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Original research article

Dosimetric comparison of conformal technique (3D) with volumetric modulated arc therapy with respect to doses obtained in the temporal lobe area in patients irradiated for brain meningioma

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ABSTRACT

Aim: The aim of the analysis was to compare doses obtained for temporal lobes in patients being irradiated for meningiomas of the brain using the conformal technique and volumetric modulated arc therapy (VMAT). We try to answer the question whether the application of VMAT would lead to higher doses within temporal lobes.
Background: In recent years a significant increase in the detection of meningiomas and effectiveness of treatment has been observed. Hence quality of life should be considered as an important aspect after a treatment course.
Materials and methods: Treatment plans of 27 patients were evaluated retrospectively. Radiotherapy procedures were carried out from 2007 until 2016 at the Department of Radiation Oncology in Wroclaw, Poland. For individual patients, alternative treatment plans were generated in relation to the ones originally used, wherein from dynamic techniques, volumetric modulated arc therapy was selected for analysis. Evaluated dosimetric parameters for temporal lobes were: mean dose, V10 Gy, V20 Gy, V45 Gy.
Results: Statistically significant differences were observed for V45 Gy for both temporal lobes ($p = 0.023$) and for V45 Gy for the right ($p = 0.001$) and the left temporal lobe ($p = 0.016$) considered for VMAT. The mean values of the V45 Gy for both temporal lobes, for the right temporal lobe and for the left temporal lobe were lower for VMAT than for 3D, respectively: 7.54% and 7.90%, 6.82% and 9.47%, 5.67% and 7.14%.

Analysis of the remaining results found no statistical differences.
Conclusion: Application of VMAT in patients treated for meningioma of the brain is not related to higher doses of radiation in the temporal lobe area, compared with the conformal technique.

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1. Background

In recent years, due to the increasing accessibility of diagnostic imaging modalities, such as magnetic resonance imaging or computer tomography, a significant increase in the detection of meningiomas has been observed. Constant development of imaging methods, operating techniques and radiotherapy contributed to satisfactory results achieved as part of meningioma treatment. It is estimated that the ten-year relative survival for meningioma is 60%. The effectiveness of treatment is also clearly better for younger patients, i.e. between 20 and 44 years old, relative to the average, and is almost 78%.[1]

The above data shows that in most patients, because of good effective treatment, quality of life should be considered as an extremely important aspect after a treatment course, especially in younger patients. One of the factors that can have a significant negative impact on the quality of life is radiation-induced temporal lobe injury related to the exposure to ionising radiation.

Recently, we have observed an extensive use of dynamic techniques in radiotherapy, such as Intensity-Modulated Radiation Therapy (IMRT), helical tomotherapy and VMAT, which help reduce doses to critical structures, without compromising dose distribution to the target volume.[2,3]

Aim

The aim of this study was to analyse dosimetric data and compare treatment plans for the 3D technique and volumetric modulated arc therapy, VMAT (RapidArc®, Varian Medical System, Inc. Palo Alto, USA), in patients treated for meningiomas with respect to doses obtained in the temporal lobe area and try to answer the question whether the application of a particular technique would lead to higher doses within temporal lobes and, therefore, be correlated with a higher risk of radiation damage.

2. Materials and methods

Treatment plans of 27 patients were evaluated retrospectively, 15 females and 12 males, who had been irradiated in the Department of Radiation Oncology in Wroclaw, Poland between July 2007 and May 2016. The mean age was 63 (36–82). The inclusion criterion was diagnosis of meningioma based on histopathology or diagnostic imaging (brain CT, brain MRI). Patients treated with an intracranial stereotactic procedure were excluded from analysis. In 21 patients surgery was initially performed, in six patients radiotherapy alone was used. Among histopathological diagnoses, benign forms dominated, WHO I ($n = 15$). Other diagnoses were atypical ($n = 5$) and malignant ($n = 2$) meningiomas. In one case, the result of the histopathological examination was non-diagnostic. The radiotherapy technique initially used was the conformal 3D technique in ten cases, in other ten cases it was IMRT, and VMAT in seven cases (RapidArc®, Varian Medical System, Inc. Palo Alto, USA).

Table 1 – Patient characteristics.

