



# An evaluation of the Monaco<sup>®</sup> treatment planning system for hypofractionated radiotherapy of multiple brain metastases using two different multileaf collimator designs

White Paper

## A comparison of VMAT plan quality (target coverage and healthy tissue sparing) and the impact of MLC design for Elekta Agility<sup>™</sup> and Varian HD120

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## Abstract

Hypofractionated radiotherapy (HF-RT), the focal delivery of a high radiation dose (20 – 35 Gy) in 3-5 fractions, is increasingly popular for the treatment of intact brain metastases and post-surgical cavities in patients with large tumor volumes (> 2 cm diameter) or in the recurrent setting. This is because fractionation may mitigate radiation-induced harm to normal tissue compared to single-fraction treatments.

Elekta's Monaco treatment planning system (TPS) was used to produce VMAT plans for multi-target brain HF-RT, comparing plans constructed for two different multileaf collimator (MLC) designs: Elekta Agility (80 x 5 mm leaf pairs across a 40 x 40 cm field size) and Varian HD120 (32 x 2.5 mm and 28 x 5 mm leaf pairs across a 22 x 32 cm field size). Twelve brain metastases patients (34 targets), originally planned and treated at the Odette Cancer Centre using Pinnacle<sup>3</sup>, were replanned in Monaco using both MLC designs. The same planning constraints were used for both MLCs: 30 Gy delivered in 5 fractions using a single-isocenter, 4-arc beam

geometry. The clinical objective was to cover > 98% of the planning target volume (PTV) with the prescription dose and to limit hotspots to < 120% of the prescription, focusing on achieving high conformality. The maximum dose limits were 25 Gy for brainstem, optic nerves and chiasm, and 8 Gy for lenses.

The results of this evaluation indicate that equivalent target coverage and conformality can be achieved with either MLC system, irrespective of leaf width. All treatment plans generated using Monaco met the clinical objectives and plans for both MLC systems satisfied all OAR dose constraints. However, the brain mean dose was lower for Agility in the majority of cases. In conclusion, Agility and HD120 are equally capable of producing VMAT plans in Monaco for HF-RT of multiple brain metastases. The excellent dose modulation available with Monaco, combined with the advanced physics design of Agility, removed any limitations due to leaf width and also offered greater brain sparing, which is important for minimizing cognitive impairment.

## Introduction

The sparing of healthy brain tissue is an important consideration in the stereotactic radiosurgery and radiotherapy of brain metastases in order to protect cognitive function and quality of life for cancer patients, particularly since recurring brain metastases are common and retreatment is frequently necessary.

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Techniques, such as intensity modulated radiotherapy (IMRT) and volumetric modulated arc radiotherapy (VMAT) offer a high degree of target conformity for stereotactic radiosurgery (SRS). In addition, it is considered that fractionation may mitigate radiation-induced harm to normal tissue compared to single-fraction treatments. As a result, hypofractionated radiotherapy (HF-RT), the focal delivery of a high radiation dose (20 – 35 Gy) in 3-5 fractions, is increasingly popular for the treatment of intact brain metastases and post-surgical cavities in patients with large tumors (> 2 cm in diameter), those that are proximal to sensitive structures, and in the recurrent setting.

Multileaf collimators (MLCs) with varying leaf widths are available. Agility™ has been shown to compare well to MLCs with smaller leaf widths in terms of plan quality in VMAT-based SRS/HF-RT planning<sup>1,2</sup>. Studies suggest that MLC leaf widths of 2.5 mm and 5 mm are equally capable of achieving good target coverage with IMRT and VMAT plans<sup>3</sup>, and that the 5 mm leaf width of Agility is more than adequate for the VMAT delivery of SRS to small targets<sup>4</sup>.

