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Dosimetric Comparison of Different Radiotherapy Techniques for Scalp Sparing Whole Brain Radiotherapy

May Gamal Ashour[1], Maha Kamaleldin[2], Neven Mahmoud[2], Emad Mohsen Barsoum[3], Ahmed Amin Abogabal[1]

[1]*Radiation Oncology department, National Cancer Institute, Cairo University, Egypt.*
[2]*Department of Clinical Oncology, Kasr Alainy School of Medicine, Cairo University, Egypt.*
[3]*Barsoum Oncology Center (BOC), Cairo, Egypt*

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Abstract

Introduction:

The brain is one of the most common sites of metastases from breast cancer primary. Whole-brain radiotherapy (WBRT) is mandatory in the treatment of some patients. The purpose of this study was to compare four different WBRT techniques and investigate their impact on the radiation dose received by the scalp and its sub-volumes. **Material and methods:** The simulation CTs of 10 different metastatic breast cancer patients who were previously treated with WBRT were used in this dosimetric study. Four different radiotherapy plans were designed for each patient. **Results:** All techniques showed comparable PTV coverage. The homogeneity index with OF-WBRT was 0.057±.09, 0.057±.0111 for FiF, and 058±.0114 for IMRT with no statistically significant difference ($p = 0.407$).

IMRT resulted in a marked decrease in all scalp parameters with a statistically significant difference, with a little difference in the dose delivered to lateral subvolumes. When the scalp parameters were introduced in optimization with Six–fields IMRT the lateral and posterior scalp mean dose reduced significantly. **Conclusion:** Scalp-sparing intensity-modulated radiation therapy (IMRT) is achievable. The Average scalp dose can be reduced by around 45% without compromising PTV coverage.

Introduction

The brain is one of the most common sites of metastases from breast cancer primary. It was reported that the incidence rate of brain metastases was 5.1% among patients with breast cancer [1, 2].

Whole-brain radiotherapy (WBRT) is mandatory in the treatment of some patients with brain metastases. It has proven its ability to control neurologic symptoms and reduce disease burden in several clinical trials from the 1980s [3-5].

Despite the ability of the WBRT to improve the survival of patients with brain metastases [6-8], it also has a negative impact on the quality of life (QOL) by increasing drowsiness, affecting neurocognitive function, and causing hair loss [9]. The hair loss was reported as one of the main factors reducing QOL scores and is typically observed in all patients undergoing WBRT [10, 11]. The standard WBRT technique applies two lateral opposed fields with an extra margin around the brain. This extra margin mostly includes the hair follicles, which are located at a depth of 5 mm below the scalp [12]. Therefore, the utilization of recent technology in patient positioning and radiotherapy treatment planning may allow for treating the whole brain with reduced margins, aiming for better QOL by sparing the scalp and minimizing hair loss[13-15].

The purpose of this study was to compare four different WBRT techniques and investigate their impact on the radiation dose received by the scalp and its sub-volumes.

Materials and Methods

The simulation CTs of 10 different metastatic breast cancer patients who were previously treated with WBRT were used in this dosemetric study. All of the 10 patients were simulated in the supine position with a thermoplastic mask for proper fixation. The clinical target volume (CTV) was contoured, including the whole brain till the upper border of the first cervical vertebrae. An expansion of 5 mm was applied to the CTV to acquire the planning target volume (PTV). The scalp was also contoured in the area between the skin and the outer table of the skull, with a maximum depth of 5mm. The scalp was subdivided into 4 sub-volumes (superior, anterior, lateral, and posterior) as shown in **Figure 1** to allow for evaluating each sub-volume separately.

Four different radiotherapy plans were designed for each patient using the following techniques **(Figure 2):**

- Standard whole brain radiotherapy by applying two lateral opposing fields (OF-WBRT).
- Two lateral opposed fields with segmentations using field-in-field technique (FiF).
- IMRT plan using two opposed fields with no constrains applied to the scalp.
- Six–fields IMRT plan including the Scalp dose in the optimization constraints. The angles of the treatment fields were 60, 102, 153, 204, 255, and 306 degrees. One extra couched field with gantry angle 320 and couch angle 270 was used.