Characteristic	*n* (%)
Age (years)	
Mean (range)	63 (36–82)
Gender	
Male	12 (44%)
Female	15 (56%)
PTV sites	
Temporal lobe	2 (7%)
Parietal lobe	7 (26%)
Frontal lobe	4 (15%)
Skull base	9 (33%)
Optic nerve	1 (4%)
Cerebellum	1 (4%)
Occipital lobe	3 (11%)
PTV volume (cm^3)	
Mean (range)	167 (28–571)
Histological grade	
WHO I	15 (68%)
WHO II	5 (23%)
WHO III	2 (9%)
Number of treatment fields	
(range)	(1–6)
Total dose (Gy)	
Mean (range)	54 (50.4–60)

Alternative treatment plans were generated for individual patients, compared to those originally used for therapy. Among the dynamic techniques, VMAT was selected for analysis. Patients treated with IMRT had two plans generated for comparative analysis, i.e. 3D and VMAT. In this group, the original IMRT plans were not dosimetrically analysed. Data on patient characteristics and irradiation techniques are included in Table 1.

All patients underwent computed tomography with immobilisation by a thermoplastic mask.

The delineating target volumes and organs at risk were based on the current principles of radiotherapy planning for meningioma. The clinical target volume for benign and atypical meningioma was delineated as a tumour bed and enhancing the mass on the post-contrast T1-weighted MRI with a 0.5 cm margin. In malignant meningioma, enhancing the mass with oedema on the post-contrast T2-weighted MRI was contoured with a 2 cm margin. The planning target volume was created by adding a 0.5–1 cm margin.[4,5]

Temporal lobes were outlined separately for the right and left sides, according to recommendations presented by Ying Sun et al. (Table 2).[6] For this purpose, magnetic resonance images were used and co-registration MRI/CT were performed.

2.1. Dosimetric parameters

Dose distributions were calculated using Eclipse PRO v.10® software (Varian Medical System, Palo Alto, USA). The total delivered dose ranged from 50.4 Gy to 60 Gy. The dose per fraction was 1.8 Gy or 2 Gy. Five weekly fractions were administered up to the completion of irradiation. The maximum and minimum volume of PTV was 571 cm^3 and 28 cm^3, respectively.

Table 2 – Anatomic boundaries of the temporal lobe.

Cranial	Caudal	Anterior	Posterior	Lateral	Medial
Cranial edge of the sylvian fissure	Base of middle cranial fossa	Temporal bone and sylvian fissure, greater wing of sphenoid	Petrous part of temporal lobe, tentorium of cerebellum, incisura preoccipitalis	Temporal bone	Cavernous sinus, sphenoid sinus, sella turcica, and sylvian fissure including parahippocampal gyrus and hippocampus

Table 3 – .

Parameters	N	Average		S.D.		*p*
		3D	VMAT	3D	VMAT	
D mean both lobes	27	13.21	13.81	8.85	9.68	0.594
D mean right lobe	27	14.99	15.03	9.83	10.78	0.732
D mean left lobe	27	12.00	12.60	10.06	11.29	0.335
V10 Gy both lobes **(%)**	27	41.66	51.33	27.72	38.48	0.135
V10 Gy right lobe **(%)**	27	44.90	55.20	28.82	39.25	0.081
V10 Gy left lobe **(%)**	27	36.84	47.14	32.06	41.26	0.109
V20 Gy both lobes **(%)**	27	23.20	25.43	21.86	22.76	0.287
V20 Gy right lobe **(%)**	27	26.41	28.48	23.66	26.53	0.605
V20 Gy left lobe **(%)**	27	20.97	21.20	24.67	28.47	0.709
V45 Gy both lobes **(%)**	27	7.90	7.54	9.21	10.43	**0.023**
V45 Gy right lobe **(%)**	27	9.47	6.82	13.64	11.35	**0.001**
V45 Gy left lobe **(%)**	27	7.14	5.67	13.01	10.72	**0.016**

The results of the evaluated parameters.
V10 Gy – per cent of volume absorbing 10 Gy dose.
V20 Gy – per cent of volume absorbing 20 Gy dose.
V45 Gy – per cent of volume absorbing 45 Gy dose.
D mean – mean dose.

For both temporal lobes and, separately, for the right and left temporal lobes, the following dosimetric parameters were determined for each treatment plan: mean dose, V10 Gy, V20 Gy, V45 Gy.

In the conformal 3D technique, the number of applied fields was between three and five, while in the arc technique, from one to four arcs.

2.2. *Statistical analysis*

The dosimetric parameters foreach patient were compared in a Wilcoxon test as an alternative to the *t*-test. The threshold for statistical significance was $p < 0.05$.

Statistical analyses were performed using STATISTICA v.12.5 software (StatSoft, Poland).

