

Technical Study

Stereotactic Radiosurgery with Elekta Versa HD™ and Monaco®

Accuracy of a single isocenter,
multiple brain metastases
VMAT plan delivered to a
pseudo-patient dosimetric
gel phantom

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Summary

Phantom details:

- RTsafe PseudoPatient phantom filled with dosimetric gel constructed based on a real patient's CT scan
- RTsafe PseudoPatient phantoms of same size and shape as above but with ionization chamber and film inserts at location of QA target

Simulated plan for:

- 6 brain metastases targets (6–25 mm)
- 1 larger QA target close to brain stem
- Isocenter at centroid of targets

HDRS treatment details:

Dose to targets = 8 Gy

5 non-coplanar VMAT arcs (lateral, vertex and 45°)

Monaco® TPS

Versa HD™

- Agility™

- XVI

- HexaPOD™

1. Introduction

The ability of Elekta Versa HD, equipped with the Agility MLC and in conjunction with the Monaco treatment planning system (TPS), to deliver accurate, precise and efficient radiosurgery to patients with multiple brain lesions was investigated in this study. The combined use of these technologies with image guidance and patient positioning (enabled by XVI and HexaPOD) allows high definition dynamic radiosurgery (HDRS). HDRS is characterized by the integration of optimization, planning, imaging and dose delivery techniques. The Monte Carlo-based TPS takes advantage of

Agility MLC capabilities to create an optimized delivery and is able to place MLC leaves at 1 mm increments rather than to a course 5 mm grid. The 5 mm leaf width can be reduced in the jaw direction by positioning the Y-jaws within leaf widths on either end of the target in steps of 1 mm (Figure 1). Since stereotactic targets only require a few open leaf pairs, this jaw positioning accuracy can significantly improve target conformity. Fast leaf motion (up to 6.5 cm/sec) produces plans with sufficient modulation without compromising accuracy.

