Radiosurgery - Gamma Knife.

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Received: January 2018
Accepted: January 2018

ABSTRACT

Gamma Knife radiosurgery (GKRS) is a type of radiation therapy used to treat tumors, vascular malformations and pain disorders. Gamma Knife radiosurgery utilizes specialized equipment which focuses 201 narrow beams of radiation on a tumor or other target. Although each beam has very little effect on the tissue it passes through, a strong dose of radiation is delivered to the site where all the beams meet. The precision of GKRS results in minimal damage to healthy tissues surrounding the target; thus having a lower risk of side effects compared with other types of radiation therapy. GKRS can be used to treat benign and malignant tumors, arteriovenous malformations, brain metastases and functional disorders such as trigeminal neuralgia (TN) and glossopharyngeal neuralgia, especially in idiopathic and medically refractory cases. It manages these conditions non-invasively, without the pain and risk of complication associated with traditional surgery with most patients being able to resume normal activities the following day. GKRS is also known as stereotactic radiotherapy, stereotactic radiosurgery, and fractionated stereotactic radiotherapy.

Keywords: Gamma Knife; Stereotactic radiosurgery; GKRS.

INTRODUCTION

The Gamma Knife is a highly specialized treatment unit that provides an advanced stereotactic approach to the treatment of tumors, vascular malformations, and pain disorders.1 Radiosurgery was originally defined by the Swedish neurosurgeon Lars Leksell as a single high dose fraction of proton beam, stereotactically directed to small area into the brain2. Gamma knife radiosurgery involves a shielded treatment unit, in which beams from multiple radioactive sources are focused so that they intersect the same location in space, resulting in a spherical region of high dose referred to as a shot of radiation. The location and width of the shots can be adjusted using focusing helmets. By properly combining a set of shots, larger treatment volumes can be successfully treated with the Gamma Knife.[1]

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Gamma Knife therapy, like all radiosurgery, uses doses of radiation to kill cancer cells and shrink tumors, delivered precisely to avoid damaging healthy tissue. Gamma Knife radiosurgery is able to accurately focus many beams of gamma radiation to converge on one or more tumors. Each individual beam is of relatively low intensity, and is concentrated only at the tumor itself.[3]

History Of Gamma Knife Radiosurgery

Stereotactic radiosurgery was first developed in 1949 by the Swedish neurosurgeon Lars Leksell to treat small targets in the brain that were not amenable to conventional surgery.[4] The initial stereotactic instrument he conceived used probes and electrodes. The first attempt with radiation was made in the early fifties, with x-rays. The principle of this instrument was to crossfire the intra-cranial target from multiple directions with narrow beams of radiation.[5] The beam paths converge in the target volume, delivering a lethal cumulative dose of radiation, while limiting the dose to the adjacent healthy tissue. Ten years later significant progress had been made, due in considerable measure to the contribution of the physicists Kurt Liden and Borje Larsson. At this time, stereotactic proton beams had replaced the x-rays. Dr. Leksell set his mind on the development of a practical, compact, precise and simple tool which could be handled by the surgeon himself. In 1968, this resulted in the Gamma Knife, which was installed at the Karolinska Institute and consisted of several radioactive sources of Cobalt-60 placed in helmet with central channels for irradiation with x-rays. This prototype was designed to produce slit-like radiation lesions for functional neurosurgical procedures to treat pain, movement disorders, or behavioral disorders that did not respond to conventional treatment.[4]

The success of this first unit led to the construction of a second device, containing 179 Cobalt-60 sources. This second gamma knife unit was designed to produce spherical lesions to treat brain tumors and intracranial arteriovenous malformations AVMs. In the 1980s the third and fourth units (with 201 Cobalt-60 sources) were installed in Buenos Aires, Argentina, and Sheffield, England. The fifth gamma knife was installed at the Presbyterian University Hospital of Pittsburgh in 1987.[4]

