# Comparison of Patient Localization Accuracy Between Stereotactic X-Ray Based Setup and Cone Beam CT Based Setup on Intensity Modulated Radiation Therapy

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## 1. Introduction

### 1.1 Background and objectives

Radiotherapy aims to deliver a radiation dose to the tumor which is high enough to kill all tumor cells. Daily patient localization variation, internal organ motion and deformation have long been a concern for radiotherapy. To account for these variations and to make sure adequate target coverage, margins for each direction are added around clinical target volume (CTV) to define a planning target volume (PTV). However, the larger margins may increase the irradiated volume. Nowadays, image-guided radiation therapy (IGRT) is used to accurate the patient localization and to deliver the radiation correctly under monitoring the respiratory motion. Recently, there are available several IGRT technologies such as kilo-voltage (kV) and megavoltage (MV) X-ray imaging, on-board kV and MV computed-tomography (CT), in-room conventional CT, and ultrasound systems. These images are most frequently used for image-guidance: positioning of the patient or target position is evaluated by a comparison of the acquired images with the planning CT or digitally reconstructed radiography (DRR) related to the planning CT. With IGRT, the dose for tumor cells is able to be escalated because that for normal tissue becomes reduced. The principle and merits of these technologies are reported by many investigators and defined in American Association of Physicists in Medicine Report.

The NovalisTx (NTX), this is manufactured by BrainLAB (Heimstetten, Germany), is a dedicated to high precision radiotherapy system that offers a versatile combination of advanced technologies for treatment of tumors and other anatomical targets (Fig. 1). NTX is equipped with a 2.5 mm high-definition multi-leaf collimator and special patient localization system for precise tissue targeting (Fig. 1). The patient localization system distinguishes into 3 systems: BrainLAB 6D system, an on-board imager (OBI) based cone

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beam computed tomography (CBCT), and an electrical portal imaging device (EPID) based megavoltage portal vision systems (MVPV).

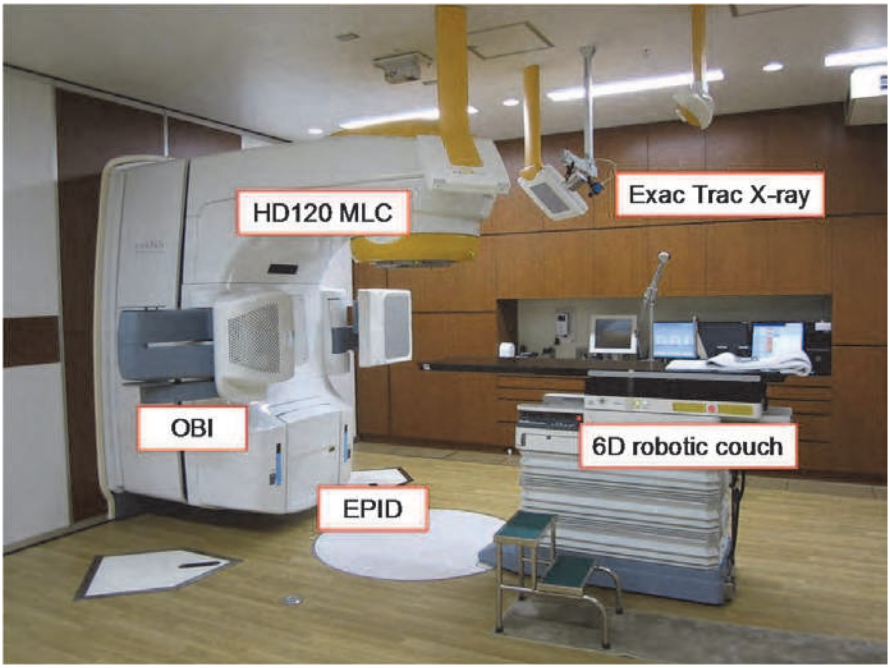

Fig. 1. Overview of Novalis Tx.
NTX is dedicated to high precision radiotherapy in combination with image-guided technology.