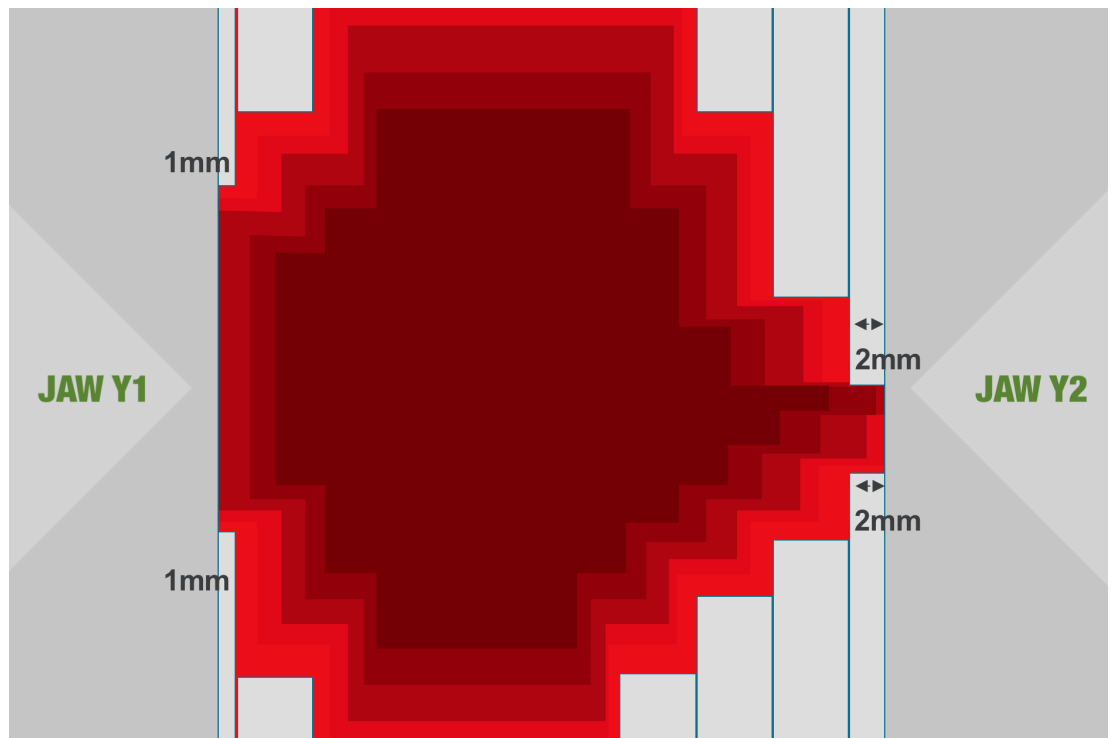


Figure 1.
Illustration of
conformity
capabilities with
jaw positioning

The chain of uncertainty in radiosurgery consists of a number of steps, many of which are independent of dose planning and delivery. Therefore, when validating the accuracy of an integrated technique such as HDRS, end-to-end tests to examine both the localization and dose delivery accuracy of the workflow are essential. In this study, such validation is performed with a patient-specific, anatomically realistic phantom filled with a dosimetric gel, in conjunction with similar phantoms equipped with ion chamber and film inserts, to evaluate the dose distributions delivered by the HDRS workflow.

This validation project was performed at the Mays Cancer Center at UT Health San Antonio. As a National Cancer Institute-designated cancer center, our institution offers a wide array of radiation therapy modalities including VMAT, IMRT, linac-based SRS/SRT/SBRT and conventional radiotherapy. A range of HDR/LDR brachytherapy procedures is also offered with the Nucletron microSelectron® system. The department is equipped with three Elekta Versa HD, a Novalis Tx, two Varian 23EX linear accelerators and a GE LightSpeed CT Scanner for simulation purposes. MOSAIQ® is the primary oncology information system (OIS), coordinating data transfer to the linear accelerators from the treatment planning systems (Pinnacle3, Monaco, Eclipse, Oncentra®).

2. Materials and Methods

Planning

A CT data set from a radiosurgery patient with multiple brain metastases was chosen as the model for the study. The metastases were artificially expanded and/or contracted in the CT data set so that a range of targets with diameters from 6–25 mm could be treated. Six targets were distributed in the brain to represent a range of possible target locations. This included targets close to the periphery of the head to test the effects of rotation on localization accuracy across the brain. The effects of small rotations would be the largest for such peripheral targets. In addition to these six targets, a larger target near the brainstem was also devised to be used for quality assurance of the dose delivery.

The endpoint of this study was accurate localization and dosimetry in an anatomically realistic measurement. Therefore, it was crucial to perform 3D dosimetry, which is only possible with a gel dosimeter. The RTsafe PseudoPatient gel phantom (RTsafe P.C, Athens, Greece) was used in this study. This is the only 3D dosimeter that can be cast in nearly any form, allowing for measurement in a patient-specific geometry. The primary advantage of gel dosimetry in an anthropomorphic phantom is that—unlike most patient-specific QA—it does not rely on a recalculation of the plan on a phantom. Rather, the measurement in the phantom can be directly compared with the patient’s calculated dose distribution.

Three phantoms were produced by RTsafe based on the actual CT data set bony anatomy and external contour for the purpose of this study. The first one was filled with a dosimetric gel (also produced by RTsafe P.C. Athens, Greece) so that 3D dose measurements could be obtained. In addition, the other two nearly identical phantoms were made