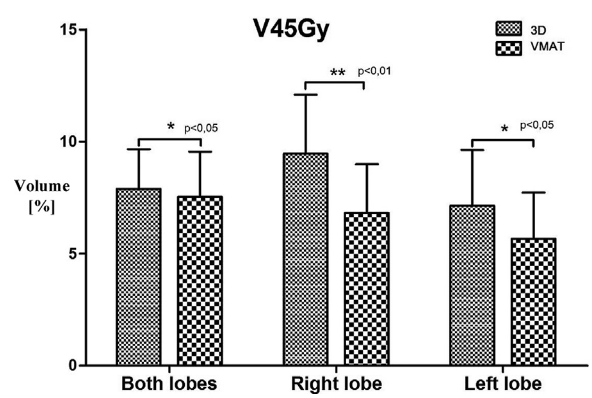

Fig. 1 – Per cent of temporal lobes volume absorbing 45 Gy dose according to radiotherapy technique.

3. Results

The results of the evaluated parameters are presented in Table 3. Statistically significant differences were demonstrated for the V45 Gy parameter for both temporal lobes ($p = 0.023$), and the V45 Gy for the right temporal lobe ($p = 0.001$) and left temporal lobe ($p = 0.016$) considered separately, obtained in VMAT, where the values were lower than in the 3D technique (Fig. 1).

Analysing the remaining results, no statistical differences were found.

The median of medium doses obtained for both temporal lobes were 12.5 Gy (3D) – 15.7 Gy (VMAT). For the right temporal lobe 14.1 Gy (3D) – 13.4 Gy (VMAT), and for the left temporal lobe 8.5 Gy (3D) – 11.4 Gy (VMAT). Mean doses were 13.2 Gy for the 3D technique and 13.8 Gy for the dynamic arc technique for both temporal lobes. When considering temporal lobes separately, mean doses for the 3D technique were in the range of 14.9 Gy (right lobe) and 12 Gy (left lobe), while for the VMAT technique these were 15 Gy and 12.6 Gy, respectively (Fig. 2).

Regarding the volume of both temporal lobes covered by the analysed dose, for 10 Gy the median was 43.2% for the 3D

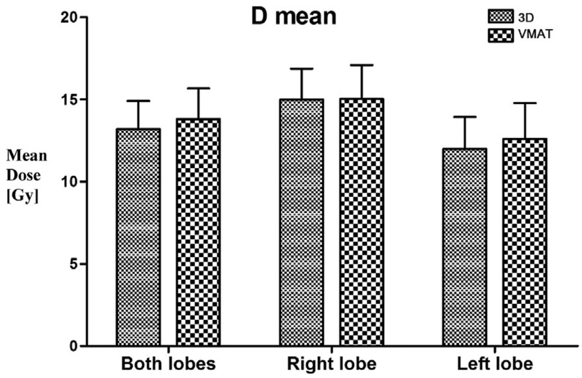

Fig. 2 – Mean dose (Gy) obtained for temporal lobes according to radiotherapy technique.

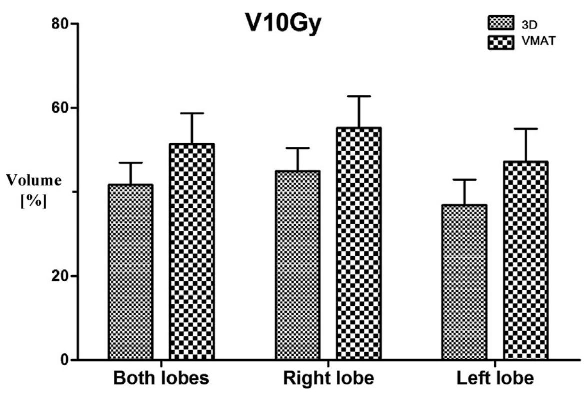

Fig. 3 – Per cent of temporal lobes volume absorbing 10 Gy dose according to radiotherapy technique.

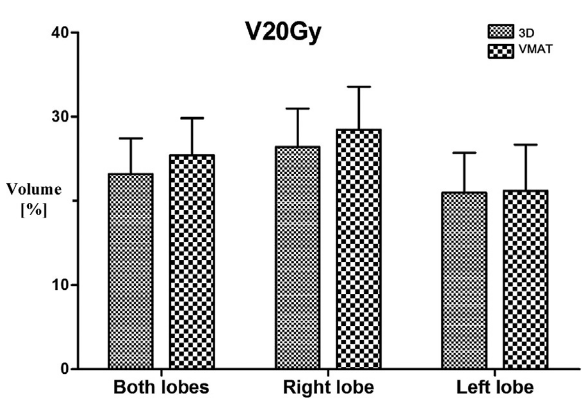

Fig. 4 – Per cent of temporal lobes volume absorbing 20 Gy dose according to radiotherapy technique.

technique and 63% for VMAT. For 20 Gy it was 15.4% and 19.9%, respectively, and for 45 Gy, 4.7% for 3D and 3% for VMAT.

For the parameters V10 Gy and V20 Gy, the use of a particular irradiation technique was not shown to be associated with a statistically significant decrease in the analysed parameters (Figs. 3 and 4).