BrainLAB 6D system consists of ExacTrac X-ray 6D (ETX) and precise robotic couch system. ETX system is one of the commercially available patient positioning devices. ETX system combines an infrared (IR)-based tracking system with a X-ray-imaging-based system. Two IR cameras are fixed to the ceiling. Two kV X-ray beams are projected from the two X-ray tubes in oblique directions for the purpose of verifying patient localization. The procedure for patient setup with the ETX system consists of three steps: in step one, the initial patient setup according to the IR body markers is performed. Normally, the IR body markers are placed asymmetrically on the patient’s body surface. The placement of each IR marker is detected by two IR cameras, and then the IR based patient localization is completed by the automatic robotic couch movement. In step two, two X-ray images are taken and compared with a DRR by specific registration software. The DRR is reconstructed by the planning CT. The specific registration software is able to be compared with DRR to calculate the patient localization accuracy in three translational directions and three rotational angles. In step three, X-ray image-based patient localization is completely corrected by the automatic robotic couch movement.

The OBI is mounted on the gantry of the linear accelerator via controlled arms in a direction orthogonal to the therapeutic beam direction. The OBI consists of a kV-X-ray source and a flat-panel detector using amorphous silicon detector. The OBI provides three acquisition modes: 2D radiographic acquisition, 2D fluoroscopic image acquisition, and 3D CBCT. When the gantry rotates around the patient with the kV-X-ray source, volumetric data are acquired as CBCT images. The transverse images are reconstructed by the specific application software when the X-ray projected data are acquired. The CBCT images are ganarated from 360 to 655 kV-photon beam projections. There are six CBCT settings available in the system: Low-dose Head, Standard-dose Head, High-quality Head, Pelvis Spotlight, Pelvis, and Low-dose Thorax. The operator should select optimal setting when CBCT acquisition. The CBCT images are able to be compared with the planning CT to evaluate the patient localization accuracy in three translational directions and one rotational angle. The patient localization errors are then corrected by shifts of the treatment couch.

The MVPV provides a 2D image using megavoltage photon therapeutic beam and also is capable of EPID based portal dosimetry QA to accurately. Clinical users are able to use them for patient localization and can select the procedure optimally case by case. After acquisition of clinical image with the device, the image fused with the digital reconstructed radiography and/or CT images for treatment planning. It is very important for high precision radiotherapy to verify the accuracy of image fusion in this procedure. After the verification, the patient will be moved to optimal position with robotic couch system. This procedure is routine step of high precision radiotherapy with NTX system.

The purpose of this study is to evaluate setup discrepancies measured with ETX system and CBCT for patients under treatments of intensity modulated radiation therapy (IMRT) for prostate cancer.

## 2. Materials and methods

In this study, the phantom-based study as for fundamental evaluation and the patient study as for clinical evaluation were performed. For fundamental study, an anthropomorphic phantom was put on intentional positions. Next, the images obtained with ETX and CBCT systems to evaluate the accuracy of each imaging systems. For clinical study, five patients with prostate cancer were analyzed retrospectively. The patients were immobilized by vacuum pillow system and localized with ETX and CBCT each other. The patient localization discrepancies were evaluated statistically with the calculated values in each modality.

### 2.1 Fundamental study

Before patient study, we performed the phantom study using anthropomorphic phantom (Fig. 2). The phantom was modified for bone, soft-tissue, and other heterogeneity with various shapes and effective atomic numbers simulating human body.

A micro spherical ball with a diameter of 5 mm was inserted to center of the phantom. Several IR markers were placed on the surface of the phantom asymmetry. The phantom without specific localizer was scanned by multi-detector CT (Asterion: Toshiba Medical Corporation, Tokyo, Japan) with slice-thickness of 1 mm. The i-plan treatment planning workstation (BrainLAB, Heimstetten, Germany) was used to design a treatment plan from these CT scans. A round-shaped target was defined at center of the micro spherical ball. The target was defined as the planning target volume (PTV). The intentional treatment plan had a single perpendicular beam from gantry angle of 0 degree with an isocenter located at center of PTV. The coordinate of the target was transferred to ETX and CBCT application for the purpose of performing IGRT technology.

