RESEARCH ARTICLE

The accuracy of cone beam computed tomography (CBCT) technique as an image-guided radiation therapy (IGRT) technique

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Abstract

Objective: To measure the setup error of the patient's positioning using cone-beam computed tomography during radiation therapy treatment fractions by finding systematic, random errors and the planned target volume errors.

Method: The observational, longitudinal cohort study was conducted at the Al-Warith International Cancer Institute, Karbala, Iraq, from January to May 2022, and comprised patients with head and neck cancer who underwent radiation therapy.

The oncologist delineated and the medical physicist planned. Then the medical physicist modified the positioning system using the cone beam computed tomography option workstation. The vertical value was taken in anteroposterior site, longitudinal in superoinferior, and lateral in e mediolateral. The SPSS 25 were used to analyse data.

Results: Of the 31 patients, 17(54.8%) were females and 14(45.2%) were males. The overall mean age was 48.3 ± 10.22 (range: 4-77 years), and 22(70.96%) patients had been treated previously with chemotherapy. The lateral shifting inaccuracy 2.501mm was above the limit, whereas the vertical shifting 1.164mm was within acceptable limits (±2mm). The longitudinal shifting had the smallest displacement 0.436mm. Random error displayed longitudinal moving 1.965mm, lateral shifting 0.623mm and vertical shifting 0.276mm. The planned target volume margins were too wide in longitudinal shifting 3.333mm. Vertical shifting 0.481mm was greater than lateral 1.092mm, but both were within limits (±2mm).

Conclusion: Radiation-induced errors in normal tissues must be reduced by reducing planned target volume margins, especially for longitudinal and lateral directions.

Key Words: Cone-beam, Oncologists, Radiotherapy, Neoplasms.

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Introduction

Accurate patient and beam positioning is critical for successful therapy. During therapy, however, patient setup problems might arise. To guarantee optimal patient placement relative to the treatment beam, image-guided radiotherapy (IGRT) is used[1-4].

The most critical component of cone-beam computed tomography (CBCT) is the X-ray source, which may be either kilovolt (30-140kV) or megavolt (1-6MV). The collimator travel range, target angle and focal spot parameters vary as per the CBCT design. The Varian source On-Board Imaging (OBI) is a spinning anode X-ray tube with oil cooling (0.4mm and 0.8mm)[5].

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To see how the patient was positioned during treatment, CBCTs are used to match up images of the patient. The image quality is determined by several factors, like contrast-to-noise ratio, high-contrast resolution, low-contrast resolution, picture uniformity, and noise. Current CBCT systems cannot see very well and are not very sensitive. The geometry of a project is called projection geometry[6]. The number of CB projections from circular orbits and reconstruction method approximations are matters of concern. CB geometry lacks enough circular orbit projections to depict volume correctly[4].

In order to guarantee that the clinical target volume (CTV) receives a tumoricidal dose, the International Commission on Radiation Measurements and Units (ICRU) recommends allocating a planned target volume (PTV) produced by giving a margin to the CTV[2,4,7,8].

Uncertainties in contouring the tumour volume, the patient immobilisation system, interfraction patient setup mistakes, intrafractional tumour motion errors, and other factors impact the PTV margins. When using a complicated radiation treatment, it is necessary to check patient setup faults for various anatomical locations and different systems. It is beneficial because a patient may be evaluated in the position in which they would receive radiation therapy either shortly before or while they are receiving treatment. This can be done at any point in time throughout the treatment process. The motion of the respiratory organ, which is one of the largest intrafractional organ motions, often causes the image to be distorted, and, as a result, provides the patient's three-dimensional (3D) positional accuracy based on the patient's bony anatomy and/or soft tissue visualisation, which aids in determining the optimal PTV margins while sparing the nearby critical structures[9-11].

Amplified scatter artifacts degrade kV CBCT image quality and diagnostic information. Different CBCT acquisition strategies have been studied to identify picture quality-degrading factors[5,6]. According to a study, a 72.8 milliampere current for each second (mAs) is a safe dosage for seeing low-contrast objects in low-dose CBCT. Detecting high-contrast objects with a diameter of 3mm require 12.2mAs overall. As a result, the quality of the CBCT image has the potential to be a limiting factor in terms of patient dose[12].

Dietrich et al.[13] evaluated the association between internal (diaphragm movement) and external (data from a respiratory gating system) information concerning breathing phase and amplitude using an inline CBCT scanner, and comparison between the reconstructed 4D CBCT images and the matching 4D CT images used for treatment planning gave the necessary data for calculating potential setup faults.

The performance characteristics and quality assurance components of the kV-CBCT technology were assessed by Saw et al.[14] The alignment of the radiographic imaging equipment was determined to be within 1mm using image-guided instruments. Using well-designed processes and phantoms, the number of IGRT system parameter checks for quality assurance may be quickly completed[14].

The current study was planned to measure and reduce the setup error of the patient's positioning using CBCT during the radiation therapy treatment fractions by finding systematic, random and margin errors of PTV.

Materials and Methods

The observational, longitudinal cohort study was conducted from January to May 2022 at the Al-Warith International Cancer Institute, Karbala, Iraq, where the CBCT had been recently introduced and needed to be calibrated to ensure that patients received safe treatment. The pregnant women and patients with a benign tumour were excluded from the study.

After approval from the ethics review committee of the College of Medicine, Mustansiriyah University, Baghdad, Iraq, the sample was raised using convenience sampling technique. Those included were patients with head and neck cancer who underwent 3D conformal radiation therapy (3D-CRT) who had been sent for CBCT scan prior to irradiation for positioning.

