Stereotactic radiosurgery for functional disorders

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Stereotactic radiosurgery (SRS) with the Gamma Knife and linear accelerator has revolutionized neurosurgery over the past 20 years. The most common indications for radiosurgery today are tumors and arteriovenous malformations of the brain. Functional indications such as treatment of movement disorders or intractable pain only contribute a small percentage of treated patients. Although SRS is the only noninvasive form of treatment for functional disorders, it also has some limitations: neurophysiological confirmation of the target structure is not possible, and one therefore must rely exclusively on anatomical targeting. Furthermore, lesion sizes may vary, and shielding adjacent radiosensitive neural structures may be difficult or impossible.

The most common indication for functional SRS is the treatment of trigeminal neuralgia. Radiosurgical treatment for epilepsy and certain psychiatric illnesses is performed in several centers as part of strict research protocols, and radiosurgical pallidotomy or medial thalamotomy is no longer recommended due to the high risk of complications. Radiosurgical ventrolateral thalamotomy for the treatment of tremor in patients with Parkinson disease or multiple sclerosis, as well as in the treatment of essential tremor, may be indicated for a select group of patients with advanced age, significant medical conditions that preclude treatment with open surgery, or patients who must receive anticoagulation therapy. A promising new application of SRS is high-dose radiosurgery delivered to the pituitary stalk. This treatment has already been successfully performed in several centers around the world to treat severe pain in patients with end-stage cancer. (DOI: 10.3171/FOC-07/12/E3)

KEY WORDS • epilepsy • pain • pallidotomy • Parkinson disease • thalamotomy • trigeminal neuralgia • psychiatric disease

Abbreviations used in this paper: GKS = Gamma Knife surgery; LINAC = linear accelerator; MR = magnetic resonance; MVD = microvascular decompression; OCD = obsessive-compulsive disorder; PD = Parkinson disease; SRS = stereotactic radiosurgery; TN = trigeminal neuralgia; TREZ = trigeminal nerve root entry zone; Vim = ventralis intermedius nucleus.
Movement Disorders

Treatment of Tremors

Radiosurgical treatment of tremor has been performed successfully for more than 25 years by directing a 4-mm-collimator shot into the posterior ventrolateral thalamus close to the internal capsule (Fig. 1). The authors of several studies have reported success rates in tremor control in patients with PD, essential tremor, and tremor related to multiple sclerosis or other causes that are comparable to those achieved using other methods. Complications are usually rare, mild, and temporary, although unusual complications and severe, permanent complications have also been reported. The most common applications of SRS in the treatment of movement disorders are summarized in Table 1.

The first reports of using GKS in the treatment of tremor were published in the early 1990s, when Rand et al. in the United States, Lindquist and colleagues in Europe, and Ohye et al. in Japan described their experiences. The positive findings of these groups have since been duplicated at numerous treatment centers around the world. The most comprehensive series was published by Young and associates, who reported on long-term follow-up of up to 8 years in 102 patients with tremor related to PD, 52 patients with essential tremor, and 4 patients with tremor as a result of stroke, encephalitis, or head injury. Treatment was performed with the Gamma Knife using a 4-mm collimator and a maximum radiation dose of 120–160 Gy. Of special note is the fact that blinded pre- and postoperative rating was performed by a team of independent evaluators skilled in evaluating movement disorders. The severity of PD was scored using a validated rating scale (Unified PD Rating Scale) to assess tremor and rigidity. In 88% of patients with parkinsonian tremor and 88% of patients with essential tremor, there was long-term relief of symptoms after GKS, which was statistically significantly improved over baseline status. In 50% of patients with other tremors there was improvement, and complications were noted in 3 of 158 patients (1.9%; 1 patient with transient and 2 with mild permanent complications).