Gamma Knife: A Technical Overview

The Gamma Knife (also known as the Leksell Gamma Knife) is a creation of Elekta AB, a Swedish public company, used to treat brain tumors by administering high-intensity cobalt radiation therapy in a manner that concentrates the radiation over a small volume.6 A Gamma Knife typically contains 201 cobalt-60 sources of approximately 30 curies each placed in a circular array in a heavily shielded assembly. The device aims gamma radiation through a target point in the patient's brain. An ablative dose of radiation is thereby sent through the tumor in one treatment session, while surrounding brain tissues are relatively spared.[7]

Before treatment, the patient is fitted with a head frame. The frame is attached to the scalp. This is done using 4 small pins or anchors that go through the skin to the surface of the skull. A local anesthetic is first given to numb the areas where the pins or anchors attach. The frame keeps the head steady during treatment. It also helps the doctor to ensure the energy beams are aimed at the exact spot in the head that needs treatment. After the frame is attached to the head, imaging tests such as CT, MRI, or angiogram are done. The images show the exact location, size, and shape of the tumor or problem area. Based on the data collected from MRI and CT scan, the neurosurgeon plans the treatment.[1]

After treatment planning is completed, patient lies on a table that slides into a machine that delivers radiation. The head frame is attached to a helmet with small openings called collimator ports. The energy beams are delivered through these ports. Each treatment takes a few minutes to 2 hours. Patient may receive more than one treatment session. Most often, no more than five sessions are needed.[8]

Mechanism of Action

Radiation from 201 separate cobalt sources is finely collimated. The rays all meet at one point. The size of the point target is adjusted by changing collimator helmets. The guaranteed machine accuracy is better than 0.5mm. A stereotactic frame is attached to the patient and the lesion target is located, guided by MRI, CT, PET and images that can be fused together. Multiple target isocentres are used to create a treatment plan in three dimensions that exactly fits the lesion shape with insignificant radiation to normal tissue. An even higher accuracy and selectivity has been achieved with newer models of Gamma Knife which use many more small (4mm) isocentres combined with an automatic positioning system controlled by computer and rapidly changes the patient's position between each treatment isocentre.[2]

Uses Of Gamma Knife Radiosurgery

Stereotactic radiosurgery targets and treats an abnormal area without damaging nearby healthy tissue.[9] Gamma Knife radiosurgery is used to treat the following types of diseases:

- Cancer that has metastasized to the brain from another part of the body. Brain metastases develop in 20%–40% of patients with systemic cancer and are a major cause of morbidity and mortality in these patients. The incidence appears to be increasing due to improved neuroimaging technology and improved systemic disease therapies. These advances have resulted in an earlier diagnosis and longer survival from the primary cancer. Whole-brain radiation therapy is one modality used to treat brain metastases and is currently the primary modality used for patients with ≥ 5 metastases. Gamma Knife surgery is a standard treatment modality for patients with a single or a limited number (≤ 4) of brain metastasis; however, its role in the treatment of patients with ≥ 5 metastases is less well defined.[10]
- Primary brain tumors
- Acoustic & other neuromas
- Pituitary tumors
- Skull base tumors
- Cerebral vascular conditions like arteriovenous malformations
- Functional disorders like epilepsy, parkinson's disease, trigeminal neuralgia, and glossopharyngeal neuralgia

Role of Gamma Knife Radiosurgery in the treatment of Trigeminal and Glossopharyngeal Neuralgia

Trigeminal neuralgia is a disabling pain syndrome responsive to both medical and surgical therapies. Stereotactic radiosurgery using the gamma knife can be used to inactivate a specified volume in the brain by cross firing multiple photon beams. In gamma knife surgery, a focused beam of radiation is aimed at the trigeminal root in the posterior fossa.11 The maximum radiation dose ranges from 65.2 to 83.6 Gy, and a 4 mm collimator is used to target the radiation to the root entry zone. It has been shown that a maximum radiosurgery dose higher than 70 Gy (70-90 Gy) is associated with a significant chance of complete pain relief.[12]

Gamma knife radiosurgery is a minimally invasive technique to treat trigeminal neuralgia. It is associated with a low risk of facial paresthesias, an approximate 80% rate of significant pain relief, and a low recurrence rate in patients who initially attain complete relief.13 GKRS is a safe and effective treatment modality for patients with medically intractable TN or those who are ineligible or refuse open surgery. A single GKS treatment is associated with good outcomes in nearly 60 % of patients in an average follow-up period of six years.[11]

