BioBacta
Journal of Bioscience and Applied Research
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Verification and assessment of the PTV margin in the treatment of brain metastases with mono-fractionated radiosurgery

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DOI: 10.21608/jbaar.2024.361548

Received: March 8, 2024. Accepted: June 14, 2024. Published: June 22, 2024

Abstract:

This study evaluated the margins between gross target volume (GTV) and planned target volume (PTV) for brain metastases treated using the stereotactic radiosurgery (SRS) technique.

Methods and Materials: 10 patients who received SRS treatment for brain metastases provided the setup data. To evaluate systematic and random errors, 30 cone beam computed tomography (CBCT) was evaluated. Following that, we used the Van Herk formula to calculate and evaluate our optimal PTV to obtain a result comparable to other studies without exceeding tolerable values. **Results:** We found that the proper margin for single-fraction SRS cases in 10 brain metastases was about 2 mm for our department in this study. Setup margins obtained were X1.23, Y 0.93, and Z 1.04 mm translation, and 1.56, 1.36, 1.47 in Pitch, Roll, and Yaw in rotation.

Conclusion: Treatment of brain metastases with SRS requires an optimal PTV to ensure better coverage and normal brain sparing. A PTV margin of 2 mm is an optimal margin in our department.

Keywords: Brain metastases, planned target volume, stereotactic radiosurgery, cone beam computed tomography.

Introduction:

Cancer patients are frequently affected by brain metastases that have a negative effect on life quality **[1]**. A local treatment for brain metastases becomes increasingly important as systemic therapies improve, patients survive longer, and they are more likely to have brain metastases **[2]**.

Surgery and stereotactic radiation therapy (SRT) are treatment options in the management of brain metastases. The choice of the ideal local treatment is determined by several factors, such as the patient's overall health, the number of extracerebral metastases, and the size and location of the metastases.

In this investigation, we will look at stereotactic radiosurgery (SRS) as a treatment option. The latter is a form of radiotherapy designed to irradiate small intracranial lesions with great precision in a single session. Also, a less invasive option as compared to surgical treatment, shown to be a secure and successful treatment, perceivedly low rate of complications is one of the benefits of SRS, particularly major complications **[3,4].** SRS can generate very high accuracy of dose distribution in various situations, containing multiple target volumes and when various organs at risk (OAR) near a target volume and call to a more precise delineation of the normal and malignant tissues **[5].** Another very important and crucial point is patient positioning and compliance with treatment. In recent years, there have been some highly innovative efforts to correct patient positioning, for example, 6-degrees-of-freedom (6dof) couches **[6],** and the use of image-guided radiation therapy (IGRT) methods that can substantially take account of translation and rotation errors and decrease the possibility of geometric positioning mistakes between therapy planning and delivery. Included in them are the decreases in random errors that changed from arc to arc and with couch movement, as well as systematic errors that would otherwise persist during therapy **[7].**

This work is to quantify the random, systematic errors to reduce them if there is a possibility without deteriorating the coverage of the PTV and at the same time protecting healthy tissue by using IGRT and 6Dof for setup accuracy to assess the adequacy of the imperial planning target volume (PTV) margin used for SRS for brain metastases; the local regional anatomy and its close proximity to adjacent vital organs were factors in the selection of this location.

Patient setup, data collection, contouring, image registration, and treatment planning all have an impact on uncertainties throughout the planning stage, all this led to a dose distribution that deviated from the intended target area, this is a systematic error. On the other hand, the patient setup, data collection for control, image registration, and dosage all have an impact on the dose delivery and can cause the cumulative dose to be displaced from its proper position, this is called a random error **[8].**

This study was aimed at evaluating setup errors for patients being treated with SRS brain and establishing an ideal PTV margin specific to our center.

Methods and Materials:

This study was a retrospective investigation, ten patients with solitary brain metastases were randomly chosen after receiving single-fraction SRS treatment. All metastases had a diameter of less than 30 mm. All patients were treated at the National Institute of Oncology in Rabat, Morocco; the duration of the study was from (2021 to 2023).

In this study, the patient's head was immobilization in a supine position using a Fraxion Thermoplastic Mask Head with Fraxion Vacuum Cushion Plus attached at six fixation points to a carbon-fiber Fraxion Head Support Module ST (Medical Intelligence Medizintechnik GmbH, Allemagne). CT simulation was performed in 2 mm slices using Siemens Somatom Sensation Open CT (Erlangen, Germany, Siemens). Target volumes and OARs were delineated using Monaco Sim pv.10.0 (Elekta) and also using the magnetic resonance imaging (MRI) brain of the patient in a position similar to that of the CT scan during simulation for fusion to help in target and OAR delineation. Radiation arcs and reference CT for subsequent positioning and treatment images were transferred to the Mosaiq Oncology Management System. These were used as reference CT for comparison with Cone beam computed tomography (CBCT) images taken by X-ray Volume Imaging (XVI) equipment.

