Stereotactic Radiosurgery – A Review


Abstract

The concepts for neurosurgeons and radio-oncologists have been changed during the last decade and have also transformed neurosurgery. Stereotactic radiosurgery is related to the history of “radiotherapy” and “stereotactic neurosurgery”. The gamma knife and the stereotactically modified linear accelerator (LINAC) are radiosurgical equipments to treat predetermined intracranial targets through the intact skull without damaging the surrounding normal brain tissue. Histological determination by stereotactic biopsy remains the basis for any otherwise undefined intracranial lesion. The impact of radiosurgery is presented for the management of gliomas, metastases, brain stem lesions, benign tumours and vascular malformations and selected functional disorders such as trigeminal neuralgia. In AVM’s it can be performed as part of a multimodality strategy including resection or endovascular embolisation. Finally, the technological advances in radiation oncology as well as stereotactic neurosurgery have led to significant improvements in radiosurgical treatment opportunities. The combination of both, the neurosurgical and the radio-oncological expertise, will help to minimize the risk for the patient while achieving a greater treatment success.

Keywords: Stereotype, Radiosurgery

Introduction

The term “radio surgery” refers to a combination of principles and methods derived from “radiotherapy” and “stereotactic neurosurgery” [1].

Already in 1908 Horsley and Clarke developed the first stereotactic apparatus in order to precisely locate the cerebellum of the rat. They included coordinates from countless brain sections for orientation within the skull. The next milestone was the development of a stereotactic system in humans by Spigel and Wycis in the late 1940’s, designed to treat movement disorders in humans for the first time. Herein, help-structures like the foramina of Monroi, the pineal gland and both the anterior and posterior commissural were defined as targets in the basal ganglia by means of pneumato cephalograms [2, 3]. Finally, Lars Leksell and Traugott Riechert, and also Robert and Wells established frame based stereotactic methods on the basis of coordinates of linear computer tomography data. This technique remains the gold standard for stereotactic planning up until now [4, 5].

However, with the introduction of new imaging modalities new frame materials, i.e. titanium, carbon or ceramics, became necessary. Importantly, the introduction of image fusion software has enabled the use of combined imaging techniques, i.e. CT, PET, SPECT, MRI, which further improved the quality and precision of stereotactic techniques [6]. However, despite the significant progress in the diagnostic accuracy of modern imaging modalities, the histological determination of brain pathologies remains necessary in most cases, especially if a radio surgical treatment is planned. Reasons for the failure of stereotactic radio surgery in achieving an adequate tumour control include an inadequate visualization of the tumour, a lack of intraoperative 3-D (volumetric) imaging, or an insufficient or limited dose (e.g. due to proximity to the brainstem) [7].

The principles of radio surgery were developed in 1951 by Leksell. This technical realization led to the development of the gamma knife and the stereotactically modified linear accelerator (LINAC). The hemispherical array of sources, the large number of small-diameter beams, and the steep dose gradients surrounding a targeted lesion bear the complexity of the physical characterization of the radiation field [8].

Malignant Gliomas

For patients with malignant glioma clear survival advantages have been demonstrated with post resection external beam radiotherapy. However, there is Level III evidence that the use of...
a radio surgery boost followed by external beam radiotherapy does not confer benefit in terms of overall survival, local brain control, or quality of life as compared with external beam radiotherapy alone. Notably, radio therapeutic doses escalating 60 Gy have been shown to solely increase toxicity [9]. Nevertheless, for these patients the total resection of >90% of the “visible” tumor masses, which is defined by contrast enhanced T1 weighted MRI, is a prerequisite. Any further “cyto-reduction” in terms of incomplete resection remains out of evidence for outcome and survival. The current standard treatment consists of external beam radiotherapy combined with concomitant and adjuvant temozolomide chemotherapy with respect to clinical and social conditions. The combined and adjuvant administration of temozolomide has been proven to be beneficial in terms of survival in newly diagnosed as well as recurrent malignant brain tumors [10].

Avm
Radio surgery has been proven to be successful in the treatment of small arteriovenous malformations (AVMs) of the brain [11, 12, 13, 14]. Until now, digital subtraction angiography (DSA) has been a mandatory tool for the planning of these interventions. By integrating different imaging modalities in the planning and follow-up procedure, e.g. MRI, many side effects can be avoided [16, 17]. However, due to the often significant volume of healthy tissue being irradiated in cases of larger AVM lesions, reduced radiation doses would be preferable in order to minimize the rate of irreversible radiation injuries. On the other hand, lower radiation doses lead to lower obliteration rates. Thus, several strategies have been developed in the past decade to overcome these dose-volume problems with larger AVMs, including reduced prescription doses, volume fractionation and fractionated stereotactic radiotherapy treatments. AVMs with a volume of ~>3 ml can be completely obliterated (obliteration rate 72-96%), whereas in larger AVMs complication rate and obliteration rate still remain unsatisfactory, especially in AVM’s >10ml [18]. However, recent optimistic reports suggest a benefit of conventional single-dose stereotactic radio surgery (SRS). Radio surgery with marginal dose or peripheral dose around 12 Gy rarely obliterates AVMs and yet most lesions diminish in size after SRS. Higher doses may be reapplied to any residual nidi after an adequate follow-up period. However, long-term data show that some authors treat the patients with lower doses with lesions that failed to completely obliterate in the first place. A recently published study of Han et al. on 218 patients with a follow-up of >2years provides a focus on the analysis of the radiation injury rate depending on the AVM volume. Investigators dispensed 25 Gy for small (<4 cm³) and medium size (4-14 cm³) AVMs, and 10 Gy for larger AVMs (>14cm³). The overall obliteration rate was 66.4 %, 81.7% for small, 53.1% for medium and 12.5% for large AVMs. The authors reported an acceptable complication rate of 1.7%-17.4%, depending on the size of the AVM [19-23].

Other Indications
Especially in the field of functional neurosurgery more indications for radio surgery are emerging. Successful treatments of trigeminal neuralgia have been reported with radio surgery of the ganglion gasseri in patients with typical trigeminal neuralgia but also with facial pain due to multiple sclerosis and petroclival meningiomas with infiltration of the trigeminal nerve. Facial pain has become a common indication for radio surgery with an acceptable rate for hypaesthesia and a meaningful relief of pain in the vast majority of the treated patients [24-26]. The overall failure rate is about 15%, which is approximately in the same as for decompression. Chen et al. identified preoperative factors which can determine the outcome for pain control: The response to anticonvulsant medication has been regarded as the single most important prognostic indicator for treatment success [27].

Summary
Radio surgery is enjoying an increasing popularity since the last decade in terms of neurosurgical treatment opportunities but also in terms of treatment options for brain metastases. External beam and interstitial radio surgery have been implemented as commonly applied treatment techniques in radiation oncology as well as neurosurgery due to significant improvements in therapy efficacy, technological safety (smaller multiyear collimators), as well as dose homogeneity provided by the newer LINAC generations and newer generation Radioactive seeds. Technological advances in stereotactic neurosurgery not only lead to higher accuracy and safety in planning of both the target coordinates and trajectories (way to the target) but also provide superior and sophisticated methods for defining any intracranial target volume.

References