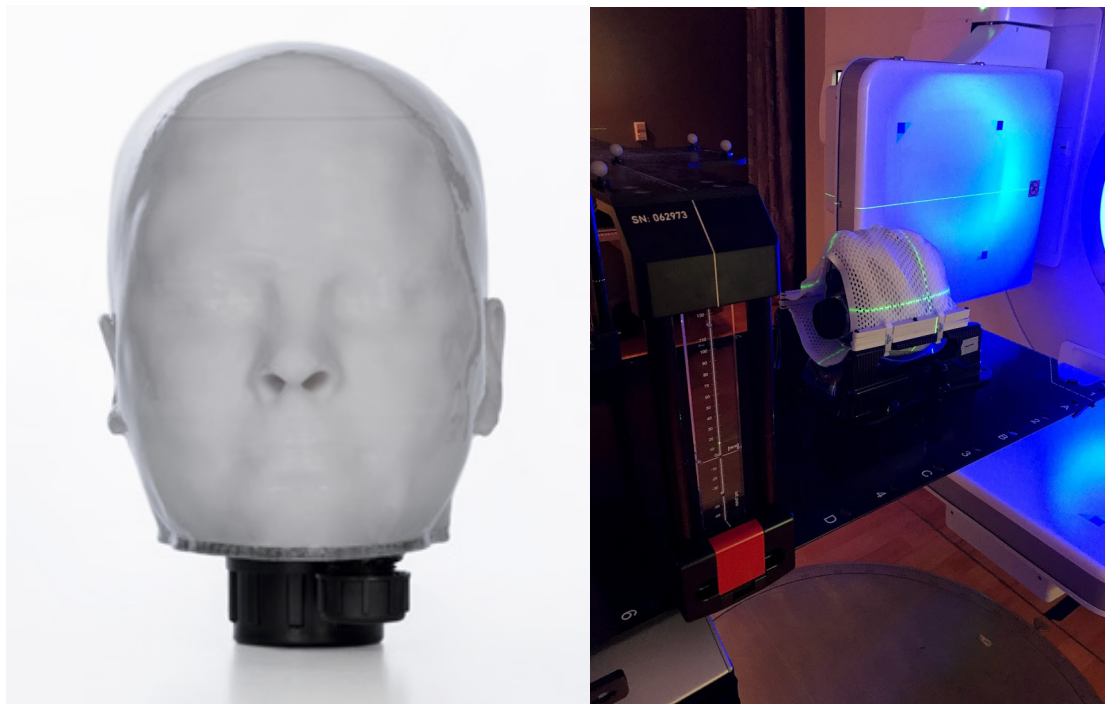
with minor modifications to accommodate other detectors. One had an insert for an A16 ionization chamber and the other had a holder for a film cassette. The ion chamber and film were situated to coincide with the location of the larger QA target. In making ion chamber and film measurements, we could validate the dosimetric accuracy in a larger target size, which is less prone to errors. Validation of the dose in this region allows for the accuracy to be transferred to the six targets in the brain via the gel phantom.

A treatment plan for HDRS delivery was created in Monaco. The CT data set and structures were imported into the planning system, and the isocenter was set based on the centroid of the targets. An arc geometry of five non-coplanar VMAT arcs was used (lateral, vertex and 45°). Since the gel saturates at a dose of 12 Gy, the plan was generated to deliver 8 Gy to the periphery of the six targets, with peaking doses remaining under 12 Gy. In the QA target, a homogeneous dose of 8 Gy was planned. Target penalty, quadratic overdose and conformality objectives were used for IMRT constraints. A 1 mm dose calculation grid spacing was used with one percent statistical uncertainty per calculation of dose to medium. In the five single arcs, 180 control points were allowed with 0.5 cm minimum segment width. Medium fluence smoothing was used.

Once the phantoms were received and scanned, the film and ion chamber phantoms were fused with the patient-derived CT data set to determine the location of the ionization chamber sensitive volume and film plane. The mean dose to the ion chamber sensitive volume was recorded and the DICOM-RT dose was exported for gel and film analysis.



Figure 2.
RTSafe PseudoPatient
gel phantom
photograph (left)
and placement for
dose delivery (right)



Delivery

For delivery of the HDRS plan, the patient-derived CT data set was sent to MOSAIQ record-and-verify, and then imported to XVI for preparation. The isocenter was confirmed and the registration clipbox was set to cover the entire skull. The gel phantom was set up on the table with a mask and other standard immobilization devices on the SRS base plate. An XVI VolumeView cone beam CT (CBCT) scan was then performed and the resulting reconstructed scan was fused with the reference CT data set. Corrections were made in 6D, and the translations and rotations provided were executed by the HexaPOD table. The five arcs were then delivered. The process was repeated for the ionization chamber and film measurements. The A16 ionization chamber was cross-calibrated prior to use. A Gafchromic EBT3 film piece from a batch calibrated at a secondary standard laboratory was used for the film phantom measurement.

Forty-eight hours after the phantom irradiation, the gel phantom was scanned on a 1.5 T MRI unit. A 2D, multi-slice, multi-echo, Half Fourier Single Shot Turbo Spin Echo (HASTE) PD to T2-weighted sequence was implemented sequentially using the head coil. The number of averages was set to 14 in order to increase signal-to-noise ratio, while the bandwidth was set to 1220 Hz/pixel in order to minimize MR-related geometric distortion. The MR protocol used is the one developed and recommended by the gel producer (RTsafe P.C.). The resulting scan was fused with the patient-derived CT data set for analysis. Quantitative analysis was performed with 3D gamma analysis and dose profile analysis. The film was scanned days later and compared with the dose distribution from the patient-derived CT.