This study compares the performance of the Monaco® treatment planning system (TPS)

(Elekta, Stockholm, Sweden) to produce VMAT plans for multi-target brain HF-RT using two different MLC designs: Agility (Elekta, Stockholm, Sweden) and HD120 (Varian Medical Systems, Palo Alto, USA). Agility has 160 leaves with 5 mm leaf width across a 40 x 40 cm field size, whereas HD120 has 120 leaves with 2.5 mm leaf width in the central 8 cm and 5 mm leaf width outside of this central region, across a 22 x 32 cm field width. MLC transmission and other MLC characteristics are available from the manufacturers.

It is proposed that comparable target coverage and sparing of critical structures will be achieved with Agility, despite the smaller leaf width of the HD120, due to the dose modulation capabilities of Monaco and the advanced physics design of Agility for dynamic treatment delivery.

## Patient details

The twelve cases used in this evaluation are shown in table 1. All patients were treated with HF-RT for intact brain metastases. The original prescriptions, set at the treating radiation oncologist's discretion, incorporated many factors, including tumor histology and treatment history, with lower prescription doses generally used for patients with larger tumor volumes or for those who had received previous whole brain radiotherapy (WBRT) and/or SRS.

The patient demographics in this group, with a wide age range, a variety of histologies, a large range of target volumes, and including patients with and without previous radiation treatment, provide a robust sample that is representative of a typical brain metastases case mix.

## A robust sample was used, representative of a typical brain metastases case mix.

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**Table 1. Patient demographics and treatment history**

Patient #	Sex	Age	Histology	Previous WBRT?	Previous SRS?	Number Mets	Original Prescription Dose (5 fractions)§§	Planning Target Volume
1	M	61	Lung	N	N	3	30 Gy	11.7 cm <sup>3</sup>
2	F	76	Lung	Y	N	4	25 Gy	19.1 cm <sup>3</sup>
3	M	43	Kidney	Y	Y	4	25 Gy	7.2 cm <sup>3</sup>
4	F	59	Breast	N	N	3	25-27.5 Gy	76.1 cm <sup>3</sup>
5	F	57	Breast	N	N	3	30 Gy	17.0 cm <sup>3</sup>
6	F	69	Lung	Y	N	5	25 Gy	16.3 cm <sup>3</sup>
7	F	61	Lung	Y	Y	3	15-20 Gy	4.3 cm <sup>3</sup>
8	F	72	Lung	N	N	2	30 Gy	15.3 cm <sup>3</sup>
9	F	58	Lung	N	N	2	30 Gy	10.7 cm <sup>3</sup>
10	F	74	Lung	N	N	1	30 Gy	7.0 cm <sup>3</sup>
11	F	40	Breast	N	Y	1***	32.5 Gy	8.9 cm <sup>3</sup>
12	F	58	Melanoma	Y	Y	3	30 Gy	8.7 cm <sup>3</sup>

WBRT=Whole brain radiotherapy; SRS=stereotactic radiosurgery.

\*\*\*Patient 11 had 3 closely spaced metastases planned, which were merged into a single target for this evaluation.

§§For the purposes of this evaluation, a planning dose of 30 Gy in 5 fractions was used for each case.

The locations of the brain metastases varied from patient to patient. Metastatic disease is typically diagnosed based on radiological findings on T1- and T2-weighted MR images

(see figure 1). Post-gadolinium acquired T1-weighted MR images are also used for target delineation in radiotherapy planning.