Sato and associates addressed the question of optimal target selection by comparing the radiosurgical target with the target used for stereotactic radiofrequency coagulation. Because the center of the radiosurgical treatment plan is positioned in such a way that the internal capsule laterally and the ventralis–caudalis sensory nucleus of the thalamus posteriorly do not suffer radiation damage, this radiosurgical target is typically located 1–2 mm more medial and anterior than the “real” target. In their study, Sato et al. describe 4 patients who underwent radiosurgical treatment planning followed by radiofrequency lesioning of the Vim for the treatment of tremor. Electrophysiological recording demonstrated that the tremor-synchronous cells with rhythmic discharge typically found in the Vim region were indeed present within the radiosurgical target. The authors concluded that current planning strategies for Vim radiosurgical thalamotomy were adequate. The issue of extent of necrosis after radiosurgical creation of a lesion was addressed by the same authors in a different publication. Specifically, the area of the blood–brain barrier disruption, seen on contrast-enhanced MR images as a ring of enhancement, was the target of their research. Two patients with tremor in whom previous GKS had failed underwent open stereotactic thalamotomy with neurophysiological recording. The authors found that the area corresponding to the ring enhancement seen on MR images was active neural tissue with viable tremor cells and not, as may be assumed, necrotic tissue.

Treatment of PD

Radiosurgical pallidotomy has been tried in several institutions but abandoned due to an unacceptable complication rate in most cases. Our own results in 4 patients indicate that the success rate is significantly lower than would be expected with other forms of treatment, such as deep brain stimulation therapy. A postmortem analysis in 1 of our pa-
Functional stereotactic radiosurgery

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Movement Disorder</th>
<th>PD</th>
<th>Tremor</th>
<th>Dystonia</th>
</tr>
</thead>
<tbody>
<tr>
<td>max. dose (Gy)</td>
<td>target</td>
<td>GPI</td>
<td>Vim</td>
<td>Vim or GPI</td>
</tr>
<tr>
<td>outcome</td>
<td>120–180</td>
<td>120–180</td>
<td>160</td>
<td></td>
</tr>
<tr>
<td>% improved</td>
<td>up to 50–85%</td>
<td>up to 88%</td>
<td>100%</td>
<td></td>
</tr>
<tr>
<td>% w/ complications</td>
<td>up to 50%; limited frequency</td>
<td>rare</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* Table is a summary of the results obtained in a number of studies on radiosurgery for movement disorders.

Abbreviation: GPI = globus pallidum internum.

Patients with PD who died 30 months after GKS pallidotomy, presumably of unrelated causes, also raises concerns over optimal lesion location, potential injury to the optic tract, and the risk of postradiosurgical vascular changes possibly resulting in a basal ganglia stroke. The authors of other studies also strongly advise against the generalized use of radiosurgery for the treatment of PD.

Radiosurgical pallidotomy was first reported on by Rand et al., who used the technique in 8 patients, 4 of whom had significant relief of contralateral rigidity. There were no reports of significant side effects. A less encouraging result was obtained by Friedman et al., who reported on 4 patients with PD treated with unilateral pallidotomy using a maximum dose of 180 Gy. Only 1 patient had reduced dyskinesia afterwards but also experienced temporary dementia and psychosis. The authors questioned the feasibility of performing radiosurgical pallidotomies.

A more positive experience is reported by Young and coworkers, who treated 2 groups of patients: 29 patients with radiosurgical pallidotomy and 22 with radiofrequency lesioning in the posteroventral pallidum internum. After a mean follow-up period of 20.6 months, more than 80% of patients in both groups had significant improvement in dyskinesia, and two thirds of patients had improvements in bradykinesia or rigidity. In 27.7% of patients in the radiofrequency lesioning group there was transient postoperative confusion. Only 1 patient in the GKS group (3.4%) had a complication in the form of a homonymous hemianopsia 9 months after treatment.

Duma cautions that radiosurgical pallidotomy may be associated with an unacceptably high risk of complications. In his experience, the combination of poor outcome and high risk have led him to abandon this radiosurgical modality altogether. This concern is shared by Okun and colleagues, who reported on a study of 38 patients (who underwent 5 thalamotomies and 3 pallidotomies) with significant complications as a result of radiosurgical lesioning, including hemiparesis, hemianopsia, and pseudobulbar laughter. The authors questioned whether the overall risks of radiosurgical lesioning for PD had been underestimated and strongly recommended that this modality should be offered only with great reservation for the treatment of PD.