For treatment planning and delivery technique, Elekta Clinac Versa HD (Elekta Limited Linac House, Crawly, United Kingdom), a linear accelerator equipped with a 160-leaf dynamic multileaf collimator, is used. Clinac Versa HD was equipped with an XVI for image system. The treatment technique used was single-isocenter coplanar and non-coplanar volumetric modulated arc therapy (VMAT). Monaco 5.11 was used as a treatment planning system (TPS). Radiation was delivered to a tumor at a dose rate of 1200 MU/min with a photon energy of 6 MV FFF.

Our goal was to evaluate each patient's CBCT images. For the hexapod robotic 6-DoF and setup field corrections, three CBCTs were carried out. The first CBCT was done before the start of the treatment, the second one was done while the treatment was being administered, and the last one was done at the end of the treatment. This is to reduce the potential loss of target coverage due to targeting errors **[9].**

The assessment protocol was an offline verification procedure. CBCT was assessed by 2 observers independently. Intuit XVI VersaHD program was used for CBCT assessment. Reference CT was compared to CBCT, and differences between them using bony landmarks were measured for each direction of translation and rotation: translational set-up errors in the X, Y, and Z axes and rotational set-up mistakes. around the pitch, roll, and yaw. If the difference in the measurements between 2 observers was <1 mm, a treatment can be started. The objective of this work was to calculate and analyze PTV margins based on GTV. To analyze setup errors for both random (σ) and systematic (∑) errors in patient setup correction,

The *Van Herk et al* formula was utilized: assuming the minimum dose to CTV to be 95% for 90% of patients [10]. The equation below displays the analytical solution for a perfect conformation :

$$\text{Van Herk et al: Margin GTV to PTV} = 2{,}5\Sigma + 0{,}7\sigma$$

Results:

Thirty CBCTs were analyzed for brain metastases, setup uncertainty was calculated, and aligning reference CT relative to the CBCT acquired. The mean and SD displacements in translation and rotation directions are shown in **Table 1**.

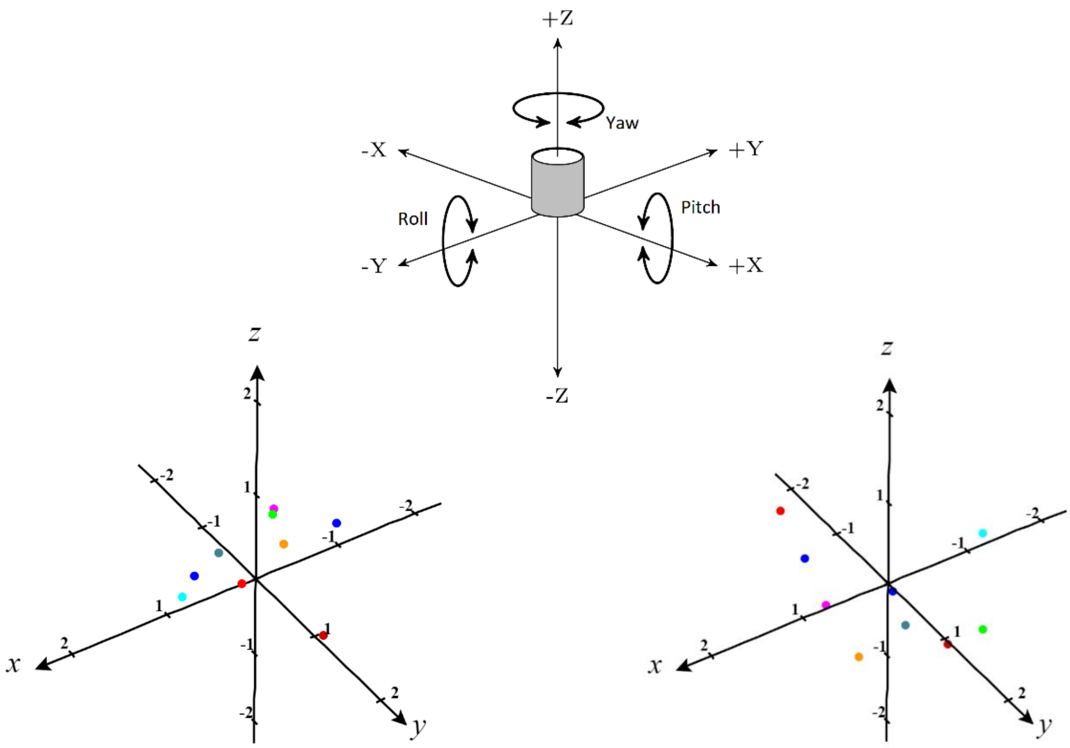
PTV displacements with translation axes tended to be localized in a small area offset from the center (systematic error), but with some dispersion (random error), as Figure 1 illustrates. With rotation axes, however, there was an important deviation.