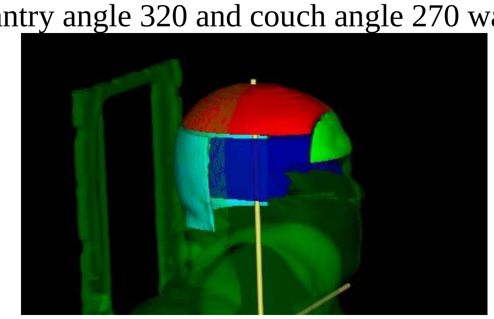

Figure (1) Scalp subvolumes

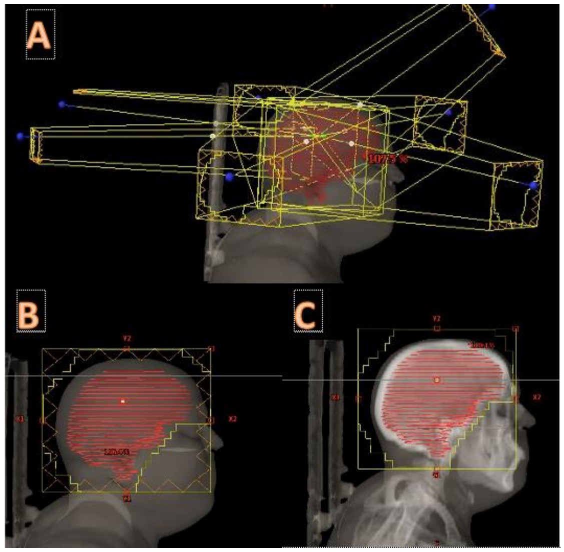

Figure (2) **A.** Six–fields IMRT, **B.** IMRT, **C.** Opposing fields-WBRT

Statistical analysis:

The dose-volume histogram parameters were assumed to be normally distributed and the comparison between the different plans was done using the Student's paired t-test with an upper bound of $p < 0.05$.

Results

All techniques showed comparable PTV coverage. The homogeneity index with OF-WBRT was 0.057±.09, 0.057±.0111 for FiF, and 058±.0114 for IMRT with no statistically significant difference ($p = 0.407$) **(Table 1).**

IMRT resulted in a marked decrease in all scalp parameters with a statistically significant difference, with a little difference in the dose delivered to lateral subvolumes **(Table 2)**.

When the scalp parameters were introduced in optimization with Six–fields IMRT the lateral and posterior scalp mean dose reduced significantly **(Table 3)**.

Table 1: PTV coverage

	OF-WBRT	FIF	IMRT	P-Value			
	Mean ± SD	Mean ± SD	Mean ± SD	All groups	OF-WBRT/ FIF	OF-WBRT / IMRT	IMRT/FIF
PTV MAX%	105.1± 0.9	104.0±0.7	105.9±1.5	<0.001	0.016	0.791	<0.001
PTV minimum%	87.2±14.5	84.4±14.0	72.1±11.5	0.007	1.000	0.042	0.011
D98%	96.9±0.7	96.9±0.7	97.1±0.7	1.000			
D50 %	99.9±0.2	100.0±0.2	99.9±0.3	0.056			
D2 %	103.4±0.9	102.7±0.5	102.8±0.6	0.038	0.042	0.535	1.000

Table 2: Dose to the scalp and its subvolumes

characteristics	OF-WBRT	FIF	IMRT	P-Value			
	Mean ± SD	Mean ± SD	Mean ± SD	All	OF-	OF-	IMRT/FI

				groups	WBRT / FIF	WBRT / IMRT	F
Scalp max	3220.9±42.9	3130.6±48.3	3031.0±68.8	<0.001	0.020	<0.001	0.539
Scalp mean	2165.7±270.5	2120.5±242.8	1385.9±306.7	<0.001	0.076	<0.001	0.076
Scalp Min	105.2±112.3	103.9±110	42.4±41.3	<0.001	0.539	0.001	0.057
Scalp V20	68.4±12.5	67.1±11.2	37.6±11.2	<0.001	0.221	<0.001	0.042
Scalp V10	91.2±10.2	90.9±9.9	62.4±12.8	<0.001	0.353	<0.001	0.030
Anterior mean	2180.9±237.8	2209.7±205.0	1267.4±462.2	<0.001	0.221	<0.001	0.042
Anterior max	3140.2±71.9	3062.8±91.7	2915.9±331.3	0.002	1.000	0.002	0.022
Anterior D50	2350.6±259.6	2393.4±210.2	1150.5±588.7	<0.001	0.211	<0.001	0.042
Lateral mean	2127.7±252.6	2136.9±249.1	2071.4±257.1	0.002	0.221	0.221	0.001
Lateral max	2975.3±73.8	2966.1±78.3	3009.1±120.2	0.407			
Lateral D50	2339.1±177.9	2292.6±195.4	2407.5±244.0	0.002	0.221	0.221	0.001
Posterior mean	2317.8±205.6	2273.3±207.8	1467.2±209.7	<0.001	0.076	0.076	<0.001
Posterior max	3169.1±80.6	3074.9±82.9	2930.8±101.3	0.002	0.022	0.002	1.000
Posterior D50	2482.5±194.2	2435.8±194.4	1517.5±328.8	<0.001	0.076	<0.001	0.076
Superior mean	2396.8±138.9	2326.1±121	1419.0± 372.4	<0.001	0.076	<0.001	0.076
Superior max	3219.6± 46.6	3124.9± 53.2	2983.2± 70.5	<0.001	0.067	<0.001	0.076
Superior D50	2553.5±128	2502.2±119.5	1313.1±545.7	<0.001	0.221	<0.001	0.042