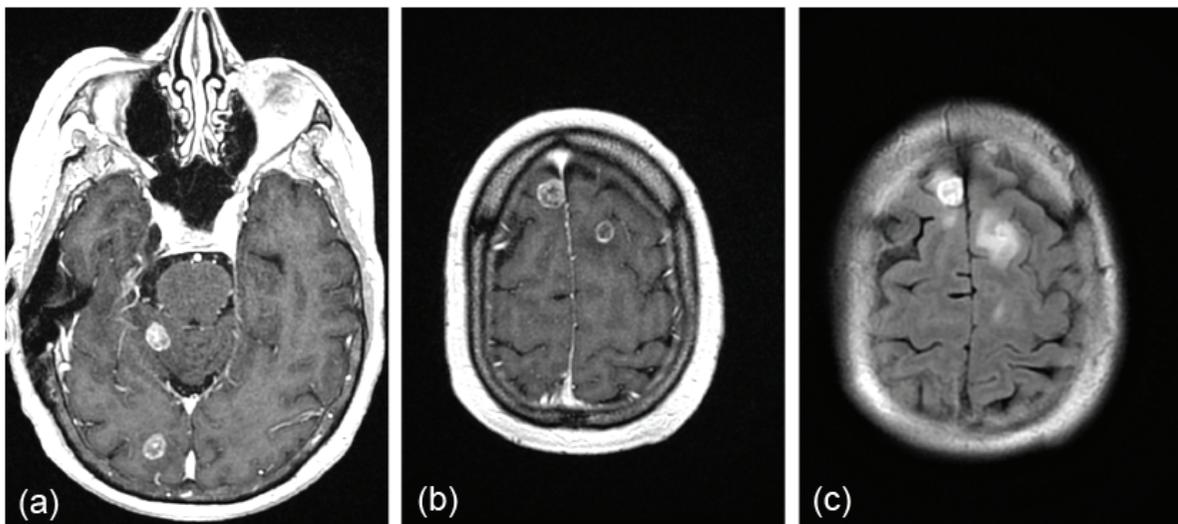


Figure 1: Examples of diagnostic MR images used in this evaluation. (a) and (b) are axial T1-weighted post-gadolinium injection images of Cases 6 and 3 respectively, each showing two enhancing lesions. (c) is an axial T2-weighted FLAIR image of Case 3 registered to the scan in (b).

## Treatment planning details

For each case, planning CT scans were acquired with the patient in treatment orientation within their immobilization device. Immobilization was achieved using a thermoplastic mask (Orfit Industries, Wijnegem, Belgium) or a bite-block system (Aktina Pinpoint). The gross tumor volume (GTV) was contoured on the axial volumetric T1 post-gadolinium MRI scan fused to the treatment planning CT and organs at risk (OAR), consisting of the brainstem, globes, lenses, optic nerves and chiasm, were contoured on the planning CT. No additional expansion to the GTV was made to define a clinical target volume (CTV) (i.e. CTV = GTV). A planning target volume (PTV) margin of 2 mm was then applied around each CTV. The original clinical plans were generated in Pinnacle<sup>3</sup> (Philips, Amsterdam, The Netherlands) following the protocol outlined by Ruschin et al<sup>5</sup>.

In this evaluation, two new plans were generated for each patient within Monaco version 5.11: one plan using an Elekta Agility beam model, based on Odette Cancer Centre's commissioning data, and another plan using a Varian HD120 beam model obtained from an Elekta library of clinical beam models.

Monaco is a comprehensive treatment planning solution for 3D, IMRT, VMAT and stereotactic techniques that uses the gold-standard Monte Carlo dose calculation algorithm to deliver highly accurate dose distributions. With a suite of optimization tools, the Monaco software is designed to generate plans that spare as much healthy tissue as possible, while maximizing dose to the target.

## The same treatment planning constraints, arc arrangement and TPS settings were used for both MLC designs.

The same treatment planning constraints were used for both MLC designs and all plans were run on a 24 core HP z820 workstation with 32 GB RAM. Each PTV was set to receive 30 Gy, defined as a relative dose level of 100% of the prescription, in five fractions. The objective for each plan was to cover  $\geq 98\%$  of the PTV with 100% of the prescription dose (i.e. V100  $\geq 98\%$ ). In order to maintain consistency with the Odette Cancer Centre's HF-RT program, attempts were made to constrain the maximum PTV dose (PTV Dmax) to 120% (i.e. 36 Gy). Furthermore, it was determined that the PTV conformity index, based on the RTOG definition (CI-RTOG), should be less than 1.3. Maximum dose constraints for critical structures were  $< 25$  Gy for the brainstem, optic nerves and chiasm, and  $< 8$  Gy for the lenses.

