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Use of Cone-Beam CT in Whole-Brain Radiation Therapy: Time and Economic Assessment

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ABSTRACT

Purpose: Whole-brain irradiation is commonly used for patients with multiple brain metastases and poor performance status, often requiring rapid treatment planning. This study compares cone-beam computed tomography (CBCT)-based planning to conventional CT simulation for whole-brain radiotherapy (RT) to evaluate dosimetric differences and cost-effectiveness. Materials and Methods: Ten patients receiving palliative whole-brain RT at Acıbadem Atakent Hospital were included. Both CT simulation and CBCT images were used to create 3D conformal RT (3DCRT) plans. Brain and lens contours were marked, and dose calculations were performed with 6MV photon energy. Plans were normalized to ensure 95% of the target volume received 99,5% of the prescribed dose. Key metrics, including conformity index (CI), lens doses, maximum brain dose, brain volume, Hounsfield Units (HU), and monitor units (MU), were compared using the Wilcoxon test. Findings: Results showed no significant differences in lens contouring or CI between CBCT- and CT-based plans. Brain volume was significantly larger in CBCT images, and CBCT-based plans had higher maximum doses and MU values due to HU adjustments. However, HU values themselves did not differ significantly. Conclusion: CBCT-based planning demonstrated shorter processing times and reduced workload, making it more efficient economically. With proper calibration, CBCT planning offers a viable alternative for urgent whole-brain RT planning, providing comparable dose and plan quality to CT-based methods.

Keywords: *Radiotherapy, whole-brain irradiation, computed tomography, cone-beam*

INTRODUCTION

Whole-brain irradiation is primarily delivered to patients with multiple brain metastases and low performance status. In some cases, urgent planning is necessary, with treatment initiation on the same day. Image-guided radiotherapy (IGRT) methods use kilovoltage (kV-kV), megavoltage (MV), or cone-beam computed tomography (CBCT) imaging. CB-CT is computed tomography (CT) imaging obtained with a 360-degree rotation around the patient by robotic arms used in kV-kV acquisition. Unlike conventional CT, which uses a fan beam, CBCT uses a cone beam, which can lead to decreased image quality at the edges of the field. The purpose of this study is to compare whole-brain radiotherapy (RT) planning using CBCT images with conventional CT-simulation-based planning. The main objective is to analyze any differences in treatment outcomes and then compare the methods in terms of cost-effectiveness.

METHODS

This study was designed at Acıbadem Atakent Hospital. CT simulation images and CBCT images taken during treatment for 10 patients receiving palliative whole-brain irradiation were used. CBCT images were acquired using the TruBeam SDx (Varian, USA) device, whereas CT-Simulation images were obtained using the Siemens Somatom Flash (Siemens, Germany) device in the radiology department situated on a separate floor within the same facility. For each patient, 3D conformal radiotherapy (3DCRT) plans were created using both CT and CBCT images. The brain, right lens, and left lens were contoured on both CT and CBCT images. External dose planning calculations were conducted on both sets of images using 6MV photon energy. The target volume was normalized so that 95% of it would receive 99,5% of prescribed dose. In both planning approaches, the maximum doses were kept below 108%. Since none of the values followed a normal distribution, a Wilcoxon analysis was performed to determine whether there were a statistically significant.

RESULTS

In this study, the conformity indexes (CI), right and left lens doses, maximum brain doses, brain volumes, Hounsfield units (HU), and monitor unit (MU) values were compared (Table 1). Also, it was shown that compared planning values for statistically in Table 2. No significant difference was found between the right and left lens contours. The brain volumes delineated in the CBCT image were significantly larger (Figure 1). Consequently, the maximum hot points were significantly higher in CBCT plans. There was no significant difference in Hounsfield Unit (HU) values; however, the Monitor Unit (MU) values were higher in CBCT-based plans compared to CT images. No significant difference was observed in the Conformity Index (CI) between the two 3DCRT plans (Figure 2). The conformity indexes (CI), right and left lens doses, maximum brain doses, brain volumes, Hounsfield units (HU), and monitor unit (MU) values were compared (Table 1). Since none of the values followed a normal distribution, a Wilcoxon analysis was performed to determine whether there were a statistically significant differences (Table 2). In the cost evaluation, there was a significant difference between CT-simulation imaging and CBCT imaging in terms of planning (48TL CT with SUT code; CBCT 36.76 with SUT code, 1245 TL without insurance for CT/CBCT simulation). The mean simulation time utilizing CBCT was 26 min, while the mean CT simulation time was 72 min.

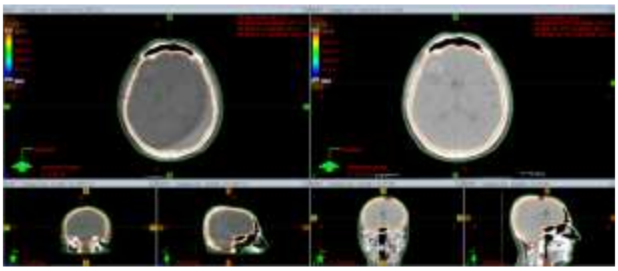

Figure 1: Dose distribution for CBCT planning

Table 1. Data of CT and CBCT

Treatment Planning	H	Avarage	Standard Deviation	P
CBCT MU	10	336,00	22,00	0,005
CT MU	10	326,00	26,96	
CBCT CI	10	0,78	0,02	0,395
CT CI	10	0,77	0,04	
CBCT Lens R	10	0,12	0,04	0,059
CT Lens R	10	0,10	0,04	
CBCT Lens L	10	0,12	0,04	0,011
CT Lens L	10	0,20	0,06	
CBCT Maximum	10	107,00	1,43	0,005
CT Maximum	10	105,00	2,05	
CBCT Brain	10	1344,00	132,68	0,005
CT Brain	10	1307,00	122,32	
CBCT HU	10	89,05	12,62	0,008
CT HU	10	41,28	15,40	