Table 3: Comparison between two IMRT plans with or without introducing the scalp in optimization			
	IMRT	Six- fields IMRT	P value
Scalp mean	1385.9±306.7	1369.6±99.1	0.864
Lateral mean	2071.4±257.1	1587.7±162.0	<0.001
Anterior mean	1267.4±462.2	1463.3±207.3	0.118
Posterior mean	1467.2±209.7	1412.3±82.5	0.270
Superior mean	1419.0± 372.4	1321.8±185.3	0.026

Discussion

Brain metastasis represents 30% of intracranial tumors, and around 20% of cancer patients are expected to be diagnosed with brain metastasis at some point during their illness. [16].

Whole brain radiotherapy is a standard palliative treatment for brain metastasis, especially when SBRT is not feasible. Palliative treatment aims to alleviate symptoms without affecting the quality of life (QOL).

Temporary alopecia is a dose-dependent condition that generally subsides within two to three months following WBRT and develops two to three weeks after the initiation of radiotherapy [17].

It is commonly known that there is some degree of uncertainty in the surface dose of RTPS computation. [18] The absorbed dose at a depth of 1 mm has reportedly been shown to be incorrectly calculated using the CCC and AAA algorithms. [18] The hair follicle was found to be 3.5–4.2 mm below the skin's surface, while the computation accuracy was considerably better in the 3–5 mm depth range [19, 20]. The study analyzed the dosage parameters and identified the scalp region as the area between 3 and 5 mm from the skin's surface, based on measurement results and literature reviews [19, 20].

We demonstrate that scalp-sparing WBRT is achievable utilizing intensity-modulated radiation therapy compared to traditional methods. The IMRT plan, which spares the scalp, resulted in a notable decrease in the maximum, mean, V10, and V20 values of the scalp compared to a traditional OF-WBRT plan ($P < 0.001$). With or without introducing scalp constraints in optimization. Crucially, the PTV coverage remained acceptable.

Kao et al. conducted a study comparing the mean scalp dose of 16.4 Gy with IMRT to 26.2 Gy with conventional whole brain radiation therapy ($p < 0.001$). No patient experienced total hair loss among the fifteen individuals. Between one and three months after receiving IM-WBRT, 27% of patients experienced less than 50% hair loss, 40% had 50 to 74% hair loss, and 33% had 75 to 99% hair loss. [21].

In our study, we reduced the scalp mean dose in the 2 IMRT plans to 1385.9±306.7 and 1369.6±99.1, respectively.

VMAT-WBRT had the capacity to decrease the subcutaneously absorbed dosage by 20.5 percent, according to dose assessments conducted in a study by De Puysseleyr et al [22].

Palma et al. conducted a study to create normal tissue complication probability (NTCP) models for radiation-induced alopecia in patients undergoing proton therapy [23].

In a study done by Mahadevan et al., multi-field intensity modulated radiation therapy, with constraints on the brain PTV and hippocampus, decreased the dose to the scalp follicles and prevented hair loss. Hippocampal sparing whole brain radiation therapy (WBRT) resulted in a considerably lower mean dose (22.42 cGy vs. 16.33 cGy, $p < 0.0001$) to the scalp with hair follicles, therefore preventing hair loss. [24].

