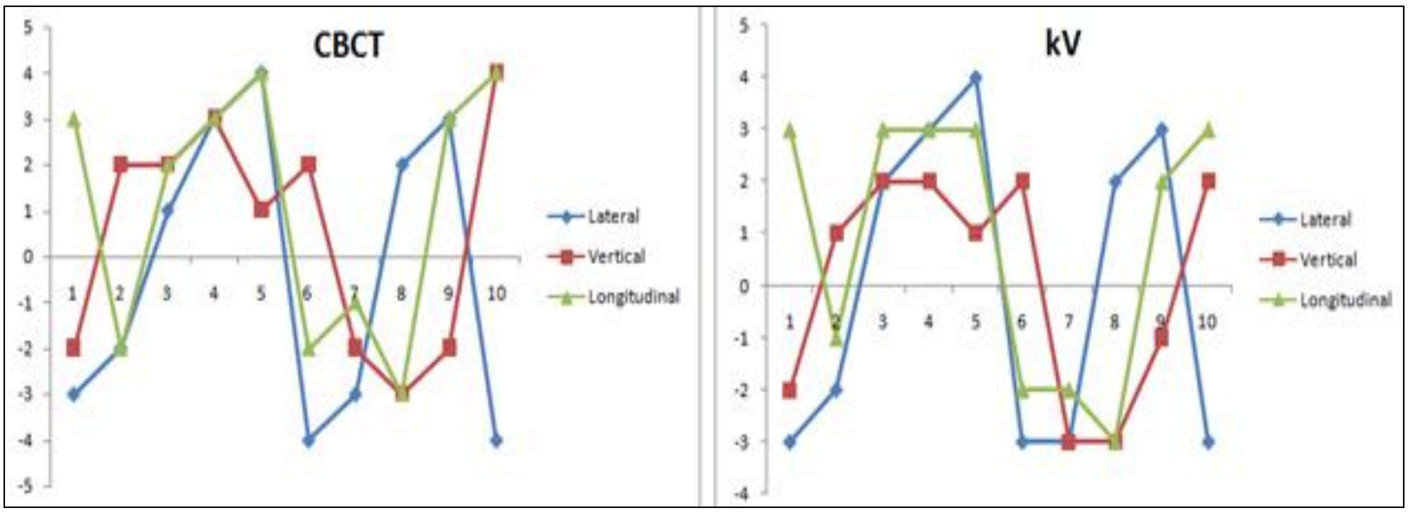

Fig 3: Mean couch shifts for Thorax

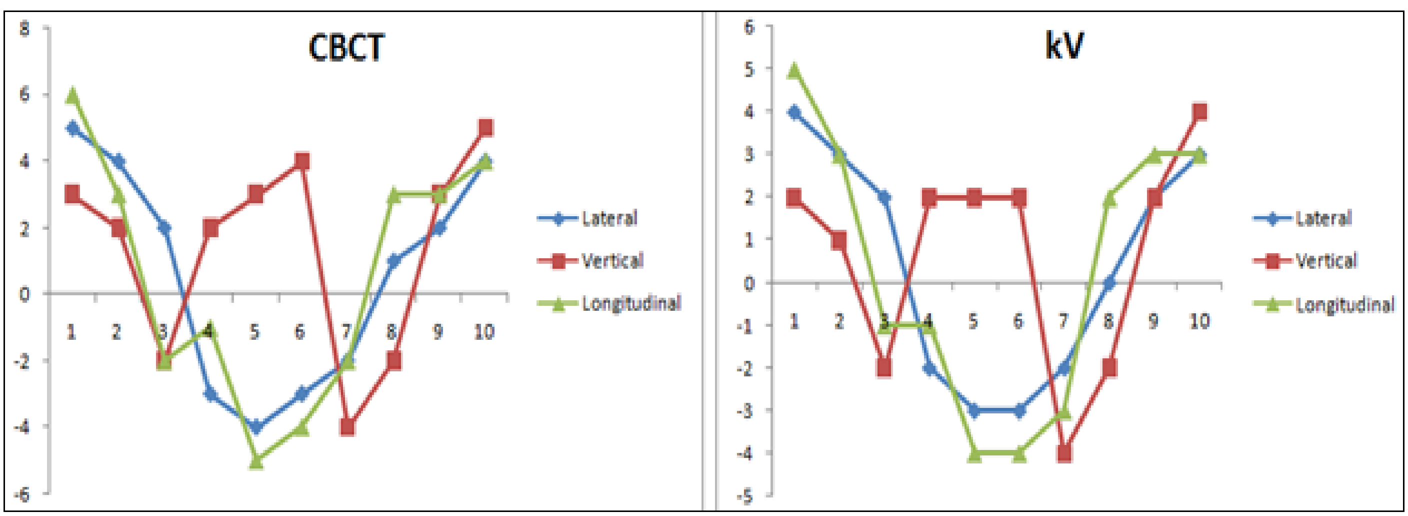

Fig 4: Mean couch shifts for Abdomen

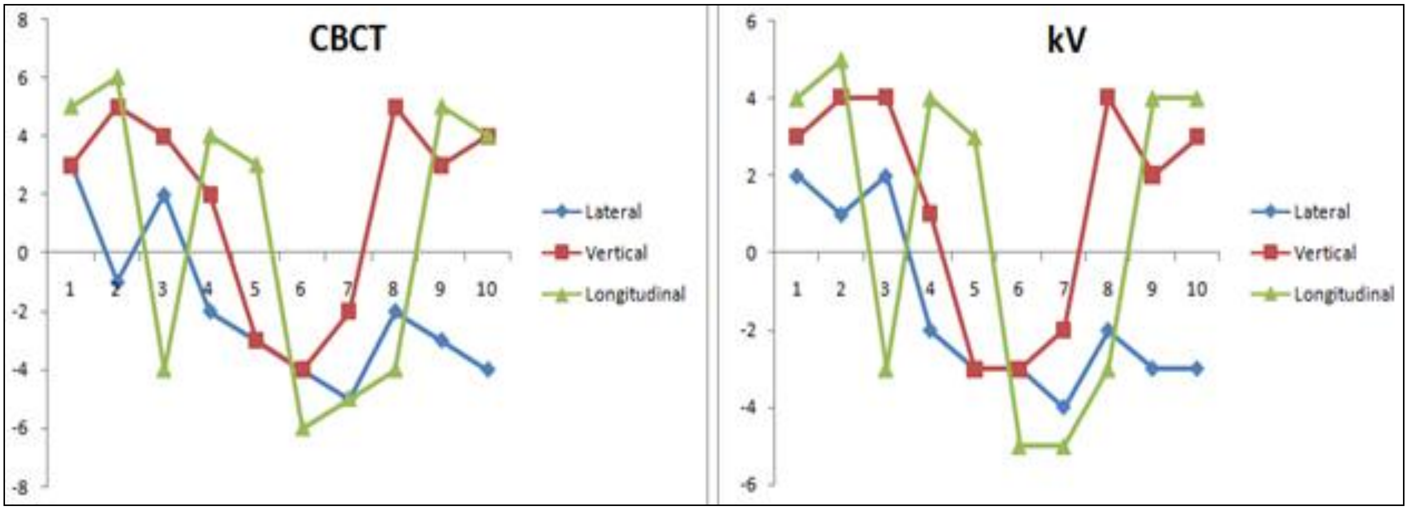

Fig 5: Mean couch shifts for Pelvis

Discussion

Two different techniques that are available commercially for pre-treatment patient set-up verification have been used in this study. kV imaging is compared with newly available CBCT imaging to determine the suitability of imaging modality for different sites. For brain case, there was the least difference between both the imaging modalities. Both kV orthogonal imaging and CBCT imaging setup analysis were comparable. In head and neck, kV imaging only bones was matched.

In CBCT the tumour was matched accurately without compromising normal structures. Whereas for thorax, pelvis and abdomen cases the difference was higher in CBCT imaging method than kV imaging method. This is because of availability of volumetric information in CBCT as compared to only bony information in kV imaging. In kV imaging, because of bony information only matching of bones is done rather than the tumour region. Whereas, in CBCT we can see both the soft tissue as well the bones similar to CT scan. Hence better matching of the region of interest that is the tumour is possible. We can proceed confidently with the treatment.

CBCT with soft tissue detection improves set-up accuracy and is currently replacing 2D verification. Safety margins can be significantly reduced by using this CBCT technology. In addition to setup verification, the systematic changes of tumor volume and shape and of the normal tissue can be monitored on a regular basis using CBCT. This in combination with intensity modulated treatment planning allows for hypo-fractionated dose escalation thereby resulting in improved rates of local tumor control with low rates of normal tissue toxicity. In brain, H&N and pelvic sites, inter-observer variability did not make any big difference with kV imaging. Whereas due to more information with CBCT, inter observer variability is also high. In pelvis site, presence of rectal filling or change in bladder filling can be monitored using CBCT data. This is really helpful in high dose prostate radiotherapy.

Conclusion

CBCT allows for pretreatment position verification and also online correction of set-up errors which improves the accuracy of patient repositioning. Although with the kV it is possible to determine setup errors by the matching of bony structures, internal movement of the organs cannot be observed. This can be done only with CBCT. We suggest that CBCT should be integrated in the image verification protocol of the institution. If we are taking CBCT images regularly, we can proceed with low CTV to PTV margins with confidence.

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