The phantom localization procedure is shown in Fig. 3. Firstly the phantom was subliminal localized using the IR markers on the surface of the phantom. Secondly the ETX-based phantom localization was performed. After the ETX-based phantom localization, another two oblique X-ray images with ETX were acquired as the localization error of ETX. Thirdly CBCT images were acquired with a slice thickness of 1 mm. The CBCT images were compared with the planning CT to verify the localization errors using online 3D registration in review software (AM workstation, Varian Medical Systems, Palo Alto, USA). The calculated errors were used as the localization error between ETX and CBCT systems. These procedures were repeated 20 times.

Fig. 2. A phantom for fundamental experiment.
A sphere ball of 5mm diameter was inserted to phantom. IR markers were put on the phantom.

### 2.2 Patient study

From September 2010 to March 2011, five patients with prostate cancer were selected for this study. All patients received IMRT treatment using NTX unit. The patients were immobilized by the vacuum cushion on the couch in a natural supine position. A planning CT image set of each patient was acquired using a CT simulator (Asteion 4, Toshiba Medical Systems, Tokyo) with a slice thickness of 2 mm. The treatment plans were designed by i-plan workstation. CTV includes prostate and seminal vesicles. The organ-at risk includes bladder and rectum.

As well as the fundamental study, IGRT techniques were used for the patient localization. The workflow of the patient localization is shown in Fig. 3. Firstly the patients subliminal localized firstly by IR markers on the surface of the patients as the skin-based setup procedure. Secondly two oblique X-ray images were acquired to carry out ETX-based patient localization. After ETX-based patient localization, another pair of two oblique X-ray images with ETX was acquired to calculate the patient localization discrepancy of ETX. Thirdly CBCT images were acquired with a slice thickness of 1 mm. In this study, no shifts were applied in between CBCT and the last pair of two X-ray images to be easier for comparison of patient position. The CBCT images were compared with the planning CT to verify the patient localization errors using online 3D registration in Varian's review software. All registrations were compared bone matching with target matching settings. The calculated errors were used as the patient localization error between ETX and CBCT systems. These procedures were performed for all patients in every fraction.

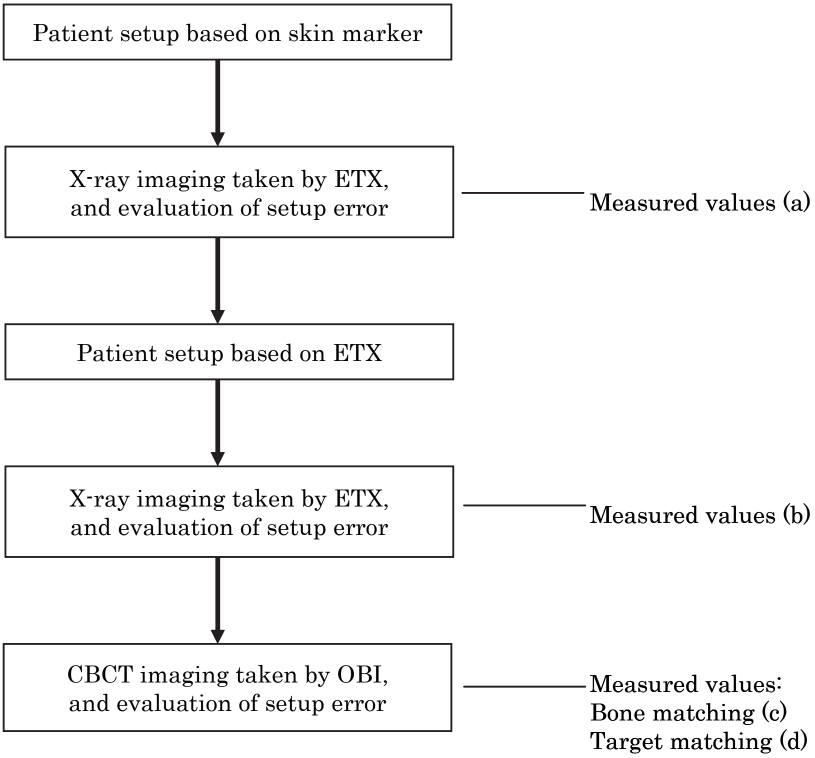

Fig. 3. Procedure of patient localization and evaluation for setup errors.