Shirata et al. found that Helical IMRT resulted in a lower scalp dose compared to 6MV-VMAT. The most effective method for reducing the average scalp dose was demonstrated in the 10MV-VMAT treatment. [25].

Takaoka et al. found that intensity modulated proton therapy (IMPT) achieved excellent hippocampus and scalp-sparing results. Utilizing intensity-modulated proton therapy (IMPT) for whole-brain radiation therapy (WBRT) with hippocampal sparing shows promise in preventing cognitive impairment and alopecia. [26].

The limitations of our study are that it is a dosimetric study with a small number of patients.

Conclusion

Scalp-sparing intensity-modulated radiation therapy (IMRT) is achievable. The Average scalp dose can be reduced by around 45% without compromising PTV coverage. In future trials, the clinical implications of this method could be explored further to assess its effectiveness in maintaining PTV coverage without reducing the dose.

Scalp-sparing IMRT for WBRT decreases scalp doses compared to traditional WBRT, particularly in the superior, anterior, and posterior directions. This approach improves the quality of life for breast cancer patients with brain metastases who are not suitable for stereotactic body radiation therapy (SBRT).

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None

Data availability statement

The datasets generated for this study are available on request to the corresponding author.

Ethics statement

Ethical review and approval taken for the study.

References

Barnholtz-Sloan J.S., Sloan A.E., Davis F.G., Vigneau F.D., Lai P., Sawaya R.E. Incidence Proportions of Brain Metastases in Patients Diagnosed (1973 to 2001) in the Metropolitan Detroit Cancer Surveillance System. J. Clin. Oncol. 2004; 22: 2865–2872.

2. Weil R.J., Palmieri D.C., Bronder J.L., Stark A.M., Steeg P.S. Breast Cancer Metastasis to the Central Nervous System. Am. J. Pathol. 2005; 167: 913–920.

Chao, J. H., Phillips, R. & Nickson, J. J. Roentgen-ray therapy of cerebral metastases. Cancer. 1954; 7: 682–689.

Kurtz, J. M., Gelber, R., Brady, L. W., Carella, R. J. & Cooper, J. S. The palliation of brain metastases in a favorable patient population: A randomized clinical trial by the Radiation Therapy Oncology Group. Int. J. Radiat. Oncol. Biol. Phys. 1981; 7: 891–895.

Borgelt, B. et al. The palliation of brain metastases: Final results of the first two studies by the Radiation Therapy Oncology Group. Int. J. Radiat. Oncol. Biol. Phys. 1980; 6: 1–9.

Ruderman NB, Hall TC. Use of glucocorticoids in the palliative treatment of metastatic brain tumors. Cancer. 1965; 18: 298–306.

Gaspar L, Scott C, Rotman M, Asbell S, Phillips T, Wasserman T, McKenna WG, Byhardt R. Recursive partitioning analysis (RPA) of prognostic factors in three Radiation Therapy Oncology Group (RTOG) brain metastases trials. Int J Radiat Oncol Biol Phys. 1997; 37: 745–751.

Horton J, Baxter DH, Olson KB. The management of metastases to the brain by irradiation and corticosteroids. Am J Roentgenol Radium Ther Nucl Med. 1971; 111: 334–336.

Steinmann D, Schafer C, van Oorschot B, Wypior HJ, Bruns F, Bolling T, Sehlen S, Hagg J, Bayerl A, Geinitz H, Hipp M, Vordermark D. Effects of radiotherapy for brain metastases on quality of life (QoL). Prospective pilot study of the DEGRO QoL working party. Strahlenther Onkol. 2009; 185: 190–197.

Gerrard GE, Prestwich RJ, Edwards A, Russon LJ, Richards F, Johnston CF, Kwok-Williams MC. Investigating the palliative efficacy of whole-brain radiotherapy for patients with multiple-brain metastases and poor prognostic features. Clin Oncol (R Coll Radiol) 2003; 15: 422–428.

Slotman BJ, Mauer ME, Bottomley A, Faivre-Finn C, Kramer GW, Rankin EM, Snee M, Hatton M, Postmus PE, Collette L, Senan S. Prophylactic cranial irradiation in extensive disease small-cell lung cancer: short-term health-related quality of life and patient reported symptoms: results of an international phase III randomized controlled trial by the EORTC radiation oncology and lung cancer groups. J Clin Oncol. 2009; 27: 78–84.

de Viragh PA, Meuli M. Human scalp hair follicle development from birth to adulthood: statistical study with special regard to putative stem cells in the bulge and proliferating cells in the matrix. Arch Dermatol Res. 1995; 287: 279–284.