The 3D-CRT planning was generated for patients using Eclipse (manufacture by Varian, US) treatment planning system (TPS) to increase the dose to the tumour while protecting the organs at risk (OARs). A medical physicist performed the delineation process and planning, while an oncologist checked and approved the plan. The patients' plans were exported to the linear accelerator (LINAC) (manufacture by Varian, US) for patient positioning setup. The medical physicist adjusted the positioning system from the workstation of the plan Eclipse from among the CBCT options for the fractions. This step was repeated for each fraction. The shifting parameters were measured for each fraction and each patient in 3D. The vertical view was obtained from the anteroposterior (AP) site, longitudinal from the superoinferior (SI), and lateral from the mediolateral (ML). The kV ranged 50-140 with half fan-beam type and full trajectory. The parameters of mAs, computed tomography dose index volume (CTDIvol), and dose length product (DLP) ranged 100-1687.50, 0.94-36.79 and 20.1-787.3, respectively.

The analysis error was applied on CBCT and calculated for each plan. The systematic and random errors were calculated using the displacement in 3D. The systematic errors (Σ) were defined as the standard deviations (SDs) between the planned patient position and average patient position of 3 consecutive treatment fractions, which means it was the SD of all individual means for each direction.

The random errors (σ) were defined as deviations between different treatment fractions taken weekly during the treatment. It was determined by calculating the root mean square of the individual SD of all patients. In addition, the frequency of 3D vector lengths was quantified and the magnitude of the 3D vector was calculated.

The SD of the average value of individual mean setup error along the vertical, longitudinal and lateral directions was used to evaluate Σ, while σ was estimated by calculating the root mean square of the individual standard deviations along the vertical, longitudinal and lateral axes[15].

The calculation of the PTV margins was performed using the van Herk formula[16]:

The SPSS 25 were used to analyse data ad calculate the equations.

Results

Of the 31 patients, 17(54.8%) were females and 14(45.2%) were males (p>0.05). The overall mean age was 48.3 ± 10.22 (range: 4-77 years), and 22(70.96%) patients had been treated previously with chemotherapy (p>0.05) (Table 1).

Table-1: Patient characteristics.

Gender	
Male	14 (45.2 %)
Female	17 (54.8 %)
Age (years)	48.3 ± 10.22 (4 – 77)
Chemotherapy	
Treated	22 (70.96%)
Not Treated	9 (29.04 %)

The lateral shifting inaccuracy 2.501mm was above the limit, whereas the vertical shifting 1.164mm was within acceptable limits (±2mm). The longitudinal shifting had the smallest displacement 0.436mm. Random error displayed longitudinal moving 1.965mm, lateral shifting 0.623mm and vertical shifting 0.276mm. The PTV margins were too wide in longitudinal shifting 3.333mm. Vertical shifting 0.481 was greater than lateral 1.092mm, but both were within limits (±2mm) (Table 2).

Table-2: Systematic errors (Σ), random errors (σ) and planning target volume (PTV) margins..

Treatment Site		Head and Neck	
Direction	**Vertical (AP)**	**Longitudinal (SI)**	**Lateral (ML)**
Systematic Error (mm)	1.164	0.436	2.501
Random Error (mm)	0.276	1.965	0.623
PTV margins in mm	0.481	3.333	1.092

AP: Anteroposterior, SI: Superoinferior, ML: Mediolateral.

Discussion

The current study employed CBCT to examine the inter-fractional setup errors for head and neck treatment sites on 31 patients. The PTV margins were calculated using the van Herk formula[1].

Uncertainties in target volume movements should be taken into consideration. Using contemporary image-guiding systems, it is possible to reduce uncertainty due to setup variation by minimising interfraction and intrafraction motions. However, for these approaches to be properly implemented, an appropriate margin around the target must be given.

The current study found the systematic and random error distances in three directions. A prior study by Hamilton D. G et al.[17] suggested somewhat higher values in longitudinal and lateral directions than the values found in the current study. These discrepancies are related to the increased use of CBCT and the increased number of patients who received therapy at various treatment locations.

Ragab et al. found that vertical, longitudinal and lateral directions were 0.27cm, 0.55cm, and 0.36cm, respectively, for head and neck cases. Overall, compared to the breast, thorax, abdomen and pelvic regions, systematic and random errors in the head and neck were minor because these treatment sites are static, and the regular differences in setup geometry are limited[18].

Cone-beam geometry covers a larger field of view than fan-beam CT in a single rotation. CBCT detects more dispersed radiation than main radiation, resulting in low Hounsfield units (HU) in the middle of the reconstructed images. The rebuilt CBCT image loses homogeneity, contrast and noise. Choosing optimal scanning settings and properly positioning and stabilising the patient helps reduce image artefacts in CBCT images. CBCT scans provide a considerable dose. As CBCT use grows, it is vital to understand its dosimetry[14].

Our findings agree with those of Kamath et al., who analysed and contrasted the picture quality features of two CBCT systems popularly used and readily accessible on the market: the X-ray Volumetric Imager (XVI) and the On-Board Imager (OBI), and concluded that OBI generally delivered higher imaging doses than XVI ([5]).

Limitation: The current study has its limitations as the sample size was not calculated which could have affected the power of the study.

Conclusion

The setup faults varied according to the location of the tumour. Image guidance was found to be a powerful tool for determining patient setup issues. Immobilisation devices of high quality and strict patient setup standards might further minimise PTV margins.

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