Treatment of Dystonia

For other movement disorders, the worldwide experience in treatment with SRS is limited. An initial case report from 1995 in which a patient with hemidystonia was treated with a radiosurgical pallidotomy was followed by the report of 2 cases, and in an additional report in 2002 of patients treated with a lesion to the anterior ventrolateral thalamus. All patients were reported to have significant improvements, observable 2–3 months after treatment. A homonymous hemianopsia developed in the patient undergoing radiosurgical pallidotomy; treatment-related side effects in the other patients were not reported. Successful radiosurgical treatment of dystonia has been reported with the posteroventral pallidum or the ventrolateral thalamus as the target, and there has also been a report of successful radiosurgical subthalamotomy with long-term follow-up.

Pain

The most common applications of SRS for the treatment of pain are summarized in Table 2.

<table>
<thead>
<tr>
<th>Pain Disorder</th>
<th>TN</th>
<th>Cluster</th>
<th>Cancer</th>
<th>Chronic Pain Syndromes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Parameter</td>
<td>TREZ</td>
<td>TREZ</td>
<td>pituitary gland &amp; stalk</td>
<td>medial thalamus</td>
</tr>
<tr>
<td>max. dose (Gy)</td>
<td>70–90</td>
<td>80</td>
<td>160</td>
<td>140–180</td>
</tr>
<tr>
<td>outcome</td>
<td>% improved</td>
<td>up to 90</td>
<td>30</td>
<td>100</td>
</tr>
<tr>
<td>% w/ complications</td>
<td>up to 25</td>
<td>90;</td>
<td>none</td>
<td>significant</td>
</tr>
</tbody>
</table>

* Table is a summary of the results obtained in a number of studies on radiosurgery for pain disorders.

Abbreviation: TREZ = trigeminal nerve root entry zone.

From 1995, in which a patient with hemidystonia was treated with a radiosurgical pallidotomy was followed by the report of 2 cases, and in an additional report in 2002 of patients treated with a lesion to the anterior ventrolateral thalamus. All patients were reported to have significant improvements, observable 2–3 months after treatment. A homonymous hemianopsia developed in the patient undergoing radiosurgical pallidotomy; treatment-related side effects in the other patients were not reported. Successful radiosurgical treatment of dystonia has been reported with the posteroventral pallidum or the ventrolateral thalamus as the target, and there has also been a report of successful radiosurgical subthalamotomy with long-term follow-up.

Trigeminal Neuralgia and Other Neuralgias

By far the most common indication for functional SRS is TN. Extensive world-wide research has been conducted regarding underlying pathophysiological mechanisms of pain relief, clinical outcomes, and comparative technologies. Because of the nonexistent procedure-related mortality rate, the low risk of significant complications, and its ability to provide pain control for tic doloreux, SRS for TN has certainly become one of the most important options when recommending treatment modalities to patients. Other forms of pain treatment with SRS have been described mostly in anecdotal form and are much less researched. We continue to rely mostly on clinical experience of some surgical centers when recommending SRS for certain chronic pain disorders. When it comes to treatment of pain related to a malignant growth, there is increasing evidence that SRS applied to the pituitary stalk region is an effective approach for patients with pain from metastatic cancer. The same approach has also been tried in patients with poststroke thalamic pain syndrome; however, a much lower rate of success and a higher rate of complications was found.

