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Review

The use of stereotactic radiosurgery for the treatment of spinal axis tumors: A review

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ABSTRACT

As the prevalence of cancer in the general population increases, a greater proportion of patients will present with symptomatic metastatic lesions to the spine. While surgery has been historically considered the treatment of choice for spinal cord/nerve root compression, mechanical instability and intractable pain, radiation therapy – particularly stereotactic radiosurgery (SRS) – has been increasingly used as either a primary or adjuvant treatment modality. In this manuscript, the authors perform a review on the principles behind SRS and its use in the treatment of spinal tumors, specifically primary and secondary malignant tumors. In the last decades, numerous retrospective studies have shown the feasibility of SRS as both primary treatment for malignant tumors, as well as adjuvant treatment following surgical resection. Although local control rates may reach 90%, future studies are warranted to determine optimal doses, fractionation of therapy and the long-term implications of irradiation to neural structures.

Contents

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1. Introduction

Cancer is one of the leading causes of death in both developed and developing countries [1]. As the prevalence of cancer increases and newer therapeutic agents allow for longer survival, it is more likely for patients to present with metastatic disease. Currently, it is estimated that 40% of all cancer patients will develop metastatic spinal disease [2]. Such metastatic lesions may cause local bone destruction causing pain or spinal cord/nerve root compression. While management of metastatic lesions involves a multidisciplinary team, radiotherapy is one of the most frequently used techniques to treat such lesions.

Newer advancements in imaging and radiation delivery have allowed for high doses of radiation to be delivered to very specific targets, in a modality known as stereotactic radiosurgery (SRS). The purpose of this article is to give an overview of the principles behind SRS, followed by its use in the treatment of primary malignant spinal lesions, as first-line treatment for spinal metastases, following failure of conventional radiation and following separation surgery.

2. Literature search strategy

The PubMed and MedLine databases were searched under the terms “stereotactic radiosurgery”, “spinal tumors” and “spinal metastasis” to identify relevant articles. Articles were independently screened by the senior attending authors, and those considered to be of higher impact were referenced in this review. Additionally, books published in the last 10 years on the use of stereotactic radiosurgery for the treatment of spinal tumors were reviewed.

3. Principles behind stereotactic radiosurgery

Swedish neurosurgeon Lars Leksell was the first to coin the term *stereotactic radiosurgery* (SRS) in 1951 [3]. SRS is based on the ability to use multiple radiation beams that intersect in a specific volume in three-dimensional space. It works on the basis of three components: (1) a planning system (including imaging tools, coordinate calculator, etc.); (2) a radiation source; and (3) a localization and placement procedure [4]. SRS relies on the use of ionizing radiation, which may be in the form of electrons (such as in linear accelerators; LINAC), protons (such as in proton beam therapy) or gamma rays (such as in the GammaKnife system). Although SRS historically referred to delivery of a *single* high dose of radiation, currently radiation doses may be fractionated into 1–5 sessions. Radiation is measured in Grays (Gy), with 1 Gy equal to absorbing 1 J of radiation energy by 1 kg of matter.

One of the greatest differences between SRS and conventional radiotherapy is that in the former the software system allows for a precise delimitation of the volume to receive the highest radiation dose, which allows for steep fall-off dose gradients to adjacent tissue [5]. For example, newer SRS systems allow for “fall-off” gradients of 10% per millimeter, meaning that if a lesion were to receive 10 Gy of radiation, the adjacent healthy tissue (e.g. spinal cord, nerve root, etc.) 1 mm away would receive only 9 Gy and so forth [6].

3.1. Gamma Knife

The Gamma Knife was first developed by Lars Leksell and is one of few radiosurgical devices that utilize cobalt-60 as a radiation source [7]. Traditional brain radiosurgery requires the use of a Leksell frame, which is fixed to the skull using percutaneous pins under local anesthesia. Variations of this frame have been utilized to treat patients with cervical spine tumors, for example [8].

A fiducial device is then attached to the frame, and MRI and/or CT images are obtained and loaded into the Leksell Gamma Plan workstation. Each pixel of imaging data is assigned an x, y, and z coordinate value, which allows for precise localization of the target and focal point of treatment beams.

The desired target is centered on the Gamma Knife device, and multiple beams of radiation intersect on this spherical volume known as a “shot” [7]. The volume of these shots depends on the size of the collimator used – 4, 8, 14 or 18 mm. The total radiation dose depends on the length of time the target spends at the focal point of the beams. One of the disadvantages of the Gamma Knife is that the framing system usually requires percutaneous pins, and fractionation is therefore impractical.

3.2. Linear accelerator-based systems

Linear accelerators (LINAC) use microwaves to accelerate electrons, which in turn collide with a heavy metal target [7]. These collisions cause the release of high-energy photons (megavoltage X-rays), which then pass through a collimator to form a beam that may be directed to a desired target. The LINAC gantry and cough can rotate on axes that are perpendicular to each other, thus allowing changes in delivery angles.

Traditional LINAC-based systems obtain target coordinates using imaging with a frame affixed to the patient. However, frameless systems have also been developed, and include the use of skeletal landmarks and/or radiofrequency or infrared fiducials [7].

Contrary to the fixed-beam design of the Gamma Knife, the radiation beam produced by LINAC-based systems can be positioned in different ways, thus allowing more precise treatments. During treatment sessions, the three-dimensional coordinates of the target are centered at “a point intersected by the vertical axis around which the couch rotates. The LINAC rotates in a single plane around a horizontal axis that intersects the vertical axis of couch rotation at the target site” [7].

3.3. Charged particle beam

Charged particle beam systems use high-energy particles such as protons. The energy released by these particles is proportional to their velocity – when they slow down and stop at a depth determined by both the type of tissue traversed and the initial energy of the beam, the majority of their energy is released (in what is known as the Bragg peak) [7]. This principle behind the Bragg peak allows for precise delivery of large amounts of radiation to a specific volume, without requiring multiple treatment arcs.

For this type of treatment, fiducial markers can be placed on or beneath the patient’s skin and can be utilized as reference points for both imaging data and target tracking during treatment.

3.4. Robot-assisted LINAC radiosurgery

Traditional treatment planning is based on obtaining computed tomography (CT) and magnetic resonance imaging (MRI) studies and contouring the lesion to be treated as well as adjacent organs at risk. As mentioned previously, these systems rely on a “frame” that must be attached to the patient for reference during the procedure.