## Average treatment planning time was just 28.9 minutes.

The same arc arrangement and TPS settings were used for both MLCs. A single isocenter and four 180 degree arcs were used, with couch angles  $+10^\circ$ ,  $-10^\circ$ ,  $+50^\circ$  and  $-50^\circ$  (as illustrated in figure 2). All planning was performed using the Monte Carlo dose calculation algorithm on a 2 mm calculation grid, with 1% statistical uncertainty per calculation, and dose calculated to medium. The minimum segment width was set at 0.5 cm. The average treatment planning time with Monaco version 5.11 (including optimization and Monte Carlo segmentation) over all cases was just 28.9 minutes.

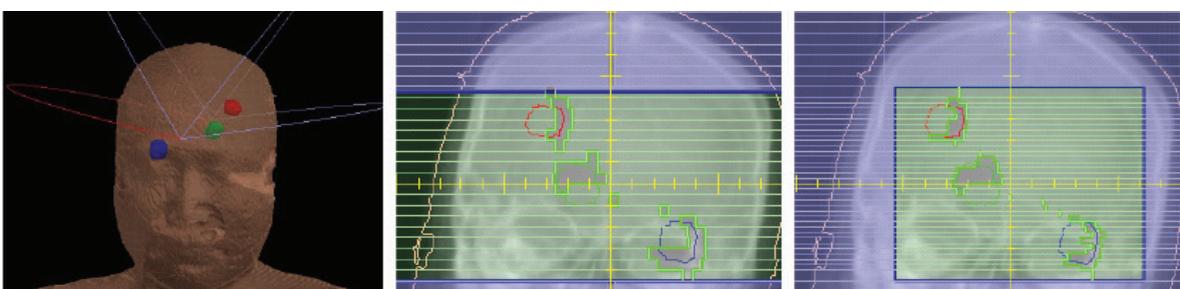


Figure 2. Illustration of planning details and parameters. Left: 3D rendering of Case 1 showing 3 targets in blue, red and green and the arc arrangement used. Middle: beam's eye view (BEV) of a segment produced with the Agility beam model. Right: BEV of same patient and angle produced with the HD120 beam model, illustrating the finer leaf width in the central 8cm of the field. Segment angle used in BEV was for Gantry 180 degrees.

## Results

All treatment plans generated in Monaco for this evaluation met the clinical objectives. Statistically, there was no difference between the Agility plans and the HD120 plans in terms of V100 ( $p=0.5$ ) or conformity index ( $p=0.6$ ), which demonstrates that the difference in leaf width between the two systems was not an issue for the TPS and that equivalent plan quality could be achieved (see figure 3 for an example plan).

**All treatment plans met the clinical objectives, with no difference in V100 or conformity index between Agility and HD120.**