In Fig. 3, the measured values of (a), (b), (c), and (d) were transacted as the discrepancies of IR (skin)-based, 2D X-ray –based, CBCT-based referring to bony structure, and CBCT-based referring to the target, respectively. The values on the verification software were statistically analyzed.

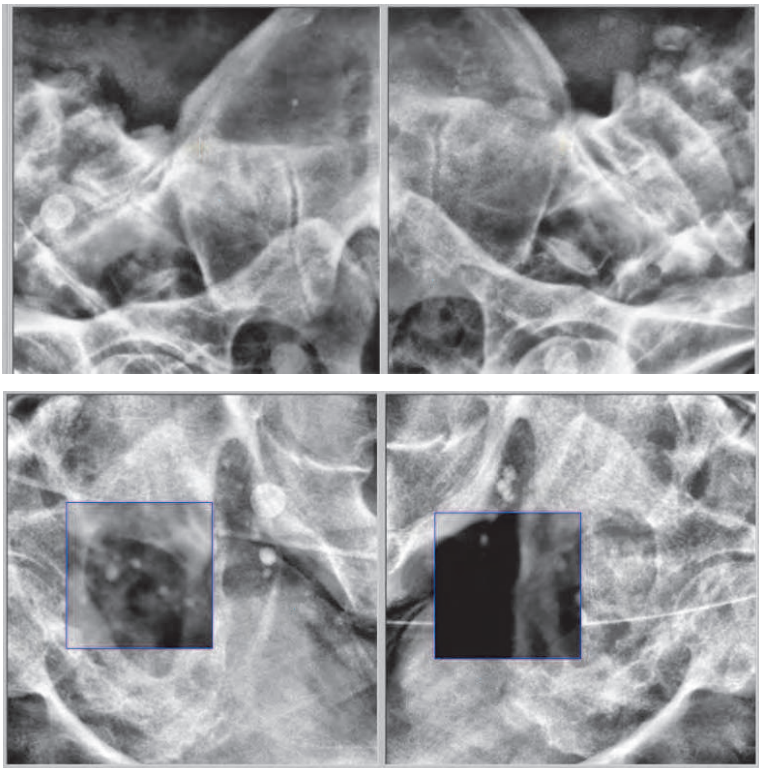

Fig. 4. The patient localization by ETX system.
Superior figure shows the snapshot of 2D oblique X-ray images.
Inferior figure shows the comparison of X-ray image (outer-ROI) and DRR (inter-ROI).

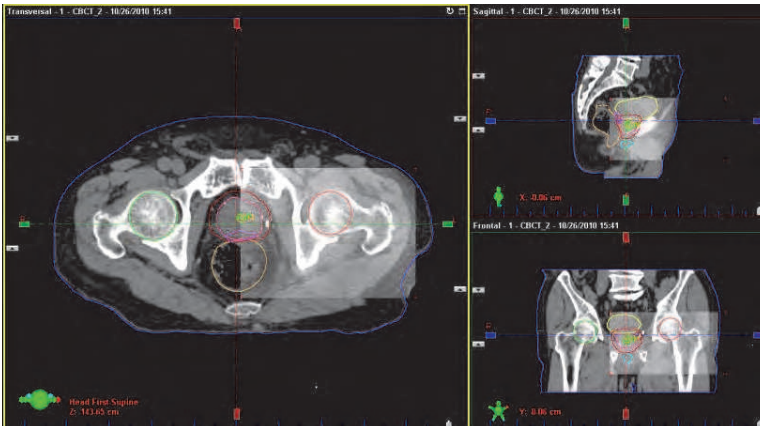

Fig. 5. CBCT guided patient registration using AM software.
The CBCT image (inter-ROI) was acquired to compare with the planning CT (Outer-ROI).

## 3. Results

This study indicates that the discrepancies between ETX and CBCT imaging systems for IMRT of prostate cancer. The results of fundamental examination indicate that translational and rotational discrepancies between ETX and CBCT were less than 0.8 mm and 0.5 degree, respectively. This means NTX system provides high precision radiotherapy and these values satisfied the tolerance of mechanical accuracy which described in American association of physicists in medicine (AAPM) task group 142.