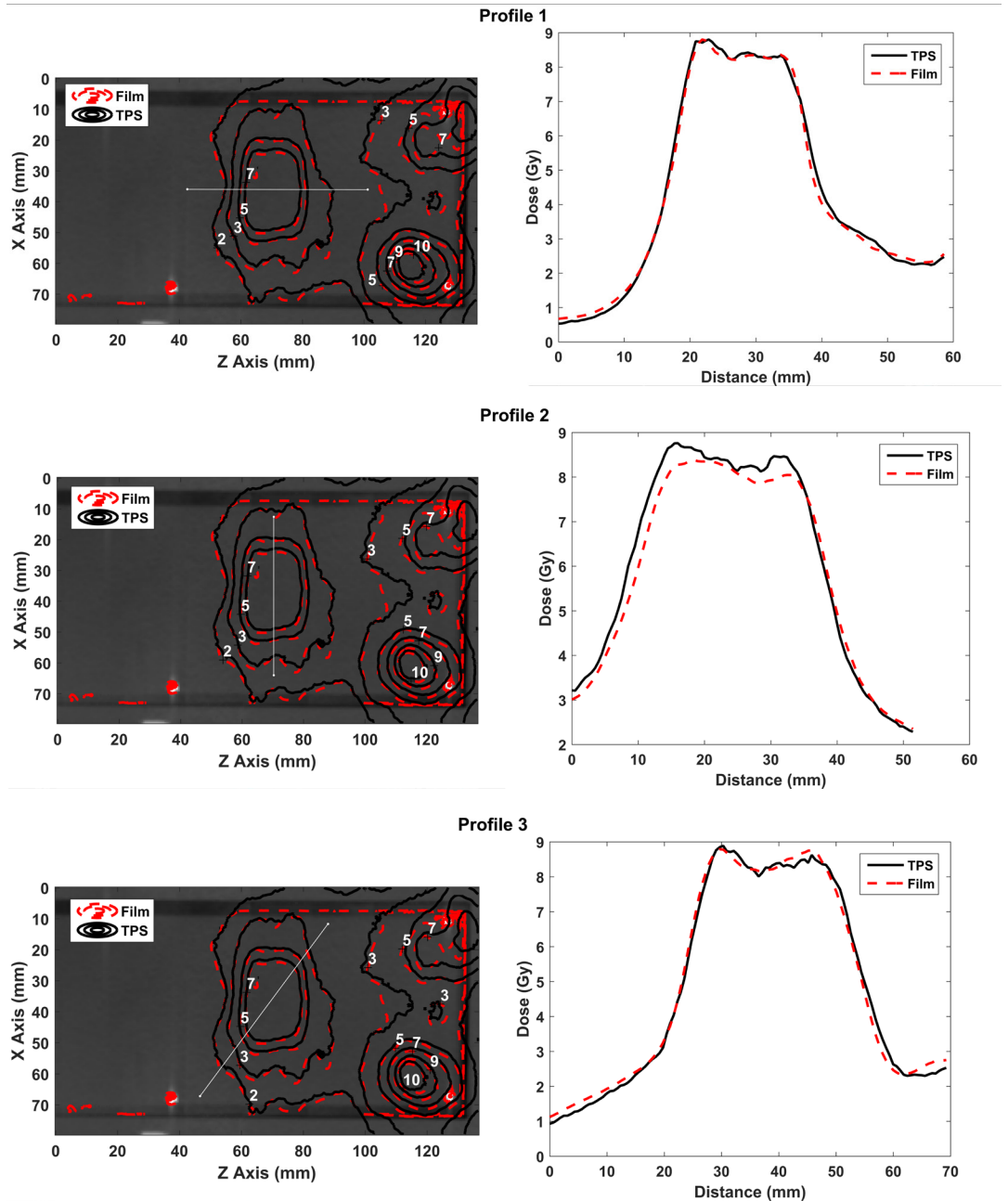


Figure 3a.
Sample profile and
isodose curves from
the film phantom
analysis

3. Results

Ion Chamber

With the A16 ion chamber measurement in the phantom, the measured dose from the plan to the QA target was 844.8 cGy. By comparison, the mean dose in the ion chamber region of the patient-derived CT dose calculation was 829 cGy. This represents an agreement within two percent, which is a sufficient level of agreement for an end-to-end test at our institution.