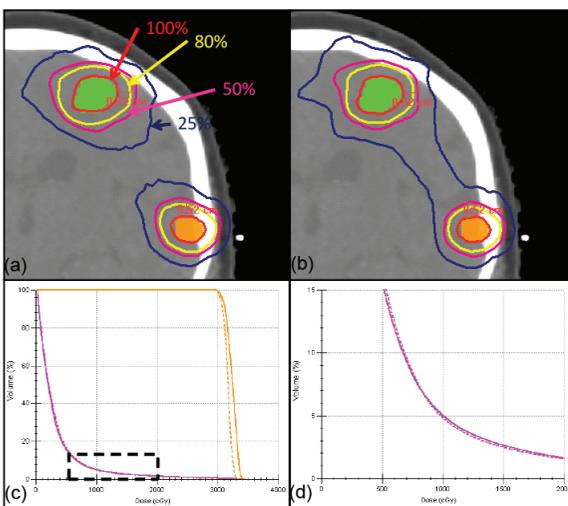


Figure 3. Example of dose distribution in coronal plane for Case 7. (a) Agility plan. (b) HD120 plan. Note the 0.52 cm annotation showing the distance from the 100% isodose line to the 50% on the HD120 does not extend to the 50% isodose line on the Agility plan. The 25% isodose line bridges both targets on the HD120 plan and is well separated on the Agility plan. (c) is the DVH for the inferior PTV and the brain contour. Dashed lines are for HD120 and solid line is for Agility. (d) is a close up of the brain DVH (indicated by dashed box in (c)) showing lower volumes for ~800 cGy and the reverse trend below ~800 cGy.

Due to the complex nature of multiple target planning, the conformity index (CI) exceeded 1.3 in 21 and 19 out of 34 targets for Agility and HD120 respectively. PTV D50, D2 and point maximum dose was on average 0.4 Gy higher for the Agility plans compared to HD120 ( $p<0.0001$ ). There was no statistically significant difference in maximum doses to brainstem, optic nerve, chiasm and lenses between Agility and HD120 plans (although more active brainstem shielding was achieved in the Agility plan for case 6, see below), highlighting comparable critical structure sparing irrespective of leaf width.

Dose fall-off was also similar for both MLC systems. The HD120 plans tended to have a tighter distribution for isodose lines from 24 Gy to 12 Gy in 9/12 cases (figure 4a and 4b), while the Agility plans had a tighter distribution for lower isodose lines in 8/12 cases (figure 4c). Overall, the mean brain dose was lower for Agility in 8/12 cases (Figure 4d), which is important for healthy brain sparing and preservation of cognitive function.

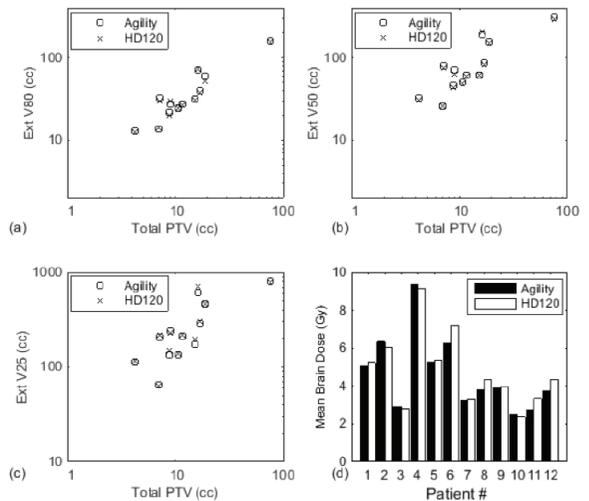


Figure 4. The total tissue receiving 80% (a), 50% (b) and 25% (c) of prescription dose are plotted against total PTV. The mean brain dose is shown for all patient plans in (d). "Ext" indicates the entire external volume, including all tissue beyond the brain itself and also including the targets.

## Overall, the mean brain dose was lower for Agility.

Case 6 was particularly challenging due to multiple targets and one PTV proximal to the brainstem (figure 5), which prevented full target coverage for this PTV. For this case, the volumes of brain receiving all isodose lines were lower for Agility than for HD120. Furthermore, the brainstem was more actively shielded in the Agility plan, as shown in the dose volume histogram (DVH) in Figure 5 (d). This is an important consideration in the treatment of brain metastases where tumors are likely to recur and the patient may require further treatment in the future. Both the Agility and the HD120 plans satisfied the brainstem clinical maximum dose requirement of < 25 Gy, achieving 24.5 Gy and 23.7 Gy respectively for case 6.

## In case 6, the brainstem was more actively shielded in the Agility plan.

The results of the present study should be interpreted with caution as the plans were not verified with measurements. It should be noted that the HD120 system tended to use more

monitor units (MU) than Agility (in 36 out of 48 arcs), with a mean difference of 87 MU ( $p=0.001$ ), and that the number of segments yielded in the HD120 plans was on average 24 higher than in the Agility plans ( $p=0.000001$ ). The higher MU and greater number of segments produced in the HD120 plans indicate a higher degree of modulation, which may be a result of the smaller leaf width.