Radiosurgical treatment for TN has been subject to
extensive research. Both GKS and linear accelerator radiosurgery have been successfully applied to treat tic doloreux refractory to medication after failed attempts at MVD, and ablative procedures such as frequency retrogasserian rhizotomy or glycerol injection.5,27,28,55

Leksell began treating patients with TN in 1953, although his first report of 2 patients was not available until 1971.32 Both patients were reported to be pain free 1 and 5 months after radiosurgery to the trigeminal nerve. Hakan

son examined these 2 patients 20 years after treatment, and they remained pain free (personal communication). The estimated target doses were 16.5–22 Gy. Several years later, Lindquist et al.33 and Rand et al.32 reported on their patients with tic doloreux treated with radiosurgery to the Gasserian ganglion. Because the results were inconsistent, the authors concluded that other targets should be considered. The first multicenter study using GKS at the Terez near the pons was initiated by the University of Pittsburgh and published in 1996.27 Five centers participated in this study, and 50 patients were enrolled, 32 of whom had undergone previous surgery for facial pain. Patients were treated with low-dose (60–65 Gy) or high-dose (70–90 Gy) radiosurgery. After a follow-up period of 11–36 months, 29 patients (58%) reported complete relief of pain, 18 (36%) had obtained good pain control (50–90% relief), and 3 (6%) experienced treatment failure. The median time to pain relief was 1 month. The authors also noted that pain relief was significantly more likely with higher doses of radiation (70–90 Gy).

In another prospective study35 radiosurgical treatment of the Terez using 70–90 Gy, 83 of 100 patients were pain free either with or without medication. A quality-of-life assessment in these patients indicated a statistically significant improvement in all tested areas. The only side effects were mild hypesthesia or paresthesia in the trigeminal area (6% of patients).

A single-center single-physician study compared GKS against MVD surgery.2 The author reports on 24 patients who underwent surgery and 61 patients who were treated with 75 Gy to the Terez. After 18 months’ follow-up, complete pain relief was seen in 68% of patients in the group that received MVD, and 24% of patients in the GKS group. Pain relief of 90% or more was reported in 78% of patients who underwent MVD surgery and in 48% of patients who received GKS. There were no significant complications seen in either group. The author concludes that both methods provide good pain control, but that MVD is more likely than GKS to provide complete relief of pain.

Linear accelerators have also been used successfully for the treatment of tic doloreux.58,63 In the original study from 1995,28 using either 5-mm or 7.5-mm collimators and applying similar doses to the Terez (70–90 Gy) as described with GKS, the authors achieved sustained pain relief of 88% of patients, with a mean follow-up period of 23 months. The only reported complication was postprocedure numbness in 25%. Although there is no study comparing linear accelerator SRS to GKS in terms of outcomes or side effects, Ma et al.37 attempted model dose falloff and error tolerances when planning radiosurgical procedures for TN. The authors found no significant differences between the 2 modalities, provided that a high number of arcs is used (≥ 7), and a small interarc error is guaranteed; however, they caution about increased treatment time for multiaarc treatment plans.

The question of whether the Terez undergoes any kind of permanent change as a result of radiosurgery is addressed in a publication by Shetter and coauthors.64 They report on 6 patients who were treated with radiosurgery with 80–135 Gy in 1 or 2 sessions. Patients had persistent or recurrent facial pain and elected to undergo MVD surgery. The authors indicate that there were no abnormal findings around the nerve entry zone that were attributable to previous radiosurgery and therefore conclude that previous radiosurgery does not preclude patients from MVD in case of pain recurrence.

Stieber et al.67 describe the only reported—and successful—treatment of glossopharyngeal neuralgia in a patient who refused MVD surgery. A maximum dose of 80 Gy was delivered to the nerve at the entry into the osseous canal of the jugular foramen using a single 4-mm-collimator shot. The patient experienced gradual pain relief starting 6 weeks after treatment and was pain free without medication 3 months after treatment. She had partial recurrence of pain 6 months after treatment but did not require further medical or surgical therapy. No complications were reported.

Pollock and Kondziolka68 describe the successful application of a single 8-mm-collimator shot to the sphenopalatine ganglion in a patient with sphenopalatine neuralgia. A maximum dose of 80 Gy was delivered, and the patient initially improved but then had recurrence of her pain that required a second treatment with the same treatment parameters. Six months after the second treatment, she was pain free and her vasomotor symptoms (nasal discharge, injected eye) also improved.