Film Analysis

The film was read out two days later and compared with the exported dose distribution from the patient-derived CT in Monaco. Sample profiles and isodose curves are shown in the following figures. Gamma analysis was also performed with various passing criteria. With 2%/2 mm criteria, the passing rate of gamma index < 1 was 94.2 percent.

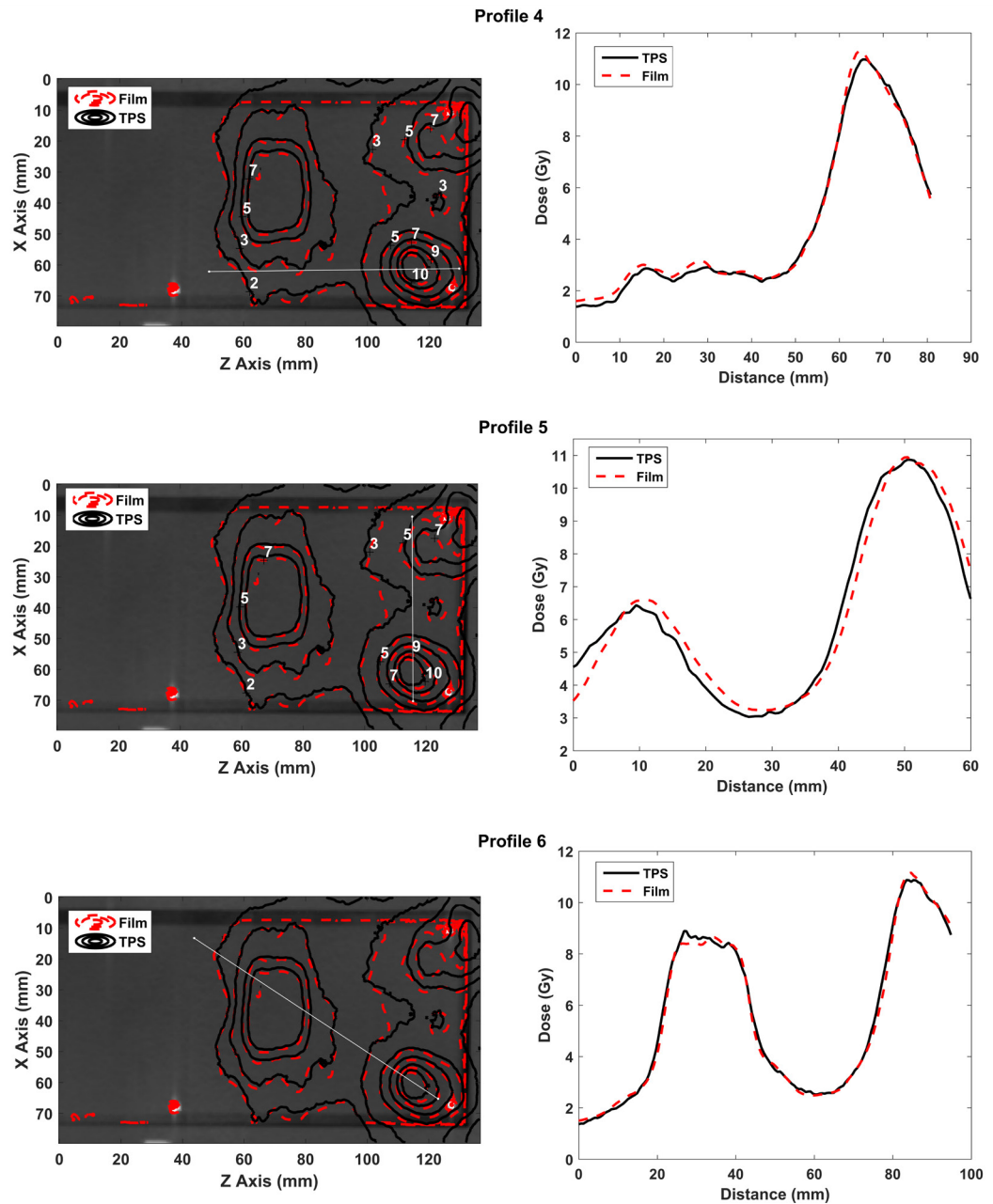


Figure 3b.
Sample profile and
isodose curves from
the film phantom
analysis

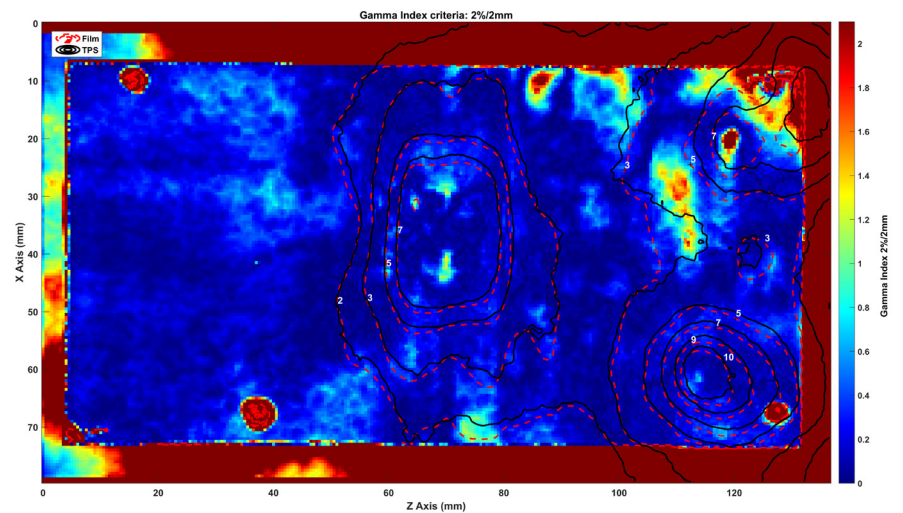
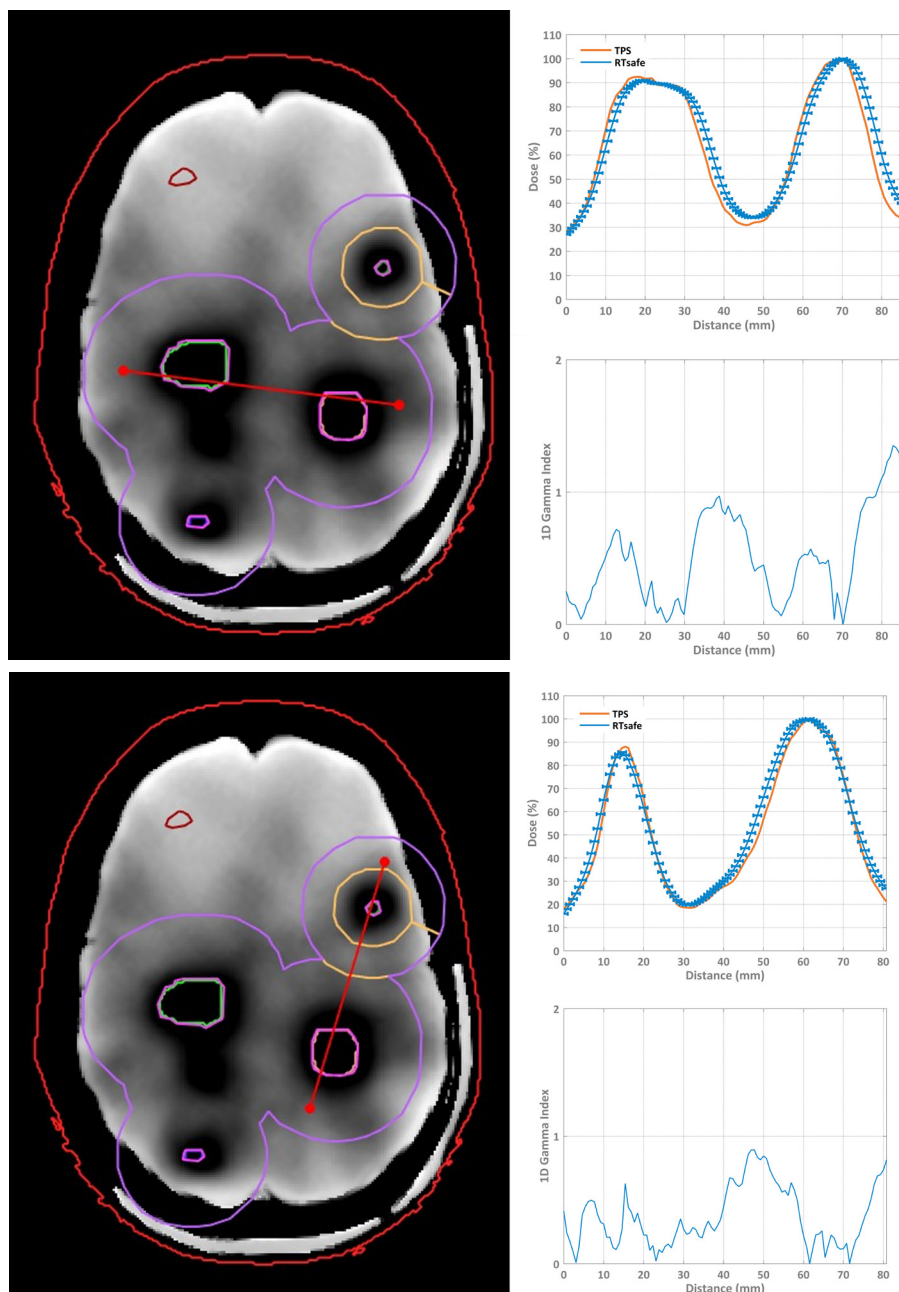


