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Technical notes

Influence of multi-leaf collimator leaf width in radiosurgery via volumetric modulated arc therapy and 3D dynamic conformal arc therapy

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ABSTRACT

Purpose: To study the influence of Multileaf Collimator (MLC) leaf width in radiosurgery treatment planning for Volumetric Modulated Arc Therapy (VMAT) and 3D Dynamic Conformal Arc Therapy (3D-DCA).
Material and methods: 16 patients with solitary brain metastases treated with radiosurgery via the non-coplanar VMAT were replanned for the 3D-DCA. For each planning technique two MLC leaf width sizes were utilized, i.e. 5 mm and 2.5 mm. These treatment plans were compared using dosimetric indices (conformity, gradient and mean dose for brain tissue) and the normal tissue complication probability (NTCP).
Results: An improvement in planning quality for VMAT was observed versus 3D-DCA for any MLC leaf width, mainly with regards to dose conformity and to a lesser extent regards dose gradient. No significant difference was observed for any of both techniques using smaller leaf width. However, dose gradient was improved in favor of the 2.5 mm MLC for either of both techniques (15% VMAT and 10% 3D-DCA); being noticeable for lesions smaller than 10 cm^3. Nonetheless, the NTCP index was not significantly affected by variations in the dose gradient index.
Conclusions: This, our present study, suggests that the use of an MLC leaf width of 2.5 mm via the noncoplanar VMAT and 3D-DCA techniques provides improvement in terms of dose gradient for small volumes, over those results obtained with an MLC leaf width of 5 mm. The 3D-DCA does also benefit from MLC leaf widths of a smaller size, mainly in terms of conformity.

Introduction

Intracranial radiosurgery is characterized by the administration of a very high dose of radiation to small target volumes, metastatic or benign lesions, lying in close proximity to critical organs at risk (OAR) such as the brain, optic chiasm, or brain stem, among others. Treatments are planned to maximize both the dose conformation according to treatment volume (PTV) and the surrounding dose gradient. There are currently a number of techniques which allow both criteria to be met to a greater or lesser extent [1]. The techniques performed using linear accelerators, such as the 3D conformal static field technique (3D-CRT), 3D dynamic conformal arc therapy (3D-DCA) and intensity modulated techniques, both static field (IMRT) and volumetric (VMAT), are based on the use of multileaf collimators (MLC) in order to conform x-ray beams according to the PTV while safeguarding OARs to the maximum. Also some authors have pointed out the importance of appropriate quality assurance of these techniques [2]. A range of studies provide a comparative assessment of these techniques with the aim of determining their suitability [3–6]. Likewise, studies have been carried out on the influence of MLC leaf width [7–11], the majority of which conclude that there is an advantage to the use of lesser leaf width in 3D techniques, above all in irregular lesions and those in extremely close proximity to OAR. Nonetheless, we found no comparative studies on the use of the VMAT technique in brain lesions among the bibliographic references consulted.

Given that the incidence of brain metastases in cancer patients is high and the former in turn strongly associated with morbidity

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and mortality [12], it is paramount further research and development on techniques and procedures be carried out in order to provide more efficient and effective treatments, without generating extra workloads for existing health services. VMAT is the technique utilized for most anatomical locations and has recently been implemented in brain radiosurgery [4]. The added advantage of utilizing non-coplanar arcs has broadened the scope of possibilities for this technique [13].

At our oncology unit, radiosurgical treatment of brain metastases is performed via 5 mm leaf width MLC and interest arose as to whether thinner MLC leaf widths might improve treatments, above all for smaller sized lesions. *A priori*, interpreting the influence MLC physical characteristics might have toward improved planning for any particular technique is no simple task. Thus we have developed the present comparative dosimetric study, with the aim of assessing the possible advantages of using 2.5 mm leaf-width MLC for radiosurgical treatment of brain metastases via VMAT and 3D-DCA.

Material and method

Treatment planning

16 patients were chosen from our data base of those with brain metastases treated via a single session of radiosurgery. The median PTV was 8.0 cm^3 (0.59–42.3 cm^3). All patients were treated in a Clinac iX accelerator equipped with a Millenium 120 collimator with a 5 mm leaf width at the isocenter and an x-ray beam of 6 MV at a maximum dose rate of 600 MU/min. The treatment plan consisted of 5 non-coplanar VMAT arcs with a rotational gantry and couch, as shown in Table 1. The arc trajectory and orientation was optimized to avoid collisions with the patient and minimize treatment time. Optimization was performed in the Eclipse v10.0 treatment planning system. Dose distribution was calculated with the AAA algorithm and the minimum grid size of 1.2 mm.