**Chronic Pain and Thalamic Pain Syndrome**

After Steiner66 and Leksell19 reported initial successes in patients with chronic pain by making radiosurgical lesions in the thalamus, it took almost 2 decades before the treatment was investigated on a larger scale. Encouraged by some positive results,30 Young30 treated 41 patients with chronic pain related to structural spinal disorders or spinal cord injury, postherpetic neuralgia, stroke, and thalamic pain syndrome, or anesthesia dolorosa of the face. The treatment target was the medial thalamus, including the

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**TABLE 3**

Radiosurgery for epilepsy*  

<table>
<thead>
<tr>
<th>Parameter</th>
<th>MTE</th>
<th>Hypothalamic Hamartoma</th>
<th>DA–GTCS</th>
</tr>
</thead>
<tbody>
<tr>
<td>target</td>
<td>amygdala, hippocampus</td>
<td>hypothalamic lesion</td>
<td>corpus callosum</td>
</tr>
<tr>
<td>max. dose (Gy)</td>
<td>48–50</td>
<td>50</td>
<td>100–140</td>
</tr>
<tr>
<td>outcome</td>
<td>70–90</td>
<td>40–60</td>
<td></td>
</tr>
<tr>
<td>% improved</td>
<td>65</td>
<td>70–90</td>
<td></td>
</tr>
<tr>
<td>% w/ complications</td>
<td>45, mild</td>
<td>rare</td>
<td>none</td>
</tr>
</tbody>
</table>

* Table is a summary of the results obtained in a number of studies on radiosurgery for epilepsy.1,3,4,6,10,11,49,53,56,57,60,64 Abbreviations: DA = drop attack; GTCS = generalized tonic-clonic seizures; MTE = mesial temporal lobe epilepsy.  

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G. M. Friehs et al.
Functional stereotactic radiosurgery

intralaminar nuclei, the lateral portions of the medial-dorsal nucleus, the centromedian nucleus, and the parafascicular nucleus. The 4-mm collimator was used to deliver 140–180 Gy in 1, 2, or 3 isocenters. Although two thirds of patients reported a reduction in their pain of 50% or more, the treatment was associated with significant side effects, including 1 death (personal communication). In another report, these unpredictable lesion sizes were studied and found to be typically seen when more than 1 isocenter was applied or when doses of more than 160 Gy were used.

Radiosurgical treatment of the pituitary stalk for post-stroke thalamic pain syndrome was recently described. In this study, 24 patients underwent GKS of the pituitary gland and stalk with a dose of 140–180 Gy. In 71% of patients, significant pain relief started as soon as 48 hours after treatment. However, after a follow-up period of 12–48 months, only 21% of patients had lasting pain relief. Ten patients (42%) also reported side effects, which were usually related to hormone imbalance.

Cancer-Related Pain Syndrome

Leksell used radiosurgery early on to treat pain related to malignant tumors with the medial thalamus as the target. Since his initial reports, there have been few studies on using the same technique for cancer-related pain. Frighetto et al. in 2004 described their experience of using a linear accelerator with a 5-mm collimator to create a lesion in the medial thalamus of 3 patients, 1 of whom had metastatic cancer. All patients, including the patient with cancer, who died 2 weeks after treatment, had substantial pain relief and were able to reduce their medications.

Backlund and coworkers used Gamma Knife hypophysectomy in the treatment of 8 patients suffering from severe pain from advanced-stage breast cancer and achieved excellent pain relief in all patients. A somewhat different approach—originally reported by Lisák and Vladyka—is described in a multicenter prospective protocol of pituitary gland and stalk ablation with GKS in patients with pain related to bone metastases. One of the inclusion criteria was that the pain had to be responsive to morphine. The authors reported on 9 patients who were treated with either a single 8-mm-collimator shot or a 2-isocenter delivery with the 4-mm collimator. A maximum dose of 160 Gy was delivered, and the radiation exposure of the optic structures was limited to 8 Gy or less. After a follow-up of 1–24 months, all 9 patients experienced significant pain relief without any reported side effects.