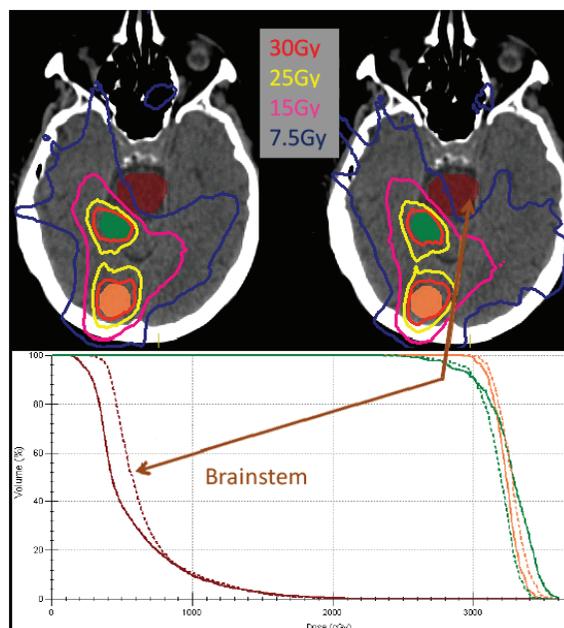


Figure 5. Sample distribution and DVH for Case 6 involving a target in close proximity to the brainstem. HD120 is top left and Agility is top right. The solid lines on the DVH are for the Agility plan and dashed is the HD120.

## Summary of results

Comparison between Elekta Agility and Varian HD120 single isocenter VMAT plans generated using Monaco version 5.11 for 12 brain metastases patients (34 targets):

Criteria	Elekta Agility	Varian HD120
Plans meeting clinical objectives	100%	100%
V100	No difference ( $p = 0.5$ )	
CI-RTOG	No difference ( $p = 0.6$ )	
Plans exceeding CI = 1.3	21	19
Maximum dose to critical structures	No difference	
Dose fall off	Comparable	
Mean brain dose	Lower in 8/12 cases	Higher in 8/12 cases
MU used	Lower overall	Higher overall (mean difference 87 MU $p = 0.001$ )
Segments yielded	Lower	Higher (by 24 on average $p=0.000001$ )

## Conclusions

Overall, the plan quality produced by Monaco using both MLC systems met the clinical objectives required at the Sunnybrook Odette Cancer Centre.

### Equivalent target coverage and conformality can be achieved with either MLC system, irrespective of leaf width.

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The results of this evaluation indicate that equivalent target coverage and conformality can be achieved with either MLC system, irrespective of leaf width. Although plans for both MLC systems satisfied all OAR dose constraints, the mean brain dose was lower for Agility in the majority of cases. As discussed, any sparing of healthy brain tissue is desirable for preserving quality of life and cognitive function for patients.

### The excellent dose modulation available with Monaco, combined with VMAT delivery and the advanced physics design of Agility, removed any limitations of leaf width.

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In conclusion, Agility and HD120 are equally capable of producing VMAT plans in Monaco for HF-RT of multiple brain metastases. The excellent dose modulation available with Monaco, combined with VMAT delivery and the advanced physics design of Agility, removed any limitations of leaf width. These findings are supported by recent published studies that compared plan quality using different MLC designs for IMRT/VMAT deliveries, and demonstrated how advances in dynamic modulation have allowed high conformality irrespective of leaf width<sup>1-3</sup>.

### Agility and HD120 are equally capable of producing VMAT plans in Monaco for HF-RT of multiple brain metastases.

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It should be noted that, when a single isocenter is used to treat multiple targets, some of the HD120 plans are not able to maximize the utilization of smaller MLC leaf width because of the targets falling outside the area covered by the 0.25 cm leaves.

