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Assessment of Target Volume Definition for Radiosurgery of Atypical Meningiomas with Multimodality Imaging

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Abstract

Objective: Meningiomas are most common intracranial benign tumors comprising around one third of all intracranial neoplasms, and typically have benign and indolent nature with slow-growing behaviour. Benign meningiomas are slow growing tumors typically following an indolent disease course. Nevertheless, atypical or anaplastic meningiomas may follow a more aggressive disease course with invasion of critical structures and recurrences. In the current study, we evaluate the incorporation of magnetic resonance imaging (MRI) for radiosurgery treatment planning of atypical meningiomas.

Materials and Methods: Atypical meningioma radiosurgery target volume determination with and without incorporation of MRI has been evaluated. Ground truth target volume used as the reference has been outlined by the board-certified group of radiation oncologists after comprehensive assessment, thorough collaboration and consensus.

Results: Target volume definition by use of Computed Tomography (CT)-only imaging and by CT-MR fusion based imaging has been comparatively evaluated in this study for linear accelerator (LINAC)-based radiosurgical management of atypical meningioma. Ground truth target volume defined by the board-certified radiation oncologists after detailed evaluation, collaboration, colleague peer review and consensus has been found to be identical to target determination by use of CT-MR fusion based imaging.

Conclusion: Despite significant progress in neurosurgical techniques over the years, complete surgical resection may not be feasible in the presence of meningiomas located at eloquent brain areas in close association with important neurovascular structures. RT may have a role in multidisciplinary management of meningiomas. Incorporation of MRI into treatment planning for radiosurgery of atypical meningiomas may improve target definition despite the need for further supporting evidence.

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Introduction

Meningiomas are most common intracranial benign tumors comprising around one third of all intracranial neoplasms, and typically have benign and indolent nature with slow-growing behaviour[1,2,3]. These dural-based tumors have been considered to arise from the arachnoid cap or meningothelial cells present in the arachnoid layer of the meninges[4,5].

Presentation is typically at the 6th to 8th decades of life and incidence increases with increasing age [2,3]. Meningiomas may be histologically classified as benign, atypical, or anaplastic (malignant) meningiomas according to World Health Organization (WHO) classification scheme with the most common type being WHO grade I benign meningiomas[2,5].

Meningiomas can be located at several locations throughout the CNS, however, supratentorial region is the most frequent location followed by the skull base and posterior fossa[6]. Meningiomas placed at the supratentorial region are parafalcine meningiomas, parasagittal meningiomas, intraventricular meningiomas and convexity meningiomas. Meningiomas occurring at the skull base include the tuberculum sellae meningiomas, sphenoid ridge meningiomas, petroclival meningiomas, olfactory groove meningiomas, cavernous sinus meningiomas, and intraorbital meningiomas. Finally, meningiomas placed at posterior fossa region include the cerebellar convexity meningiomas, cerebellopontine angle meningiomas, jugular foramen meningiomas, foramen magnum meningiomas, and peritorcular meningiomas[6].

Benign meningiomas are slow growing tumors typically following an indolent disease course. Nevertheless, atypical or anaplastic meningiomas may follow a more aggressive disease course with invasion of critical structures and recurrences [7-9].

Magnetic resonance imaging (MRI) constitutes the principal modality for imaging of meningiomas. Nevertheless, computed tomography (CT) imaging may aid in detection of tumoral calcifications, intraosseous growth of the tumor particularly for base of skull lesions, and hyperostosis of the neighboring bone[10]. MRI may be utilized for detection of the dural tail as post-contrast linear thickening of duramater in vicinity of the meningioma lesion in some patients and may provide improved contrast differentiation, which may assist in differentiation between intra axial and extra axial meningioma lesions. Typically, a meningioma lesion is visualized as an extra axial mass with well-defined borders. Homogeneous contrast enhancement is typical, nevertheless, areas of central necrosis or calcification may not show enhancement. Incidental detection of meningiomas is quite common, however, affected patients may also suffer from a variety of symptoms associated with location of meningioma.

Active surveillance with periodical neuroimaging can be a viable option for incidentally detected and asymptomatic meningiomas[10,11]. However, surgery has an essential role in treatment particularly in the presence of symptoms due to the mass effect from large lesions at surgically accessible locations[12]. Simpson described the 5 grades of meningioma removal and reported an association between aggressiveness of surgical resection and subsequent recurrences of meningiomas[12]. Although there has been significant progress in neurosurgical techniques over the years, complete surgical resection may not be feasible in the presence of tumors located at eloquent brain areas in close relationship with important neurovascular structures[13-16]. Despite surgical resection of some meningioma lesions, recurrences may occur[11,12]. A multimodality treatment strategy with less extensive surgical resection followed by adjuvant radiation therapy (RT) may be preferred in selected patients to avoid excessive toxicity[16]. Advanced RT techniques and radiosurgery in the forms of Stereotactic Radiosurgery (SRS), Stereotactic Body Radiotherapy (SBRT) and Hypofractionated Stereotactic Radiation Therapy (HFSRT) can be utilized for focused irradiation of several CNS disorders as well as tumors located throughout the human body with encouraging treatment outcomes[17-37].