Cluster Headaches

In 1998, Ford et al. published the first report of successful treatment of cluster headaches by GKS. Of 6 patients treated with a 70-Gy maximum dose to the TREZ, 4 had excellent pain relief for a follow-up period of 8–14 months. No side effects were reported. A few years later, a prospective study was begun, which was just recently completed and published. Of the 10 patients treated in this study, only 3 had complete or almost complete relief of symptoms. Due to the high incidence of side effects (9 of 10 patients) with trigeminal paresthesia, hypesthesia, or deafferentation pain, the authors do not recommend treatment of cluster headaches with trigeminal radiosurgery. McClelland et al. confirmed the negative findings.

Targeting the sphenopalatine ganglion instead of the TREZ could be a promising solution and is being investigated.

Epilepsy

The most common applications of SRS for the treatment of epilepsy are summarized in Table 3.

Mesial Temporal Lobe Epilepsy

Mesial temporal lobe epilepsy and its treatment with SRS is one of the areas in radiosurgery with extensive evidentiary support. After first reports in humans, a French group conducted basic laboratory tests to gain further insight into the mechanisms underlying radiosurgical antiepileptogenesis. Rats received doses of 100 Gy to the striatum, resulting in a differential effect on different enzymes (glutamate decarboxylase and choline acetyltransferase) and secondarily between excitatory amino acids and nonexcitatory amino acids, particularly γ-aminobutyric acid. Another animal study examined a kainic-acid rat model of epilepsy and the effect of varying doses of radiation. The authors were able to establish a clear relationship between increasing radiosurgical dose and decreasing seizure frequency measured by electroencephalography. A dose in the 40–60 Gy range was found sufficient to provide good seizure control without causing brain tissue necrosis and was therefore deemed appropriate for human use.

In 1985, Barcia-Salorio and colleagues reported on 6 patients treated with a cobalt unit using a 10-mm collimator. The epileptic foci in these patients received an estimated dose of 10 Gy. In 1994, the same group reported a long-term analysis using doses between 10–20 Gy. Five of 11 patients had complete cessation of seizures and another 5 were improved starting 3–12 months after treatment. Further experience was then reported from Sweden by Hellstrand et al. with more advanced techniques of localizing the epileptic focus, including magnetoencephalography and the use of GKS. In 1993, Régis and associates performed the first selective radiosurgical amygdalohippocampotomies for mesial temporal epilepsy. The 2 patients in their study both received a dose of 25 Gy to the 50% isodose and were seizure free within 1 year. Postoperative MR imaging studies in these patients revealed contrast enhancement corresponding to the 50% isodose. The same researchers then initiated a multicenter study, which was conducted at 3 European centers. Twenty patients underwent radiosurgery with 24–25 Gy delivered to the mesial temporal lobe for intractable mesial temporal lobe epilepsy. After a follow-up period of 2 years, 65% of these patients were seizure free, however, it took about 12 months post-surgery for the seizure frequency to begin to drop significantly. The authors also commented on the fact that all of their patients experienced a transient increase in seizures, mostly auras, before the number of seizures started to diminish. Nine patients (45%) were reported to have visual field defects, which, according to the authors, compares favorably with the results of microsurgical selective amygdalohippocampectomy or anterior temporal lobectomy, in which >70% of patients have postoperative visual field deficits. Other transient complications included headache, nausea, vomiting, depression, and dizziness.
Hypothalamic Hamartomas, Gelastic Seizures

In 1998, Arita et al. reported the first case of a patient with a hypothalamic hamartoma suffering from gelastic and tonic-clonic seizures to be treated with SRS. The patient became seizure free with a follow up of almost 2 years. The reported MRI findings indicate a complete disappearance of the hypothalamic changes. As a result of this report, a multicenter retrospective study was conducted including 10 patients in 7 international centers. All patients reported improvement of their seizures, with 4 being seizure-free after a follow-up period of 12–71 months. The authors advocate a dose to the margin of the lesion of 17 Gy. These findings have since been confirmed using linear accelerator radiosurgery.

