Physica Medica 54 (2018) 146–151

Contents lists available at ScienceDirect

Physica Medica

journal homepage: www.elsevier.com/locate/ejmp

Original paper

Dosimetric and localization accuracy of Elekta high definition dynamic radiosurgery

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ABSTRACT

Background and Purpose: With the increasingly prominent role of stereotactic radiosurgery in radiation therapy, there is a clinical need for robust, efficient, and accurate solutions for targeting multiple sites with one patient setup. The end-to-end accuracy of high definition dynamic radiosurgery with Elekta treatment planning and delivery systems was investigated in this study.

Materials and Methods: A patient-derived CT scan was used to create a radiosurgery plan to seven targets in the brain. Monaco was used for treatment planning using 5 VMAT non-coplanar arcs. Prior to delivery, 3D-printed phantoms from RTsafe were ordered including a gel phantom for 3D dosimetry, phantom with 2D film insert, and an ion chamber phantom for point dose measurement. Delivery was performed using the Elekta VersaHD, XVI cone-beam CT, and HexaPOD six degree of freedom tabletop.

Results: Absolute dose accuracy was verified within 2%. 3D global gamma analysis in the film measurement revealed 3%/2 mm passing rates > 95%. Gel dosimetry 3D global gamma analysis (3%/2 mm) were above 90% for all targets with the exception of one. Results were indicative of typical end-to-end accuracies (< 1 mm spatial uncertainty, 2% dose accuracy) within 4 cm of isocenter. Beyond 4 cm, 2 mm accuracy was found.

Conclusions: High definition dynamic radiosurgery expands clinically acceptable stereotactic accuracy to a sphere around isocenter allowing for radiosurgery of several targets with one setup with a high degree of dosimetric precision. Gel dosimetry proved to be an essential tool for the validation of the 3D dose distributions in this technique.

1. Introduction

In recent years, considerable clinical investigation has focused on the role of stereotactic radiosurgery (SRS) in the modern radiation oncology and neurosurgery clinics. Many studies have compared the use of SRS versus whole-brain radiotherapy (WBRT) [1–5]. The rationale motivating the discussion includes the normal tissue sparing and potential decrease in side effects with SRS compared to WBRT [6]. Most studies evaluating SRS versus WBRT focus on patients with one to four metastases leaving five or more in the realm of WBRT [7–9]. However, Yamamoto et al. showed that post-SRS overall survival for patients with 5–10 tumors had similar overall survival to those with 2–4 [10]. Given the decreased side effects of SRS, including cognitive function, it makes sense to treat up to 10 targets if SRS is indicated.

The clinical challenge becomes the efficient radiation delivery to many targets in a clinically realistic and tolerable time frame. The most intuitive method to treat many lesions efficiently is to employ a single setup (single isocenter) treatment technique in which multi-leaf collimators (MLC) are used to dynamically treat targets concurrently. Many solutions to treat multiple brain metastases with a single isocenter exist, and have been delivered with a number of techniques. Dynamic conformal arc (DCAT), 3D, volumetrically modulated arc therapy (VMAT), and HyperArc approaches have been employed with various linear accelerators (Novalis TX, Varian TrueBeam, Elekta Synergy) [11–16]. Treatment planning has been performed in a number of environments including iPlan (BrainLAB, Germany) and Eclipse (Varian, USA). Studies have assessed the safety and accuracy of the treatment technique as a function of rotational uncertainties and distance from isocenter [17–20].

In this study, we investigate the end-to-end accuracy for single-isocenter multiple-metastasis SRS using the Elekta Versa HD equipped with the Agility MLC in conjunction with the Elekta Monaco treatment planning system (TPS). These technologies are integrated with XVI and HexaPOD for 6 degree-of-freedom correction based on cone-beam CT (CBCT) to allow for high definition dynamic radiosurgery (HDRS). The treatment planning system which is Monte Carlo-based also employs the dynamic use of the Y-jaws to define the field control points to overcome the 5 mm MLC width definedgrid. Rapid leaf motion (3.5 cm/sec) produces plans with sufficient modulation and low leakage to treat multiple targets without compromising accuracy. End-to-end accuracy

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https://doi.org/10.1016/j.ejmp.2018.10.003
Received 4 August 2018; Received in revised form 24 August 2018; Accepted 2 October 2018