Ting J, Thomas CR, McClure JA, Scarbrough TJ. “Alopecia-less” whole brain radiotherapy (WBRT) via IMRT: preliminary experience and outcomes. Int J Radiat Oncol Biol Phys. 2005; 63: S263–S264.

Mancini BR, Kim LH, Shaitelman SF, Yan D, Kestin LL, Grills IS. Intensity modulated or volumetric modulated radiation therapy (IMRT or VMAT) to reduce alopecia, xerostomia, and otitis after whole brain radiation therapy for brain metastases: a planning analysis. Int J Radiat Oncol Biol Phys. 2010; 78: S840.

Roberge D, Parker W, Niazi TM, Olivares M. Treating the contents and not the container: dosimetric study of hair-sparing whole brain intensity modulated radiation therapy. Technol Cancer Res Treat. 2005; 4: 567–570.

Achrol AS, Rennert RC, Anders C, Soffietti R, Ahluwalia MS, Nayak L, et al. Brain metastases. Nat Rev Dis Primers 2019; 5: 5.

Scoccianti S, Simontacchi G, Greto D, Perna M, Terziani F, Talamonti C, Teriaca MA, Caramia G, Lo Russo M, Olmetto E, Delli Paoli C, Grassi R, Carfora V, Saieva C, Bonomo P, Detti B, Mangoni M, Desideri I, Francolini G, Di Cataldo V, Marrazzo L, Pallotta S, Livi L. Dosimetric Predictors of Acute and Chronic Alopecia in Primary Brain Cancer Patients Treated With Volumetric Modulated Arc Therapy. Front Oncol. 2020 Apr 8;10:467.

Cao Y, Yang X, Yang Z, Qiu X, Lv Z, Lei M, et al. Superficial dose evaluation of four dose calculation algorithms. Radiation Physics and Chemistry 2017; 137: 23–28.

Blume-Peytavi U, Vogt A. Human hair follicle: reservoir function and selective targeting. Br J Dermatol 2011; 165 Suppl 2:13–17.

Vogt A, Hadam S, Heiderhoff M, Audring H, Lademann J, Sterry W, et al. Morphometry of human terminal and vellus hair follicles. Exp Dermatol 2007; 16: 946–50.

Kao J, Darakchiev B, Conboy L, Ogurek S, Sharma N, Ren X, Pettit J. Tumor Directed, Scalp Sparing Intensity Modulated Whole Brain Radiotherapy for Brain Metastases. Technol Cancer Res Treat. 2015 Oct;14(5):547-55.

De Puysseleyr A, Van De Velde J, Speleers B, Vercauteren T, Goedgebeur A, Van Hoof T, Boterberg T, De Neve W, De Wagter C, Ost P. Hair-sparing whole brain radiotherapy with volumetric arc therapy in patients treated for brain metastases: dosimetric and clinical results of a phase II trial. Radiat Oncol. 2014 Jul 29;9:170.

Palma G, Taffelli A, Fellin F, D'Avino V, Scartoni D, Tommasino F, Scifoni E, Durante M, Amichetti M, Schwarz M, Amelio D, Cella L. Modelling the risk of radiation-induced alopecia in brain tumor patients treated with scanned proton beams. Radiother Oncol. 2020 Mar;144:127-134.

Mahadevan A, Sampson C, LaRosa S, Floyd SR, Wong ET, Uhlmann EJ, Sengupta S, Kasper EM. Dosimetric analysis of the alopecia preventing effect of hippocampus sparing whole brain radiation therapy. Radiat Oncol. 2015 Nov 26;10:245.

Shirata R, Inoue T, Sugimoto S, Saito AI, Omura M, Minagawa Y, Sasai K. Dosimetric investigation of whole-brain radiotherapy with helical intensity modulated radiation therapy and volumetric modulated arc therapy for scalp sparing. BJR Open. 2023 Mar 22;5(1):20220037.
Takaoka T, Tomita N, Mizuno T, Hashimoto S, Tsuchiya T, Tomida M, Yanagi T. Dosimetric Comparison of Helical Tomotherapy and Intensity-Modulated Proton Therapy in Hippocampus- and Scalp-Sparing Whole Brain Radiotherapy. Technol Cancer Res Treat. 2021 Jan-Dec;20:15330338211060170.