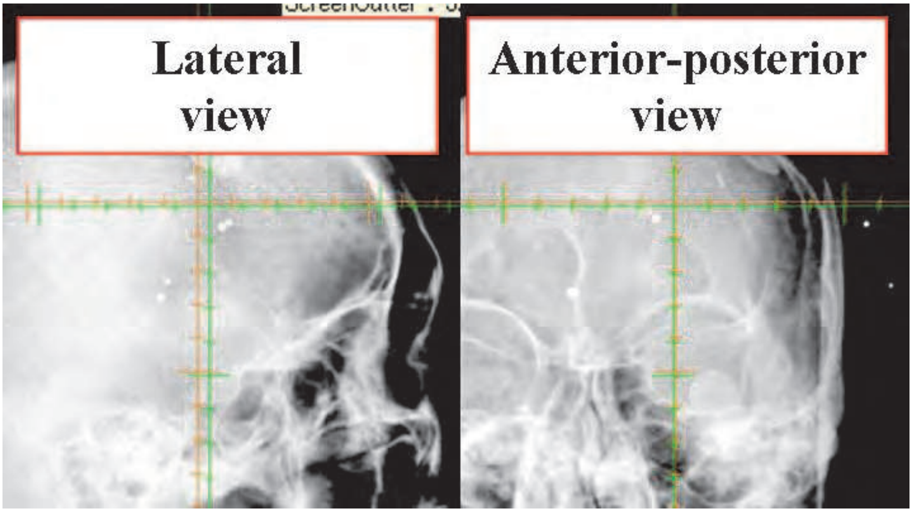

Fig. 6. OBI guided patient registration using AM software.

The results of clinical study are shown in Table 1 and 2. The setup discrepancies in translational error between skin-based setup and bony structure-based setup were measured respectively as -0.28±3.85 (mm) vertically, 147±4.48 (mm) longitudinally, -1.24±2.17 (mm) laterally shifts. The angle errors between those were less than 1 degree in all directions.

The setup discrepancies in translational error between ETX and CBCT setup referring to bony structure were measured respectively as -0.14±0.18 (mm) vertically, 0.00±0.18 (mm) longitudinally, -0.04±0.12 (mm) laterally shifts. There is no significant angle error between those setup methods. The setup discrepancies in translational error between ETX and CBCT setup referring to target structure were measured respectively as -2.04±3.26 (mm) vertically, 0.80±1.13 (mm) longitudinally, -1.01±2.12 (mm) laterally shifts. There is no significant angle error between those setup methods. With these values, the setup discrepancies in translational error between CBCT setup referring to bony structure and that referring to target structure were calculated as 2.11±3.30 (mm) vertical, 0.80±1.15 (mm) longitudinally, 1.03±2.09 (mm) laterally shifts and -0.50±0.27 (degree) rotational angle.

| | | | Direction | Sample | Average ± SD | Maximum | Minimum |
|---|---|---|---|---|---|---|---|
| ETX | Skin | Shift (mm) | Vertical | 150 | -1.21±3.74 | 6.53 | -11.05 |
| | | | Longitudinal | 150 | 1.55±4.63 | 14.53 | -10.33 |
| | | | Lateral | 150 | -0.83±2.27 | 5.55 | -8.59 |
| | | Angle (degree) | Vertical | 150 | 0.46±1.00 | 2.99 | -1.93 |
| | | | Longitudinal | 150 | 0.32±0.83 | 3.53 | -2.87 |
| | | | Lateral | 150 | 0.59±1.50 | 5.52 | -2.32 |
| | Bone | Shift (mm) | Vertical | 142 | -0.93±0.76 | 0.99 | -4.28 |
| | | | Longitudinal | 142 | 0.01±1.09 | 2.15 | -2.19 |
| | | | Lateral | 142 | 0.40±0.89 | 3.13 | -2.30 |
| | | Angle (degree) | Vertical | 142 | 0.50±0.98 | 3.04 | -1.94 |
| | | | Longitudinal | 142 | -0.06±0.22 | 0.77 | -0.86 |
| | | | Lateral | 142 | 0.07±0.41 | 3.19 | -0.94 |
| | Skin vs Bone | Shift (mm) | Vertical | 142 | -0.28±3.85 | 7.44 | -10.87 |
| | | | Longitudinal | 142 | 1.47±4.48 | 15.48 | -9.91 |
| | | | Lateral | 142 | -1.24±2.17 | 4.76 | -10.61 |
| | | Angle (degree) | Vertical | 142 | -0.03±0.20 | 1.39 | -1.04 |
| | | | Longitudinal | 142 | 0.35±0.92 | 4.01 | -2.43 |
| | | | Lateral | 142 | 0.52±1.45 | 4.45 | -2.48 |

