Multimodality Imaging for Radiosurgical Management of Arteriovenous Malformations

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ABSTRACT---
Background: Cerebral arteriovenous malformations (AVMs) are rarely seen congenital vascular anomalies. AVMs may lead to intracranial hemorrhages due to disorganized tangle of vessels. Lifetime risk of bleeding from AVMs may be significant given the diagnosis at typically earlier ages of the lifespan, and complications associated with hemorrhage may lead to substantial morbidity or mortality. Management of AVMs aims at eliminating or reducing the risk of subsequent bleeding. In this context, microvascular surgical resection, endovascular embolization and radiosurgical treatment may be used for management of AVMs.

Objective: In this study, we assessed the incorporation of Magnetic Resonance Imaging (MRI) in treatment planning for AVM radiosurgery.

Methods: We identified 25 patients receiving radiosurgery for AVMs at our institution. Radiosurgery target volumes generated by using CT-only based imaging and CT-MR fusion based imaging for each patient were evaluated.

Results: Twenty five patients undergoing SRS for AVMs were evaluated for target volume determination in this study. Mean target volume was 4.9 cc (range: 1.3-15.9 cc) on CT-only imaging, and 5.7 cc (range: 1.4-16.7 cc) on CT-MR fusion based imaging. Target definition based on CT-MR fusion based imaging was identical to the consensus decision of all treating physicians in majority of patients.

Conclusions: Treatment planning for AVM radiosurgery may be improved by incorporating CT-MR fusion based imaging, which clearly should be supplemented with additional data from angiography. There is need for additional studies to establish a consensus on optimal target definition by multimodality imaging for SRS of AVMs.

Keywords--- stereotactic radiosurgery (SRS), arteriovenous malformation (AVM), target volume, magnetic resonance imaging (MRI)

1. INTRODUCTION

Cerebral arteriovenous malformations (AVMs) are rarely seen congenital vascular anomalies which are found in 0.01-0.05% of the population mostly at the 3rd and 4th decades [1,2]. AVMs may lead to intracranial hemorrhages due to disorganized tangle of vessels. Lifetime risk of bleeding from AVMs may be significant given the diagnosis at typically earlier ages of the lifespan, and complications associated with hemorrhage may lead to substantial morbidity or mortality [2-5].

Management of AVMs aims at eliminating or reducing the risk of subsequent bleeding. In this context, microvascular surgical resection, endovascular embolization and radiosurgical treatment may be used for management of AVMs. Stereotactic Radiosurgery (SRS) has been utilized for management of several benign and malign indications with considerable success [6-24]. In the context of AVMs, surgery offers effective management of AVMs in selected patients, however, radiosurgery may be considered when there may be an excessive risk of surgical complications for deep-seated lesions located at eloquent brain regions. Several studies have reported 3-year obliteration rates in the order of 60% to 90%, with safe and effective management of AVMs using SRS, even for larger lesions by use of staged procedures [2,3,8,25-30].

Nevertheless, SRS is not devoid of complications [31,32]. The risk of radiosurgical complications correlate with irradiated volume. From this standpoint, accurate target volume determination has been an indespensable part of successful radiosurgical applications. Considering that adverse radiation effects may be an important aspect of SRS, precision is warranted for treatment to improve the therapeutic ratio.

Initial detection of AVMs is typically based on cross-sectional imaging. Presence of a nidus and arteriovenous shunting are critical components of establishing the diagnosis. In addition to Computed Tomography (CT) simulation, treatment planning for radiosurgery requires incorporating different imaging modalities such as Magnetic Resonance Imaging (MRI) and cerebral angiography. While cerebral angiography may offer a viable imaging modality for diagnosis, treatment planning, and follow up of the patients, MR images may be fused with planning CT images for
improving target determination for SRS of AVMs. In this study, we assessed the incorporation of MRI in treatment planning for AVM radiosurgery.