Significantly, Monaco with Agility was able to produce comparable plan quality to the HD120 MLC using fewer MU and a smaller number of segments. Although a high degree of modulation is possible within Monaco for complex cases, if required (with 1024 modulation points available when used with Agility), the Agility plans in this evaluation generally required less modulation to meet planning constraints, allowing precise and efficient dose delivery.

### Agility was able to produce comparable plan quality, using fewer MU and a smaller number of segments.

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It should be noted that, for published MLC widths (i.e. 2.5 mm to 5 mm), the desired plan quality can often be achieved by adjusting the optimization objectives used in treatment planning. However, in adjusting planning objectives, other changes to the treatment plan can result, such as more MUs, more modulation, etc., which should be carefully evaluated in addition to plan quality. The work to verify the treatment plans in this evaluation, by delivering the plans to phantoms, is ongoing. It should also be noted that the treatment plans in this study were generated using a TPS that employs radiobiological cost functions, and that other methods of setting objectives (e.g. DVH-based constraints) were not evaluated.

## References

- [1] Sarkar B, Pradhan A, Munshi A (2016) Do technological advances in linear accelerators improve dosimetric outcomes in stereotaxy? A head-on comparison of seven linear accelerators using volumetric modulated arc therapy-based stereotactic planning. *Indian J Cancer* 53:166-73.
- [2] Ruschin M, Sahgal A, Iradji S et al. (2016) Investigation of two linear accelerator head designs for treating brain metastases with hypofractionated volumetric-modulated arc radiotherapy. *Br J Radiol* 89: 20160093
- [3] Luzzara, M, Santoro, L, Brown, K. (2016) Has IMRT Changed the Impact of MLC Leaf Width? A Systematic Review and Meta-Analysis of TPS Studies. AAPM 2016 presentation, Washington DC.
- [4] Iwai, Y, Ozawa, S, Ageishi, T et al. (2014) Feasibility of single-isocenter, multi-arc non-coplanar volumetric modulated arc therapy for multiple brain tumors using a linear accelerator with a 160-leaf multileaf collimator: a phantom study. *J Radiat Res.* 55(5):1015-20.
- [5] Ruschin, M, Lee, Y, Beachey, D et al. (2016) Investigation of Dose Falloff for Intact Brain Metastases and Surgical Cavities Using Hypofractionated Volumetric Modulated Arc Radiotherapy. *Technology in Cancer Research & Treatment* 15(1):130-8.

## Disclaimers

This publication is based on the experience and application of a medical expert, and is intended as an illustration of an innovative use of Elekta solutions. It is not intended to promote or exclude any particular treatment approach to the management of a condition. Any such approach should be determined by a qualified medical practitioner.

It is important to note that radiation treatments, while usually beneficial, may cause side effects that vary depending on the clinical site being treated along with other medical circumstances. The most frequent side effects are typically temporary and may include, but are not limited to, skin redness and irritation, hair loss, respiratory, digestive, urinary or reproductive system irritation, rib, bone, joint or soft tissue (muscle) pain, fatigue, nausea and vomiting. In some patients, these side effects may be severe. Treatment sessions may also vary in frequency, complexity and duration. Finally, radiation treatments are not appropriate for all cancers, and their use along with the potential benefits and risks should be discussed before treatment.

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Elekta's purpose is to invent and develop effective solutions for the treatment of cancer and brain disorders. Our goal is to help our customers deliver the best care for every patient. Our oncology and neurosurgery tools and treatment planning systems are used in more than 6,000 hospitals worldwide. They help treat over 100,000 patients every day. The company was founded in 1974 by Professor Lars Leksell, a physician. Today, with its headquarters in Stockholm, Sweden, Elekta employs around 3,600 people in more than 30 offices across 24 countries. The company is listed on NASDAQ OMX Stockholm.



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