A second MLC with 2.5 mm leaf width, the Varian High Definition MLC (HD-MLC), was modeled in the treatment planning system. The MLC used in the Eclipse treatment planning system involved a set of two parameters, i.e., the transmission of radiation and the dosimetric leaf gap, which is related to the dose of transmitted radiation when opposing leaves are closed. For the MLC-120, these parameters were measured during the clinical acceptance of the linear accelerator as being 1.6% for transmission and a 1.8 mm dosimetric leaf gap [14]; and for the HD-MLC the dosimetric data was taken from Refs. [15], 1.2% transmission and 0.4 mm dosimetric leaf gap.

In order to avoid operator bias when optimizing both types of MLC, restrictions, objectives and priorities for PTV and OAR were set at the starting of the optimization process and not subject to modification. With the aim of improving dose gradient in proximity to the PTV, two conditions were imposed: i) a dose inhomogeneity of 10% was permitted; in a previous work we studied the influence of maximum dose allowed inside de PTV during the optimization on the dose gradient, so that an homogeneity around 10% gives a good balance between dose gradient and maximum dose [16]; ii) according to the procedure established by Audet et al. [13] an optimization volume from 3 to 10 mm encircling the PTV was generated, imposing two upper constraints, i.e. no more than the 65% and 55% of the prescription dose is allowed inside the ring, with a weight priority of 10% of the PTV one.

Likewise, the influence of MLC leaf width on 3D conformal arc therapy technique was assessed, such that for the same group of patients, a 3D-DCA plan was also performed. In our case, this technique consisted in adapting the MLC to the PTV, with a 2 mm margin, during gantry rotation. Gantry and patient couch rotation were maintained as per Table 1. An identical dose weight was utilized for all arcs. The dose calculation algorithm and grid size were equal to those of the VMAT technique.

The prescribed dose for these radiosurgery techniques was from 12 to 18 Gy, depending on lesion volume and quantity, as well as the patient's clinical conditions. In order to be able to consistently compare the results across all patients, all planned doses were prescribed at 18 Gy, such that 100% of the PTV received at least 99% of the prescribed dose.

Table 1
Non-coplanar VMAT technique used in our radiosurgery technique.

Arc	Table rotation	Initial angle	Final angle	Rotational direction
1	60°	30°	181°	Clockwise
2	30°	30°	181°	Clockwise
3	0°	181°	179°	Anti-clockwise
4	330°	330°	179°	Anti-clockwise
5	300°	330°	179°	Anti-clockwise

Planning comparison

The comparison of both VMAT and 3D-DCA plans was performed using 3 dosimetric indexes and 1 radiobiological index. The dosimetric indexes were: the Paddick conformity index [17], the gradient index (GI), as the ratio of the 50% isodose volume to the prescription isodose volume [18]; the mean brain dose; and the radiobiological index was the normal tissue complication probability (NTCP), calculated according to Gay et al. [19] based on the Equivalent Uniform Dose, EUD, using the following formula:

$$NTCP = \frac{1}{1 + \left(\frac{TD_{50}}{EUD}\right)^{4 \cdot \gamma_{50}}}$$

The parameters used were those indicated by Gay et al. [18] for brain complications, a = 5, TD_{50} = 60 Gy, γ_{50} = 3. We assumed a value for α/β=1 as per Bender [20] and obtained from clinical data regarding the incidence of brain radionecrosis.

Statistical analysis

The statistical analysis of the data obtained was carried using the SPSS v22 software package.

The Wilcoxon signed-rank was performed to assess differences between different plans, with a p-value <0.05 defining statistical significance. This test is intended for matched pairs, in such a way that the parameters analyzed are from the same case and different MLCs or technique.

The correlation between indexes was analyzed via non-parametric Spearman's rho, assuming significance when $p < 0.05$.

Results

Table 2 shows the conformity and gradient indices and NTCP, for both treatment techniques and MLC leaf widths.

Table 2
Summary of dosimetric and radiobiological indices.

	Conformity index	Gradient index	NTCP
5 mm VMAT	0.91 ± 0.05	3.7 ± 1.1	7 ± 9
2.5 mm VMAT	0.91 ± 0.05	3.2 ± 0.8	6 ± 8
5 mm 3D-DCA	0.72 ± 0.06	3.7 ± 0.9	9 ± 12
2.5 mm 3D-DCA	0.74 ± 0.05	3.4 ± 0.7	10 ± 11