Figure 4.
2D gamma analysis (2%/2 mm)
between TPS and film
measured dose

Figures 5–6:

(left) slice of the derived T2 maps of the irradiated phantom. High dose regions correspond to darker areas; (right) 1D profile comparison between calculated (TPS) and measured (RTsafe) dose distributions at the location depicted by the red line; error bars correspond to ± 1 mm spatial uncertainty; 1D gamma index calculations are also given using passing criteria 5%/2 mm

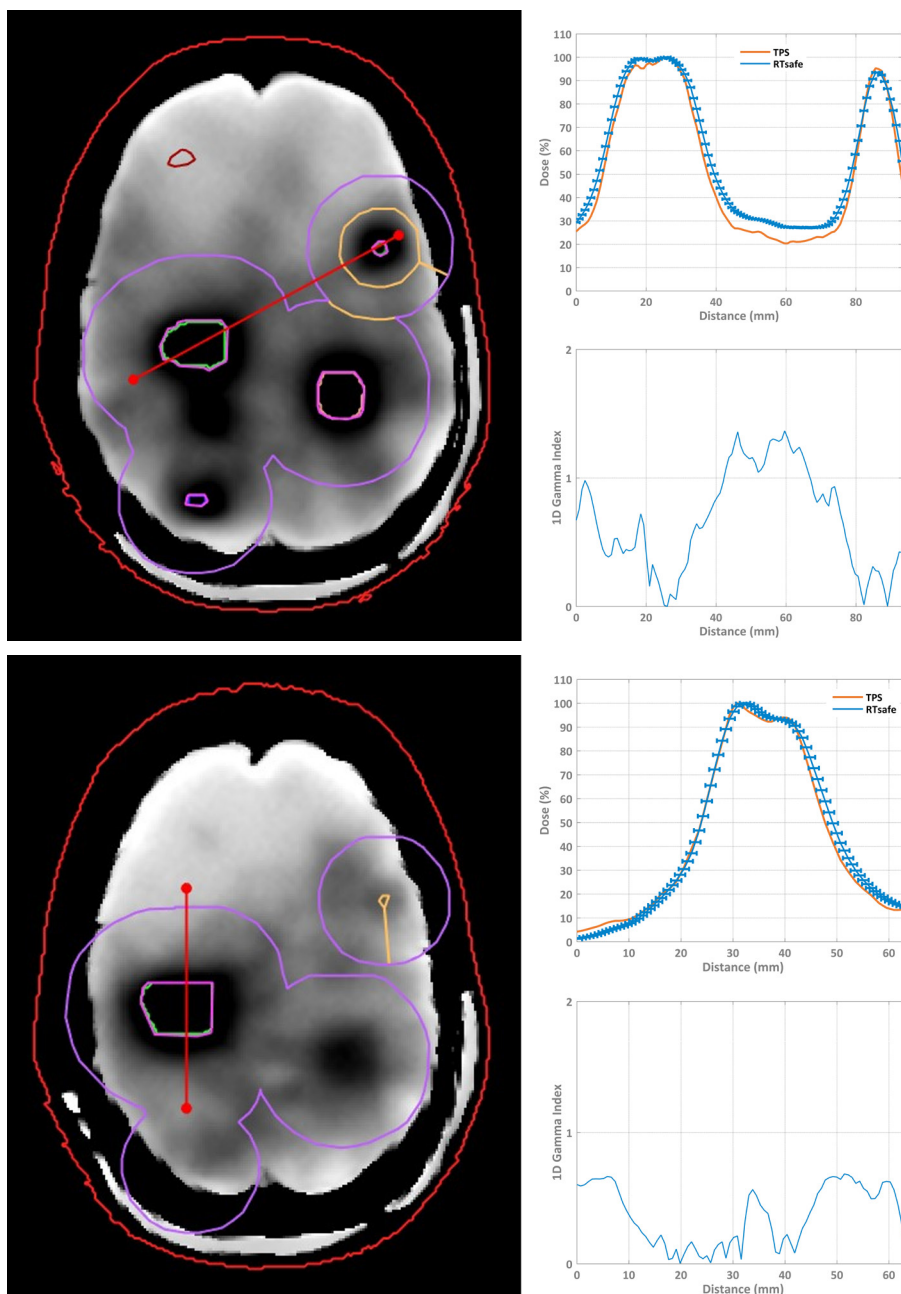


Gel Phantom Analysis

Analysis of the gel was performed by registering the MR scan with the patient CT, and then comparing profiles and 3D gamma analyses between the TPS and measured dose distributions. Figures 5–8 show the dose profile comparisons and 1D gamma analysis along the profiles (5%, 2 mm). In the Figures, the target contours are also shown so the high dose region (in black) can be seen as the dose conforms to the target contours. In the QA target, 3D gamma analysis with criteria of 3%, 2 mm showed that 95.7 percent of the points had a gamma index < 1 .

Figures 7–8:

(left) slice of the derived T2 maps of the irradiated phantom. High dose regions correspond to darker areas; (right) 1D profile comparison between calculated (TPS) and measured (RTsafe) dose distributions at the location depicted by the red line; error bars correspond to ± 1 mm spatial uncertainty; 1D gamma index calculations are also given using passing criteria 5%/2 mm



4. Discussion

The results show the feasibility of highly efficient radiosurgery delivery. The absolute dose delivery accuracy of within three percent, and within one percent when calculated on the phantom itself, suggest a high degree of dosimetric precision with Elekta Versa HD, Agility and Monaco. This agreement validates the very low MLC leakage and precise control systems in place in the Elekta digital linear accelerator, as well as the dosimetric accuracy of the Monaco Monte Carlo TPS.