Table 1. Overall analysis of setup errors evaluated by ETX

| | | | Direction | Sample | Average ± SD | Maximum | Minimum |
|---|---|---|---|---|---|---|---|
| CBCT | Bone match | Shift (mm) | Vertical | 137 | -0.14±0.18 | 0.5 | -0.6 |
| | | | Longitudinal | 137 | 0.00±0.18 | 0.4 | -0.4 |
| | | | Lateral | 137 | -0.04±0.12 | 0.3 | -0.4 |
| | | Rotation (degree) | | 137 | 0.10±0.21 | 1.0 | -1.0 |
| | Target match | Shift (mm) | Vertical | 114 | -2.04±3.26 | 7.6 | -3.8 |
| | | | Longitudinal | 114 | 0.80±1.13 | 2.4 | -1.4 |
| | | | Lateral | 114 | -1.01±2.12 | 3.3 | -2.5 |
| | | Rotation (degree) | | 114 | -0.80±0.50 | 1.0 | -1.00 |
| | Bone vs Target | Shift (mm) | Vertical | 114 | 2.11±3.30 | 7.1 | -3.2 |
| | | | Longitudinal | 114 | 0.80±1.15 | 2.5 | -1.6 |
| | | | Lateral | 114 | 1.03±2.09 | 2.3 | -2.2 |
| | | Rotation (degree) | | 114 | -0.50±0.27 | 1.0 | -1.0 |

Table 2. Overall analysis of setup errors evaluated by CBCT

## 4. Discussions

The geometric and localization accuracy between ETX and CBCT systems was compared by determining the subliminal localization errors. For the evaluation of geometrical accuracy and patient localization accuracy, the phantom examination and clinical patient's examination were performed, respectively.

In clinical situation, ETX and CBCT images are majorly applied to the patient localization before treatment. These are useful to be close to origin of the coordinate of PTV. In addition, it is possible to monitor the intra-fraction organ motion if we use them during treatment. The advantages of ETX are easier registration with bone matching, short-time patient localization, and low imaging dose compared to CBCT. The advantages of CBCT are the availability of 3D image information, and visualization of soft-tissue and/or target such as pelvis lesion. In addition, there is an opportunity for online re-planning and adaptive radiation therapy. With careful consideration and strategy of image guidance in radiation therapy, each modality has been widely adopted to provide real-time geometric and anatomic information with the patient in treatment position.

However, the disadvantage of ETX and CBCT systems is an excessive radiation dose when used routinely in radiation therapy. The concomitant dose should be carefully considered and recorded when designing treatment imaging process in order to remain faithful to the radiology principle of "As Low As Reasonably Achievable (ALARA)". Because the evaluation of cumulative imaging dose is non-trivial problem, a separate AAPM Task group 75 has produced a report analyzing the radiation dose delivered during IGRT. According to the report, the imaging dose of ETX and for body lesion was 0.551 mGy. On the other hand, the imaging dose of CBCT for pelvis lesion was 60 mGy as $CTDI_{air}$. Song et al. (2008) investigated the CBCT imaging dose in comparison of Elekta XVI system and Varian OBI CBCT systems. They summarized that the average dose for XVI system ranged from 0.1 to 3.5 cGy with the highest dose measured in prostate region. The average dose for the OBI system ranged from 1.1 to 8.3 cGy with the highest dose measured. The reason of this difference was the availability of half-scan in XVI system. Therefore there is no significant change of imaging dose between different vendor's CBCT systems. Operator of CBCT should select optimal setting of