Glossopharyngeal neuralgia (GPN) is a rare disorder of the ninth cranial nerve characterized by severe paroxysmal pain affecting the ear, tongue, and throat. Though traditional treatment for GPN involves medical management at first and surgery for refractory cases, these therapies are often poorly tolerated in the elderly population. Gamma Knife radiosurgery offers an alternative in such cases. The treatment involves targeting the glossopharyngeal nerve root at its entry into the osseous canal of the jugular foramen. A maximum dose of 80 Gy is delivered with a single shot using the 4-mm collimator helmet. The treatment is both effective and very well tolerated and deserves careful consideration as a treatment option in this population.[14]

Risks and Limitations of Radiosurgery

GKRS has proven effective for patients with benign or malignant brain tumors, vascular malformations and functional disorders such as trigeminal neuralgia (TN). The risks of GKRS treatment are very low, and complications are related to the condition being treated.[15]

As compared to other types of radiation therapy, Gamma Knife treatment is much less likely to damage nearby healthy tissue.16 Immediate side effects are moderate headache, skin hypersensitivity if the target is near the surface and acute cranial nerve disturbances (e.g. dizziness and vomiting). These effects however, are temporary and fade away with time. Delayed complications are mainly local swelling in or around the lesion 6-9 months after treatment.[17]

Currently the main limitation of recommending Gamma Knife Radiosurgery is the treatment expense that limits widespread usage making it a reserve treatment option for patients who cannot undergo open surgery or have blood coagulation problems.[3]

Prognosis

Often the patient is able to go home 1 hour after the treatment.8 Patient can resume regular activities the next day if there are no complications. If there are complications, then the patient may need to stay in the hospital overnight for monitoring. The effects of GKRS may take weeks or months to be seen. The prognosis depends on the condition being treated. The health care provider monitors the progress using imaging tests such as MRI and CT scans.[18]

DISCUSSION

Radiosurgery is indicated primarily for the therapy of tumors, vascular lesions and functional disorders. Significant clinical judgment must be used with this technique and considerations must include lesion type, pathology if available, size, location, age and general health of the patient.[6] General contraindications to radiosurgery include excessively large size of the target lesion or lesions too numerous for practical treatment. Patients can be treated within one to five days and on an outpatient basis. Radiosurgery outcome may not be evident until months after the treatment.[15] Since radiosurgery does not remove the tumor, but results in a biological inactivation of the tumor, lack of growth of the lesion is normally considered to be the treatment success. General indications for radiosurgery include brain tumors, metastases to brain, trigeminal neuralgia, arteriovenous malformations and skull base tumors.[19] Expansion of stereotactic radiotherapy to extracranial lesions is increasing, and includes metastases, liver cancer, lung cancer, pancreatic cancer, etc.[20] Several studies have shown that Gamma Knife treatment of single metastases can produce tumour control and survival as good as surgery. Moreover the results for Gamma Knife are the same for multiple metastases as for a single lesion. The chance of local recurrence is less than after surgical removal and control does not depend on the histological diagnosis. Radiosurgery is a good treatment option for such patients as it has a significantly lower complication rate. The Gamma Knife is a very powerful tool with significantly less complication rates; however it needs careful and experienced handling.[17]

CONCLUSION

Gamma Knife radiosurgery is considered to be the “gold standard” of stereotactic radiosurgery for brain lesions, vascular malformations as well as functional disorders, providing results comparable to or better than conventional surgery in many cases, without the need for a surgical incision or protracted recovery in hospital. GKRS is a safe and effective management approach for patients diagnosed with typical TN with short treatment time, a high probability of treated-lesion with low normal tissue complication.21 However, further controlled randomized trials and supporting research are needed on the effects of surgical treatment, number of radiosurgery procedures, and maximum radiosurgery dose have on GKRS clinical outcomes.[21]

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How to cite this article: Singh A, Ahmed A, Sajad M, Sahoo S, Goel A, Sagar M. Radiosurgery - Gamma Knife. Ann. Int. Med. Den. Res. 2018; 4(2): DE47-DE50.

Source of Support: Nil, **Conflict of Interest:** None declared