Accurate definition of the target volume is an integral part of successful radiosurgery applications given the smaller treatment volumes receiving higher doses per fraction. Radiosurgery treatment planning has been traditionally based on CT-simulation images of the patients acquired at treatment position. In the current study, we evaluate the incorporation of MRI for radiosurgery treatment planning of atypical meningiomas.

Materials and Methods

Atypical meningioma radiosurgery target volume determination with and without incorporation of MRI has been evaluated. Ground truth target volume used as the reference has been outlined by the board-certified group of radiation oncologists after comprehensive assessment, thorough collaboration and consensus. Informed consents have been provided before treatment, and management with radiosurgery has been decided by multidisciplinary collaboration of a team of experts from neuroradiology, neurosurgery, and radiation oncology. Comprehensive evaluation has been performed taking into account the lesion location, size, symptomatology and patient preferences. CT-simulation for radiosurgery treatment planning has been performed at the CT-simulator (GE Lightspeed RT, GE Healthcare, Chalfont St. Giles, UK) available at our department. Planning CT images have been acquired at CT-simulation and these images have been transferred to the contouring workstation (SimMD, GE, UK) for delineation of treatment volumes and critical structures. Target volume definition for radiosurgical management has been performed by use of the CT-simulation images only or fused CT and T1 gadolinium-enhanced MR images. Target definition with CT only and by incorporation of CT-MR fusion has been comparatively assessed. Definition of the ground truth target volume has been performed by board certified radiation oncologists after detailed assessment, colleague peer review, collaboration and consensus to be used for actual treatment and comparison purposes.

Results

Target volume definition by use of CT-only imaging and by CT-MR fusion based imaging has been comparatively evaluated in this study for linear accelerator (LINAC)-based radiosurgical management of atypical meningioma. Ground truth target volume defined by the board-certified radiation oncologists after detailed evaluation, collaboration, colleague peer review and consensus has been found to be identical to target determination by use of CT-MR fusion based imaging.

Treatment planning for LINAC-based radiosurgery has been performed by ERGO ++ (CMS, Elekta, UK) radiosurgery planning system. Optimal target coverage and normal tissue sparing has been achieved by using a single 360-degree arc, double 360-degree arcs, or five 180-degree arcs in radiosurgery planning. Synergy (Elekta, UK) LINAC available at our department has been used in delivery of treatment. Delineation of the target volume on planning CT and MR images has been optimized by selecting the appropriate windows and levels for radiosurgery planning. Sagittal and coronal images have been used in addition to the axial planning CT images to achieve accurate contouring of target volume and critical structures. Arc Modulation Optimization Algorithm (AMOA) has been utilized for optimization of target volume coverage and critical organ sparing. Figure 1 shows coronal CT image of a patient with atypical meningioma, and figure 2 shows the corresponding coronal MR image of the same patient with atypical meningioma.

Discussion

Histological subtypes of WHO grade I meningioma are psammomatous meningioma, meningothelial (syncytial) meningioma, transitional (mixed) meningioma, fibroblastic (fibrous) meningioma, secretory meningioma, lymphoplasmacyte-rich meningioma, transitional (mixed) meningioma, microcystic meningioma, and metaplastic meningioma with respect to the WHO classification of Central Nervous System (CNS) tumors[6]. WHO grade II meningioma histological subtypes as per the WHO classification are atypical meningioma, clear cell meningioma, and chordoid meningioma[6]. Finally, WHO grade III meningioma histological subtypes are anaplastic (malignant) meningioma, rhabdoid meningioma, and papillary meningioma[6].

Benign meningiomas typically follow an indolent disease course with a low risk of recurrence after complete surgical removal. However, atypical or anaplastic meningiomas may follow a more aggressive disease course with predilection for invasion of critical structures and recurrences despite surgical management[7-9]. In this context, RT may serve as an integral component in multimodality management of meningiomas, particularly in the setting of incomplete resection.

There have been substantial advances in the discipline of radiation oncology recently including contemporary treatment strategies such as Image Guided Radiation Therapy (IGRT), Adaptive Radiation Therapy (ART), Intensity Modulated Radiation Therapy (IMRT), Breathing Adapted Radiation Therapy (BART), and stereotactic irradiation with SRS, HFSRT, and