2. METHODS

We identified 25 patients receiving radiosurgery for AVMs at our institution. SRS was performed after informed consent of the included patients and decision making for treatment with radiosurgery was decided by a multidisciplinary team of experts on neurosurgery, neuroradiology, and radiation oncology. Details of the radiosurgery procedure was described previously [8]. Briefly, a stereotactic head frame was affixed to the patients’ skull under local anesthesia, supplemented with sedation if necessary. Contrast-enhanced planning CT images were acquired at CT simulator (GE Lightspeed RT, GE Healthcare, Chalfont St. Giles, UK) available at our department using a slice thickness of 1.25 mm. After completion of image acquisition at the CT simulator, image data sets were sent to the delineation workstation (SimMD, GE, UK) for contouring of target volume and critical structures in close neighbourhood of the target. For the purpose of our study, determination of target volumes was based on either CT simulation images only or by fusion of T1 gadolinium-enhanced volumetric Magnetic Resonance (MR) images acquired within 1 week before radiosurgery. The 2 target volumes generated by using CT-only based imaging and CT-MR fusion based imaging for each patient were evaluated. Ground truth target volume for each patient was decided by consensus, colleague peer review, and collaboration of the treating physicians to be used for actual patient treatment and comparative assessment of generated target volumes. The radiosurgery planning system used in this study was ERGO ++ (CMS, Elekta, UK) and treatment machine was Synergy (Elekta, UK) Linear Accelerator (LINAC) with 3 mm thickness head-on micro multileaf collimator. In radiosurgery planning, a single 360-degree arc, double 360-degree arcs, or five 180-degree arcs were selected to achieve the institutional planning objectives. Windows and levels of the planning CT simulation images were adjusted to improve target and critical structure visualization. Coronal and sagittal images were used in addition to axial images to achieve improved target and critical structure contouring accuracy. Target coverage and normal tissue sparing was further optimized by use of Arc Modulation Optimization Algorithm. Median dose was 18 Gy (range: 12-20 Gy) prescribed to the 85%-95% isodose line encompassing the target volume. Setup verification was secured by use of kV-CBCT (kilovoltage Cone Beam CT) and XVI (X-ray Volumetric Imaging, Elekta, UK) system. All patients received intravenous dexamethasone with H2-antihistamines immediately after radiosurgical treatment.

3. RESULTS AND DISCUSSION

Twenty five patients undergoing SRS for AVMs were evaluated for target volume determination in this study. Mean target volume was 4.9 cc (range: 1.3-15.9 cc) on CT-only imaging, 5.7 cc (range: 1.4-16.7 cc) on CT-MR fusion based imaging, and 5.9 cc (range: 1.4-16.9 cc) on consensus decision of all treating physicians with colleague peer review. Target definition based on CT-MR fusion based imaging was identical to the consensus decision of all treating physicians in majority of patients. Figure 1 shows the AVM lesion (black arrow) of a patient on axial and coronal planning CT and MR images.
Radiosurgery has been judiciously used for reducing the risk of hemorrhages in adult and pediatric patients with AVMs [33-35]. Several studies using LINAC radiosurgery or gamma knife radiosurgery consistently revealed significant decrease in future bleeding risk after SRS along with early return to normal daily living activities [33-35]. Repeat radiosurgery has also been used for safe and effective management of selected patients [36].

Our study adds to the literature by demonstrating improved target determination with incorporation of multimodality imaging in treatment planning for AVM radiosurgery. It has been shown in several studies that targeting errors may lead to suboptimal outcomes for patients receiving SRS for AVMs [37-39]. While inadequate definition of the nidus may substantially reduce obliteration rates, inclusion of excessive normal brain tissue within the target volume may result in adverse radiation effects. In this context, improving the accuracy of target determination becomes more critical considering the delivery of high dose radiation in a single session with SRS. Since MR images may provide additional information which may be utilized for improved target definition, complementing planning CT images with fusion of MRI may offer precise targeting. Nevertheless, accuracy of target determination warrants further imaging data such as angiography for achieving the best results.

4. CONCLUSIONS

In conclusion, treatment planning for AVM radiosurgery may be improved by incorporating CT-MR fusion based imaging, which clearly should be supplemented with additional data from angiography. There is need for additional studies to establish a consensus on optimal target definition by multimodality imaging for SRS of AVMs.

5. LIMITATIONS

Despite its advantages such as offering a noninvasive treatment modality, there may be a risk of consequent bleeding during the period after SRS of AVM [40-44]. In this context, continued follow up of patients may be considered.
even after obliteration of AVM after SRS. Also, optimal target definition by multimodality imaging should be further investigated in the context of treatment planning for AVM radiosurgery.

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7. REFERENCES