Corpus Callosotomy

Another fairly novel way of using radiosurgery in the treatment of epilepsy was first described in 1999 by Pendel et al., who described the treatment of 2 patients with long-standing Lennox–Gastaut syndrome and 1 patient with tonic-clonic and absence seizures with a corpus callosotomy of the anterior third of the corpus callosum. After a mean follow-up period of 36 months, all patients had improvement in their seizures. Encouraged by these results, the same group later published a report on 8 patients undergoing either anterior callosotomy (6 patients) or posterior callosotomy (2 patients) after previous surgical callosotomy. The patients were followed up for a minimum of 1 year (range 1–12 years). Drop-attack seizures were abolished in 3 patients, and 3 more patients had a 40–60% improvement of drop attacks. Generalized tonic-clonic seizures were abolished in 2 patients, and 2 other patients had a 50–60% improvement. Other seizure types did not respond as well to treatment, with a 20–70% reduction seen in 3 patients. There were only minor transient side effects in 2 patients, and mild changes on MR imaging were noted in only 25% of patients. The favorable results have since been confirmed and repeated with the use of a linear accelerator and have also been reported in children.

Psychiatric Disease

The first radiosurgical treatments of psychiatric disease were performed by Leksell in 1953 with a 300-kV x-ray device. Seven patients with OCD were treated by placing radiosurgical lesions into the anterior limb of the internal capsule. After 7 years' follow-up, 5 patients reported improvement of their seizures, with 4 being seizure-free after a follow-up period of 12–71 months. The authors advocate a dose to the margin of the lesion of 17 Gy. These findings have since been confirmed using linear accelerator radiosurgery.

Conclusions

There is sufficient evidence in the literature to support the use of radiosurgery in the treatment of certain functional disorders. Stereotactic radiosurgery has become a standard neurosurgical tool for the treatment of TN because of favorable results and very limited risk of complications. Radiosurgical treatment of some other pain syndromes is promising with certain techniques (SRS to the pituitary stalk), while other techniques (such as medial thalamotomy) are no longer recommended. Certain types of epilepsy appear to respond well to SRS with acceptable risks. The supportive evidence on the treatment of hypothalamic hamartomas with SRS continues to accumulate. Although some procedures for the treatment of movement disorders are associated with high risks (radiosurgical pallidotomy, for example) it is feasible to offer radiosurgical thalamotomy to patients with tremor, especially in situations where open stereotactic approaches for lesioning or deep brain stimulation therapy are not possible or are too risky. The widespread use of radiosurgery in the treatment of psychiatric disorders is strongly discouraged unless performed within the confines of a research protocol and accompanied by the strong support of a dedicated psychiatry team.

References

7. De Salles AA, Meleaga WP, Lacan G, Steele LJ, Solberg TD: from the Karolinska Institute. Because there are significant ethical concerns and organizational issues associated with the treatment of such patients, we have offered this treatment exclusively to an extremely treatment-refractory group of patients who were selected by a team of psychiatrists as part of a strict research protocol. At our own institution we continue to provide radiosurgical treatment for OCD to a small group of very treatment-resistant patients as part of an ongoing open-label research study. Our current treatment protocol calls for 2-isocenter shots with the 4-mm collimator to each side with a maximum dose of 180 Gy per shot (2 lesions on each side are created). With this treatment method we have achieved long-term and significant reduction of OCD symptoms in roughly two thirds of our patients. Preliminary findings are encouraging but longer follow-up is needed.
Functional stereotactic radiosurgery

Radiosurgery performed with the aid of a 3-mm collimator in the subthalamic nucleus and substantia nigra of the rhesus monkey. *J Neurosurg* 95:990–997, 2001


50. Pollock BE, Kondziolka D: Stereotactic radiosurgical treatment of


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