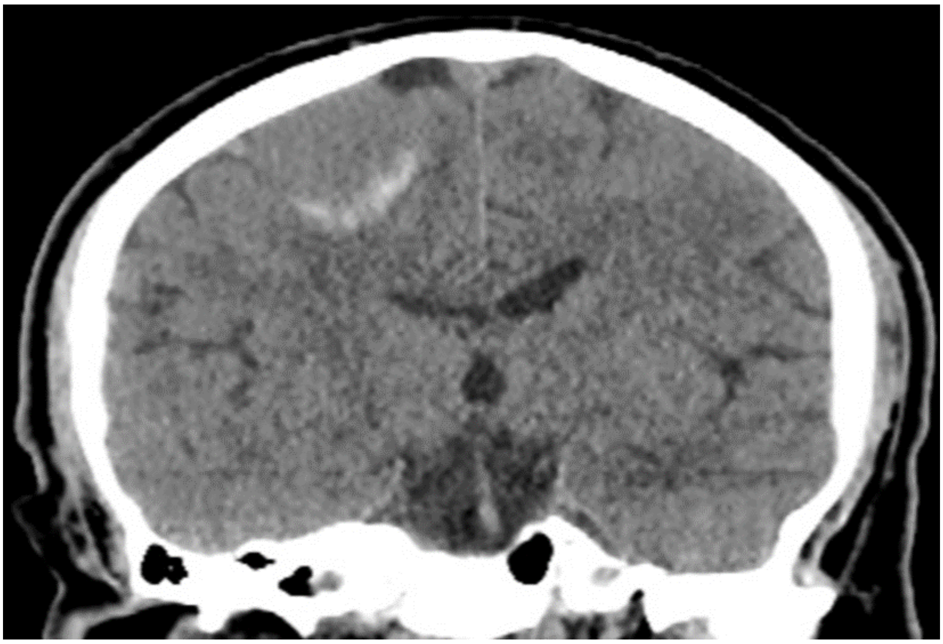

Figure 1. Coronal CT image of a patient with atypical meningioma

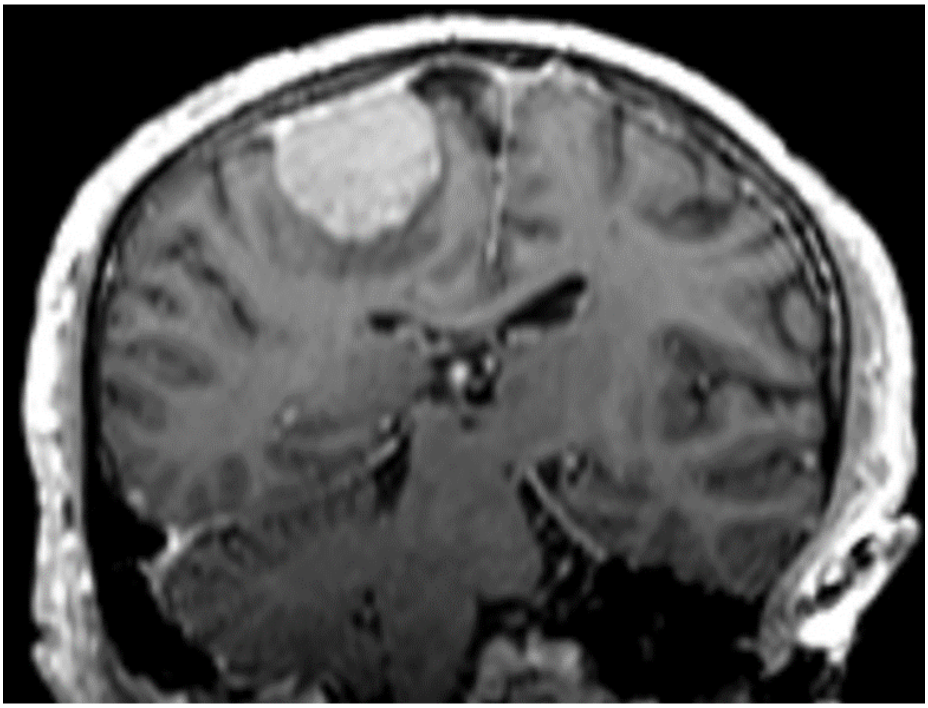

Figure 2. Corresponding coronal MR image of the same patient with atypical meningioma

SBRT[38-44].

Radiosurgery has been utilized for management of atypical meningiomas with encouraging outcomes[45-51]. Radiosurgery may be utilized for improved precision in RT delivery by use of stereotactic localization and optimized normal tissue sparing with steeper dose gradients around the target volume. Delineation of target volume for radiosurgery is a critical aspect of management. Excessive toxicity may result from determination of larger target volumes and geopraphical misses may occur when smaller than actual target volumes are determined. Multimodality imaging may add to the accuracy and precision in target contouring. Combined use of fused CT and MR images may supplement each other for accuracy in contouring of target volume for radiosurgery. Utility of multimodality imaging for radiosurgery treatment planning for atypical meningiomas has been poorly addressed in the literature. In this context, our study adds to the literature by reporting improved target definition by incorporation of MRI in radiosurgery treatment planning for atypical meningiomas. Indeed, several other studies have addressed the utility of multimodality imaging for radiosurgery target volume definition [52-63].

In conclusion, incorporation of MRI into treatment planning for radiosurgery of atypical meningiomas may improve target definition despite the need for further supporting evidence.

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