Regarding localization accuracy, the effect of rotations is still the primary concern for a highly accurate stereotactic delivery across the range of the brain. When analyzing dose profiles across a wide range of regions of interest, some highly conformal profiles were found in conjunction with regions of slight misalignment. Some disagreement is to be expected for any 1D analysis. For example, they may consider misinformation from neighboring slices where high dose gradients may exist. Nevertheless, the localization results were promising given that CBCT of a gel phantom provides a limited amount of image detail to fuse with a planning CT.

From a patient standpoint, these results indicate a vast increase in treatment efficiency by using a single isocenter VMAT technique. This translates to reduced time spent in a mask, thus minimizing uncertainty due to patient motion and couch shifts between isocenters, further increasing treatment accuracy. In addition, treatment time is of the utmost concern given the increased presence of radiosurgery in the modern radiation therapy clinic. Patients with multiple metastases would specifically benefit from HDRS, although very small lesions in the periphery of the head could benefit from separate isocenters to minimize rotational uncertainties, unless a target expansion could be clinically feasible, to account for those uncertainties. Targets located near bony interfaces or near the sinuses, for example, may also specifically benefit from the increased dose calculation accuracy offered by the Monte Carlo algorithm. This is a topic for future investigation.



...the results at this site are very promising as far as accurate, dynamic and efficient dose delivery is concerned.

5. Conclusions

Radiosurgery of multiple metastases in a single isocenter is clearly more efficient than multiple isocenter dose delivery but is subject to increased areas for concern. While it remains to be seen if end-to-end delivery verification is universally accurate across multiple

radiation therapy departments, (something to be verified in a multiple-institution study already underway), the results at this site are very promising as far as accurate, dynamic and efficient dose delivery is concerned.

Disclaimer

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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