The general acceptable imaging dose management is represented by the acronym ALALA. We should use IGRT devices with acceptable effective dose without reducing the image information. For diagnostic image, the relationship between exposure condition and image quality is trade it off. To gain high contrast for the image, the expose dose should be increased. In IGRT, the beam alignment information derived from images used for the targeting of tumors is less dependent on image quality because it is dependent on imaging frequency to observe the constancy of patient localization before/during treatment. In radiotherapy process, a large number of the images will yield smaller errors in dose alignment. On the other hand, a large number of the images will add more imaging radiation dose to normal tissue. The frequency and settings of IGRT process should be optimized with considering the relationship between imaging dose and the benefit such as obtaining the alignment error.

There are three modalities for IGRT including ETX, CBCT and EPID in NTX system. Hence, the localization accuracy using NTX is able to increase. This characteristic advantage of NTX can reduce the safety margin adding to CTV.

When initial corrections of the patient localization were done only with the ETX system, it is sometimes not sufficient to answer the question whether the localization of PTV is correct or not because ETX system is only possible to detect bone and/or high contrast marker in 2D-to-3D matching. The patient localization using CBCT system can be performed based on both bony and soft-tissue matching.

However, this study was a preliminary evaluation of patient localization accuracy of multi-modality IGRT in prostate cases. Therefore the number of samples was not enough to construct the evidence. Additional evaluation with more patients and further images should be analyzed to ensure the usefulness and organ motion. In addition, this evaluation included only prostate cases. It would be exciting to extend this evaluation to other regions.

## 5. Conclusions

Image guidance with various technologies is recently applied to radiotherapy. The characteristic advantage of each technology provides the accurate patient localization with guidance of body surface, bony and target structures. Accuracy of CT scanning for treatment planning might be consequently sure to construct the accurate coordinate scale of image guidance for patient localization. Furthermore,

The ETX system provides speedy patient localization with high precision and accuracy. However, it will not detect the soft tissue movement. For accurate patient localization in IMRT for prostate cancer, it requires to obtain clear images with each device and to fuse each image correctly. The optimal selection of imaging device is important and leads to reduce setup margins.

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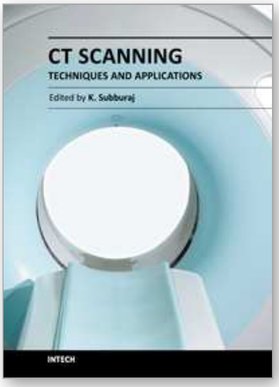

**CT Scanning - Techniques and Applications**
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Since its introduction in 1972, X-ray computed tomography (CT) has evolved into an essential diagnostic imaging tool for a continually increasing variety of clinical applications. The goal of this book was not simply to summarize currently available CT imaging techniques but also to provide clinical perspectives, advances in hybrid technologies, new applications other than medicine and an outlook on future developments. Major experts in this growing field contributed to this book, which is geared to radiologists, orthopedic surgeons, engineers, and clinical and basic researchers. We believe that CT scanning is an effective and essential tools in treatment planning, basic understanding of physiology, and and tackling the ever-increasing challenge of diagnosis in our society.

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The European document: Cone beam CT for dental and maxillofacial radiology. Evidence based guidelines8 also provides comprehensive recommendations that are useful for handling CBCT devices. In terms of image quality, this document focuses on the use of one single phantom for image quality measurements. 20.Â  X-ray tube potential Using a digital kV meter, the x-ray tube potential over a range of values that contain all the clinically used kV settings is measured and must be within Â±5 kilovolts or Â±10 percent, whichever is greater, of the indicated value8,26,27,28. 21. CHAPTER 2. Initial patient setup used the infrared positioning system with body markers. Stereotactic X-ray imaging was then performed and correction was made if the initial setup error exceeded predetermined institutional tolerances, 1.5 mm for translation and 2Â° for rotation. Three additional sets of verification X-rays were obtained pre-, mid-, and post-treatment for all treatments. Results: Intrafraction motion regardless of immobilization technique was found to be 1.28 Â± 0.57 mm. The mean and standard deviation of the variances along each direction were as follows: Superior-inferior, 0.56 Â± 0.39 mm