Table 2. Comparation of CBCT and CT data

Treatment Planning	H	Avarage	Standard Deviation	P
CBCT MU	10	336,00	22,00	0,005
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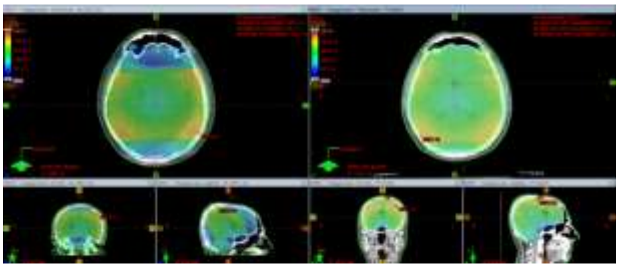

Figure 1: Dose distribution for 3DCRT planning

DISCUSSION

The present study finds no significant differences in dose and plan quality between CBCT- and CT-based planning, but notes that CBCT plans exhibit higher monitor unit (MU) values due to HU discrepancies. This aligns with Huaiqun Guan et al., who emphasize the critical role of accurate HU calibration in CBCT, demonstrating that improper calibration can lead to significant dosimetric deviations (up to 6,70%). They recommend avoiding certain calibration methods, such as using the Catphan 500, and advocate for more robust calibration processes.[1] Similarly, Venkatesan et al. identify HU variations in CBCT compared to fan-beam CT (FBCT), particularly in peripheral regions due to ring artifacts and scatter. While these differences do not significantly impact dose accuracy for symmetric/asymmetric fields (<1,20%) or IMRT plans (<2,00%), they underline the limitations of CBCT for primary planning, suggesting enhancements to reconstruction algorithms and careful artifact assessment. [2] Yong Yang et al. further validate the feasibility of CBCT for dose calculations by calibrating it against planning CT using a Catphan-600 phantom. They note good agreement in static phantoms but emphasize the impact of motion artifacts on dosimetric accuracy, necessitating adaptive strategies for moving targets.[3] The findings from the provided study and the three referenced studies highlight the common challenge of Hounsfield Unit (HU) calibration in using cone-beam computed tomography (CBCT) for radiotherapy treatment planning and dose calculations. Hiroshi Watanabe et al. mitigates artifacts in CBCT images by overriding the lung density, achieving a dose error of ±1% between the recalculated CBCT dose and the treatment plan, thus providing a valuable tool for accurate dose calculation in Adaptive Radiotherapy (ART). [4] Kavitha Srinivasan et al. asserts that the increasing utilization of Cone-beam Computed Tomography (CBCT) in radiotherapy is attributed to the integration of kilovoltage systems in modern linear accelerators, enhancing its role in Image-Guided Radiotherapy (IGRT) and facilitating real-time treatment plan adjustments for Adaptive Radiotherapy (ART). This paper examines the primary applications of linac-mounted CBCT in radiation therapy, focusing on planning, dose calculation, and key challenges such as imaging artifacts, dose, and image quality, while providing insights into its therapeutic applications for medical physicists and oncologists. [5] Yi Rong et al. emphasizes that accurate calibration of Hounsfield units (HU) to electron density (HU-density) is crucial for dose calculations, and while on-board kV cone beam computed tomography (CBCT) is primarily utilized for patient positioning, it possesses potential for dose calculation as well. This study investigates the impact of imaging parameters (mAs, source-imager distance [SID], and cone angle) and phantom size on HU accuracy and HU density calibration, and proposes a site-specific calibration method that improves dose accuracy by approximately 2% in adaptive radiotherapy when applied to CBCT images. [6] This study compares treatment planning based on CT (Computed Tomography) and CBCT (Cone Beam Computed Tomography) images. The findings indicate no significant difference in dose and quality between the two methods. However, treatment planning utilizing CBCT images resulted in higher MU (monitor unit) values due to HU (Hounsfield Unit) values. This discrepancy can be addressed through CBCT calibration [7]. In terms of cost, planning using CBCT imaging is approximately 3 times cheaper than planning using CT simulation. Since the CT device is not available in our radiotherapy department, planning with CBCT imaging is completed in a shorter time and creates less workload. Therefore, especially in busy clinics and in cases where patient mobilization cannot be ensured, performing whole brain treatment planning over CBCT with CBCT calibration can be considered as an option in terms of treatment planning [8,9,10].

CONCLUSION

In conclusion, while CBCT is a viable tool for radiotherapy planning, particularly for adaptive and palliative applications, consistent calibration, artifact management, and further algorithm improvements are crucial to ensure accuracy and reliability across various clinical scenarios. In emergency cases and when physical conditions are suboptimal, planning with CBCT can be implemented as a more expedient and cost-effective method.

Conflict of Interest

There are no conflicts of interest and no acknowledgements.

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