There are multiple explanations for the variance in mean displacement. The first two are the geometric precision of the Linac and variations in patient positioning between the CT scan and single treatment session. Radiation therapists may experience considerable uncertainty in patient positioning due to the patient's marking processes, which involve the use of a permanent marker whose thickness and the set-up of the patient using an immobilization system.

Table 1 shows the statistics of translational and rotational (about the isocenter) intra-fractional movements of the head. Deviations in lateral, vertical, and longitudinal directions for the translation and pitch, roll, and yaw directions for the rotation were found to have magnitudes of (mean ± SD) 0.13 ± 0.49 mm, 0.11 ± 0.37 mm, 0.27 ± 0.41 mm, 0.16 ± 0.62°, 0.13 ± 0.65°, and 0.16 ± 0.59°, respectively.

Figures N. (2, 3) indicate setup variations with means and SD in lateral, vertical, longitudinal, pitch, roll, and yaw directions dimensions for 10 patients under brain metastasis treatment.

PTV margin was calculated for brain metastatic cancer using the formula of Van Herk (Table 2). The margin in X 1.23, Y 0.93, and Z 1.04 mm directions.



Displacement of patients with Translation axes Displacement of patients with Rotation axes

Figure 1: Displacement of patients along translation and rotation axes.

Table 1: Mean and SD of setup errors for our sample patients.

	Translations (mm)			Rotations (°)		
	X	Y	Z	Pitch	Roll	Yaw
Mean	0.13	0.11	0.27	0.16	0.13	0.16
SD	0.49	0.37	0.41	0.62	0.65	0.59

The mean of translation and rotation values were insignificant when compared to SD, suggesting that intra-fraction motions contributed very little systematic error.

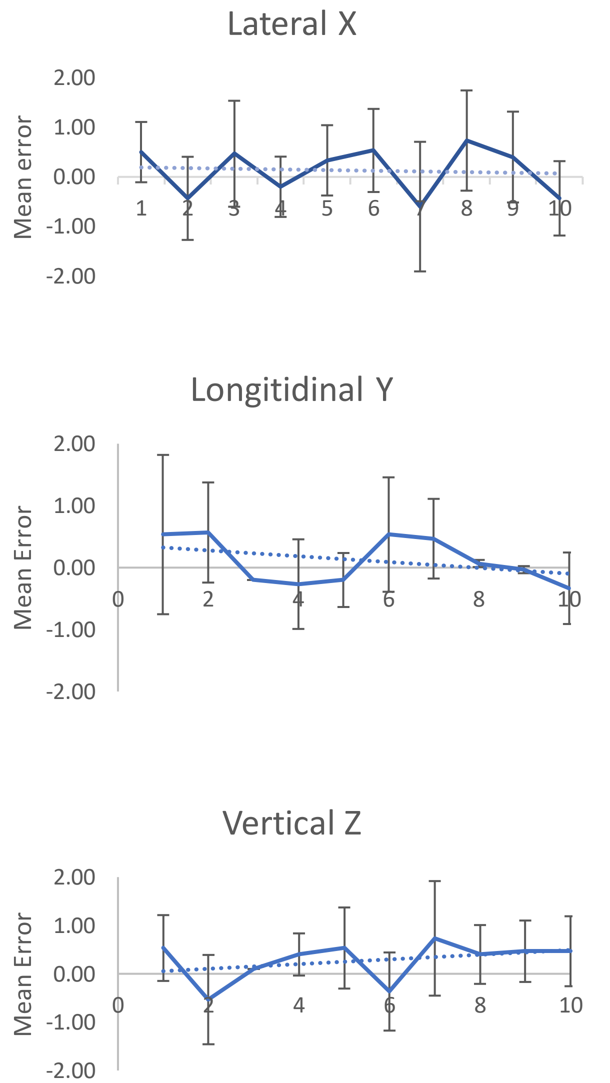


Figure 2. Mean with error bars showing an SD of individual patient setup errors along the X, Y, and Z directions for 10 patients.