4. Discussion

Numerous clinical trials have established a standard of care for brain meningioma, based on a maximally complete resection of the tumour and postoperative radiotherapy depending on the grade of histopathological malignancy and the extent of the resection.[7–10]

High efficiency of the therapeutic methods in use, including radiotherapy, increases the importance of the quality of life after treatment and, especially, minimising late adverse effects after radiotherapy of the brain becomes a major concern.

Due to the constant development of radiotherapy techniques, this modality offers technological tools which can potentially decrease the toxicity related to treatment and, thereby, decrease the risk of temporal lobe injury after irradiation. The main symptoms of this late complication after radiotherapy are memory disturbance, dysfunctions of social behaviour, due to the location of memory within the temporal lobes and interpretation of facial expressions of emotion,[11] and also deterioration in motor dexterity.[12]

Numerous impaired interactions between central nervous cells, including astrocytes, oligodendrocytes, microglia and reduction in the number of endothelial cells in blood vessels occurred as a negative impact of ionising radiation.[13]

Previous data on temporal lobe injury after irradiation come usually from a group of patients treated with radiotherapy for nasopharyngeal cancer.[14–16]

Zhou et al. retrospectively evaluated the risk of radiation-induced temporal lobe damage in patients undergoing radical radiotherapy for nasopharyngeal cancer.

Two applied radiotherapy techniques, 2D and IMRT were investigated. The analysis showed a statistically lower risk of the above complication after application of the IMRT technique compared to 2D.[17] Ying Sun et al. showed an increased risk of radiation damage to the temporal lobes depending on the maximum dose assessed at 69 Gy and its correlation with dosimetric parameters, such as V30 Gy, V45 Gy, V55 Gy and V60 Gy.[18]

The research presented in this publication is based on a comparison between two widely used radiotherapy techniques, conformal (3D) and VMAT in relation to the doses obtained in the temporal lobe area, in this case considered as critical organs.

Demonstration of lower doses in the temporal lobes using one of the evaluated techniques could suggest lower toxicity of treatment by this technique. Because of the better conformality of the dynamic technique at the expense of a higher integral dose, it was expected that use of this technique would result in larger volumes of temporal lobes exposed to ionising radiation in the range of the compared doses (Dmean, V10 Gy, V20 Gy, V45 Gy).

The study did not confirm this, showing no significant differences between the tested techniques and in one of the analysed parameters (V45 Gy) a statistically lower percentage of the volume of the temporal lobes covered by the dose of 45 Gy was obtained when VMAT was used.

In the above analysis, the selected dosimetric parameters (mean dose, V10 Gy, V20 Gy and V45 Gy) were set for dosimetric analysis purposes only, and not to determine their impact on the risk of radiation damage to the temporal lobes.

The use of VMAT is associated with high conformality of the dose distribution in the target volume with simultaneous shortening of the duration of exposure, compared, for example, with the classical dynamic technique, IMRT.[19–21]

Popescu et al., in a study comparing a dynamic arc technique with conventional IMRT in patients undergoing left breast radiotherapy, reported comparable coverage with a prescribed dose of the target volume and doses obtained for critical organs between these two techniques.

However, the delivery time of the fraction was shorter by 55% in the case of the VMAT.[22] Moreover, citing the results of tests evaluating obtained dosimetric parameters using different radiotherapy techniques like 3D, IMRT or VMAT, the dynamic arc technique may be characterised by the best results among the ones mentioned above.[23–25]

Due to the constant increase in the number of patients requiring the use of teleradiotherapy, the issue of optimising the treatment time and capability of therapeutic devices can become an important factor in the choice of an irradiation technique, maintaining physical parameters of the delivered radiation at a high level at the same time.

When discussing the benefits of using dynamic techniques, especially VMAT, one cannot ignore data suggesting an increased risk of secondary cancers in patients undergoing such a radiotherapy technique.[26,27] An example of this is the analysis carried out by a research group from Mannheim who assessed the risk of secondary cancer in patients undergoing breast radiotherapy. Comparing the 3D technique with the dynamic arc technique, the risk of radiation-induced cancer was over 30% greater for the dynamic technique.[28]

The study cited above applies to extracranial radiotherapy; however, considering ionising radiation as a potential carcinogen, this may also be a significant problem in other locations.

This particularly refers to patients with benign tumours, e.g. meningioma, where the treatment is associated with a high percentage of long-term local controls and overall survival.

5. Conclusions

The results presented in our study indicate that the use of VMAT in the treatment of brain meningioma is not associated with obtaining higher doses of ionising radiation in the temporal lobe area, compared to the use of radiotherapy in 3D technique, making VMAT an alternative to the conformal technique.

Conflict of interest

None declared.

Financial disclosure

None declared.

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