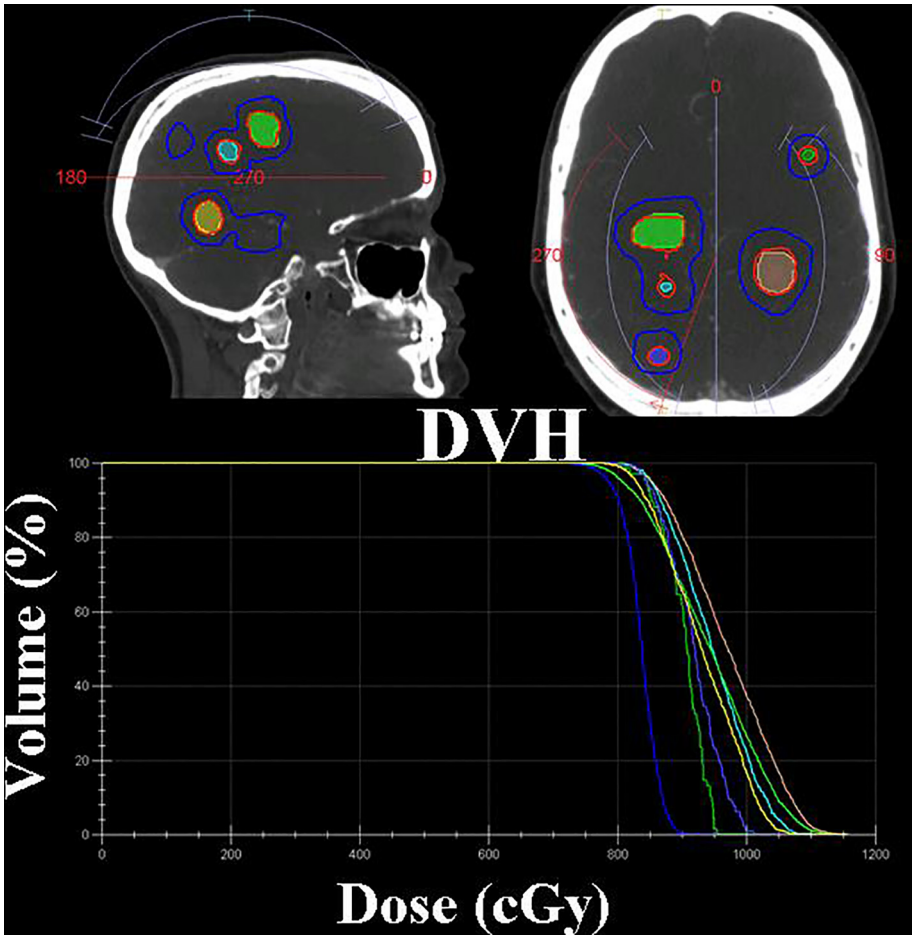

Fig. 1. (Upper) Sagittal and axial slices indicating sample targets (colorwash) and isodose lines (8 Gy and 4 Gy). (Lower) DVH for the six targets (peaking 9.5–11.5 Gy) and film target (8–9 Gy).

has been reported for more general SRS techniques in the literature with sub-millimeter accuracy [21]. Furthermore, studies have investigated specifically the dosimetric accuracy of VMAT delivery of the Agility MLC [22]. This study ties these topics together to investigate the precision achievable with the specific set of technologies which comprise HDRS.

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.

2. Methods

2.1. 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 to 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 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 (QA) of the dose delivery.

As SRS to multiple-metastases consists of numerous well-defined targets, 1D or 2D dosimetry alone is not sufficient to assess the accuracy of the delivered dose distribution. Therefore, 3D gel dosimetry was employed. The RTsafe PseudoPatient™ gel phantom (RTsafe PC, Athens, Greece) was chosen for this application as it is virtually the only 3D dosimeter which can be cast in nearly any form. In this case, the phantom was 3D-printed based on the de-identified CT data set used for planning. This allows for measurement in a patient-specific geometry and does not require recalculation of the planned dose onto a phantom. Instead, the 3D gel phantom can be aligned and treated as if it were the real patient, and the measured dose can be compared directly with the planned dose itself.

Three distinct phantoms were obtained from RTsafe for extended analysis. The first is 3D-printed to include all anatomically realistic bony anatomy and pre-filled with a dosimetric gel produced by RTsafe. The second phantom has an insert for a film cassette. All other space is filled with water prior to delivery. The third phantom is identical to the others but with an insert for an A16 ionization chamber (Standard Imaging, Middleton, WI, USA). For the film and ion chamber phantom, these detectors were placed in the QA target near the brainstem. This target has a larger volume, making it more robust to spatial errors. Note that this does not minimize the end-to-end accuracy assessment which is ultimately measured in the 3D gel phantom for all six small targets as well.

A treatment plan for HDRS delivery was created in Monaco. The CT