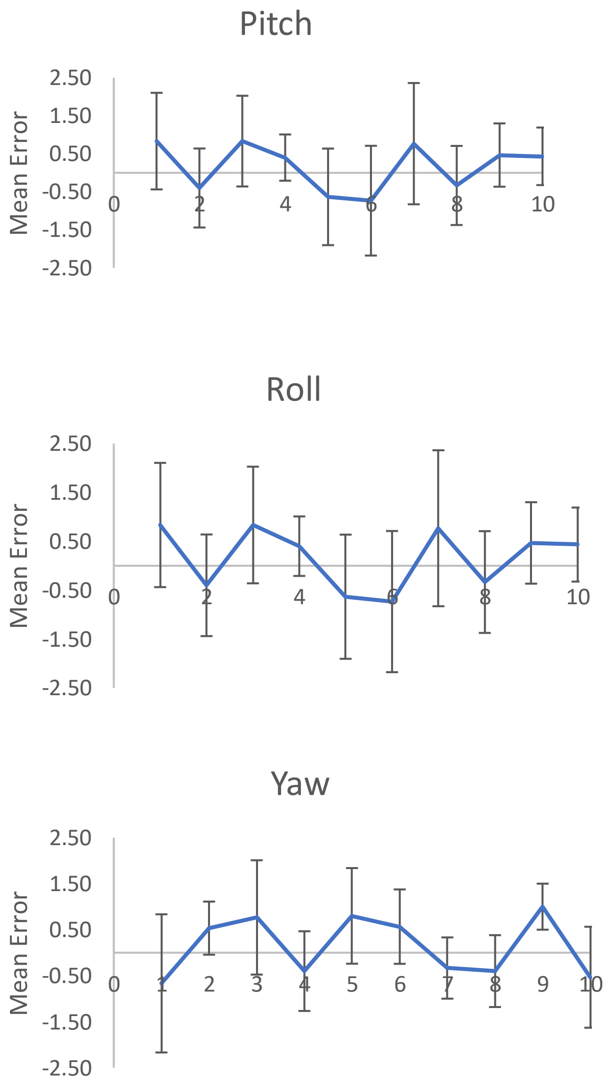


Figure 3. Mean with error bars showing an SD of individual patient setup errors along the Pitch, Roll, and Yaw directions for 10 patients.

Table 2: PTV margins (mm) using a formula of Van Herk

	X	Y	Z	Pitch	Roll	Yaw
PTV (mm)	1.23	0.93	1.04	1.56	1.63	1.47

Discussion:

PTV margin assessment is essential to manage the dose in normal tissues, which can result in unacceptable consequences [11]. Optimal SRS necessitates more accurate delineation of both tumor and normal tissues compared with VMAT and traditional RT because of the consequence of high absorbed dose gradients.

This study used CBCT to assess the setup accuracy in patients receiving SRS for brain metastasis cancer. We found the PTV margin around GTV to be 1.23, 0.93, and 1.04mm in X, Y, and Z in translation, respectively. Also similarly, in rotation, it was 1.56, 1.63, and 1.47mm in the Pitch, Roll, and Yaw directions, respectively. Currently, our center uses a 2 mm margin in all directions for brain metastatic cancer.

All of the results presented are consistent with previous research [12-14] despite variations in tumor location relative to the OAR and the immobilization systems used for this location. When a 2mm margin was used, several studies have not noted an increase in complication rate using a 2 mm margin for PTV. On the other hand, these studies revealed a significant increase in local control [15,16], and margins below 2 mm can compromise local control due to GTV miss, PTV margins account for registration, target delineation, immobilization, and treatment delivery incertitude [17-19], furthermore, other outcomes of previous works [20-22] are similar to the ones that our study reported; the implications, improving our procedures to guarantee improved coverage of target volumes. In our department, the PTV margin for brain metastases was set at 2 mm.

Conclusion:

As more patients with brain metastases become eligible for SRS, there is a need to make an optimal PTV, that will allow a reduction in dose to critical structures maintaining good local control. Our results were compared with those of related published research. We obtained margins found by applying the Van Herk formula were rather similar to those used at the institution (2mm), allowing for a good balance between the margin and local control. Therefore, CBCT-based setup verification is highly helpful in assessing setup uncertainties and calculating setup margins for brain metastases.

Acknowledgment:

We would like to thank colleagues: N. Boudchich, S. Masbane, N. Jettou, and K. Nouni at the National Cancer Institute, Department of Radiotherapy, Rabat, Morocco. Who helped us collect data and for the direct and indirect coordination with the research team.

Ethical consideration:

The study protocols were evaluated and approved by the ethics committee at the National Institute of Oncology in Rabat, Morocco. Participation was entirely voluntary, and each patient provided informed consent after receiving a clear explanation of the research objectives. All participants were aware that their care was not contingent on their involvement in the study. Confidentiality and anonymity of their data were guaranteed.

Funding:

This study did not receive any funding.

Competing interests:

The authors declare that they have no competing interests. The views expressed in this paper are those of the authors and do not represent the official views of their organizations.

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