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Gamma Knife Radiosurgery: A Review on Minimally Invasive Approach to Trigeminal Neuralgia Pain Relief

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ABSTRACT

Gamma Knife Radiosurgery (GKRS) has emerged as an extremely effective treatment for trigeminal neuralgia (TN), particularly for patients who do not respond favourably to medical interventions. TN is a chronic pain disorder characterized by intense, sudden, and electric shock-like facial pain, significantly impacting patients' quality of life. Studies indicate an initial success rate of 80-90% for pain relief following GKRS, with many patients experiencing substantial pain reduction shortly after the procedure. GKRS involves precisely targeting the trigeminal nerve root with focused gamma radiation, disrupting pain signal transmission. Complications, albeit rare, may include dry eyes and occasionally more significant nerve damage. This review assesses the effectiveness of Gamma Knife Radiosurgery in managing Trigeminal Neuralgia.

Keywords: Trigeminal Neuralgia, Gamma Knife Radiosurgery, Chronic Pain, Pain Relief, Oral and Maxillofacial Surgery

INTRODUCTION

Trigeminal neuralgia, also known as Tic Douloureux, is a rare neurological disorder that results in sudden, severe, brief episodes of stabbing pain affecting the face, typically in the areas served by one or more branches of the trigeminal nerve. This condition is often caused by the compression of the trigeminal nerve by a nearby blood vessel, though sometimes no clear cause is identified. Due to its symptoms, it can be mistaken for dental issues, jaw problems, or even psychological conditions.[1] Once correctly diagnosed, various medical and surgical treatments are available to help alleviate the intense pain associated with this disorder.[2] The initial treatment for trigeminal neuralgia (TN) typically involves medication, with surgery considered only as a last resort due to its associated risks. The most commonly used drugs are anti-convulsants, which, though initially developed for epilepsy, are effective for nerve pain management in TN. Carbamazepine is the most frequently prescribed, providing partial pain relief for 80-90% of patients. In these cases, more targeted approaches like surgery or radiosurgery come into play.[3] Radiofrequency lesioning, also known as radiofrequency rhizotomy, is an effective option for severe trigeminal neuralgia (TN) pain in high-risk patients, such as those with other illnesses making open surgery too dangerous, and patients with multiple sclerosis (MS), whose TN is typically not caused by vascular compression.[4] This procedure, like Gamma Knife treatment, does not address the root cause of TN but instead damages the trigeminal nerve to halt pain signal transmission. An electrode inserted through the cheek heats and selectively damages the nerve, providing immediate pain relief in up to 90% of patients. However, it can cause more facial numbness than other procedures and has a pain recurrence rate of 40% within 2 to 3 years, though it can be repeated if necessary.[5] Microvascular decompression (MVD), also known as the Jannetta procedure, is the most common and invasive surgical option for TN. It involves making an incision behind the ear, drilling a small hole in the skull, and exposing the trigeminal nerve under microscopic visualization to move the compressing blood vessel away from the nerve, usually using Teflon felt for padding. MVD addresses the underlying cause of TN—vascular compression—causing the least damage to the trigeminal nerve and offering the longest pain-free periods and the best chance of being permanently off medication, with a long-term success rate of approximately 80%. The procedure requires an average hospital stay of two days and a recovery period of four to six weeks.[6] Gamma Knife Radiosurgery (GKRS) is the least invasive surgical option for TN, technically not surgery but a form of precise, controlled radiation therapy. It targets the trigeminal nerve at the brainstem to disrupt pain signal transmission. Performed on an outpatient basis with little or no anesthesia, GKRS provides significant pain control or reduction in over 80% of patients. The response time varies, with some patients experiencing relief within 4 to 6 weeks and others taking 3 to 8 months. Most patients remain on full doses of medication for at least 3 to 6 months post-treatment, with medication tapering beginning only after achieving pain relief. This method is also known as Gamma Knife radiosurgery or Gamma Knife radiation and is a form of stereotactic radiosurgery.[7] This review article will explore Gamma Knife radiosurgery, a non-invasive procedure that utilizes focused radiation beams to treat Trigeminal Neuralgia.

GAMMA KNIFE SURGERY

Gamma Knife surgery is a noninvasive radiation therapy that utilizes computer-guided planning to treat brain and upper spine conditions and tumors by delivering highly focused beams of energy to a specific area, thereby minimizing damage to surrounding tissues. Although termed "surgery," it involves

no incisions or knives; the name refers to the precision of gamma rays, which are high-energy photons used to target brain areas accurately without physical cutting. This form of stereotactic radiosurgery treats various brain abnormalities such as brain tumors (both cancerous and noncancerous), blood vessel abnormalities, and nerve abnormalities. Common tumors treated include acoustic neuroma, brain metastases, chondrosarcomas, chordomas, craniopharyngiomas, gliomas, meningiomas, paragangliomas, and pituitary adenomas. Additionally, it addresses conditions like arteriovenous malformations (AVM), epilepsy, essential tremor or Parkinson's disease symptoms, and trigeminal neuralgia, particularly benefiting patients whose lesions are inoperable or those unable to undergo traditional surgery. Preparation involves a physical exam, disclosure of medical implants, specific fasting instructions, and arranging for transportation post-procedure. Gamma Knife systems may use either a fitted metal frame to prevent head movement or a frameless thermoplastic mask or net. On the day of the procedure, patients receive an IV for contrast agents and sedatives, undergo CT or MRI scans for precise targeting, and have their treatment planned by a multidisciplinary team. During the procedure, which typically lasts 30 minutes to two hours, patients do not feel pain and can communicate with the care team via a microphone.[8] Post-procedure, patients often resume normal activities the next day, though specific aftercare instructions are provided if a frame was used. Gamma Knife surgery offers numerous benefits, including the absence of incisions, the ability to reach deep-seated brain tumors, targeting multiple areas simultaneously, minimal tissue damage, and quick recovery times.[9] However, risks include nausea, headache, fatigue, and rare severe complications like brain swelling or seizures. Efficacy studies indicate an initial pain relief success rate of 80-90%, with long-term effectiveness declining to 46-56% over five years. Gamma Knife Radiosurgery (GKRS) disrupts pain transmission in the trigeminal nerve and is generally well-tolerated, with common side effects like facial numbness correlating with better pain relief outcomes.[10] GKRS is particularly effective for patients with multiple sclerosis-associated trigeminal neuralgia compared to other treatments

OPTIMIZATION AND CHALLENGES IN GAMMA KNIFE RADIOSURGERY FOR TRIGEMINAL NEURALGIA

In the early days of Gamma Knife Radiosurgery (GKRS) for trigeminal neuralgia (TN), many controversial issues about optimal conditions such as dose, target location, number of isocenters, and influence of dose rate were addressed through clinical data accumulation, though some questions remain unresolved.[11] Early trials by Lindquist et al. (1991) demonstrated that focusing radiation on the gasserian ganglion and moving to the retrogasserian ganglion and root entry zone (REZ) could reduce pain, with higher doses on the retrogasserian target showing more effective pain control but increased sensory complications near the brainstem.[12] Systemic reviews have suggested a maximum dose of 70-90 Gy, noting that higher doses prompt faster pain reduction and better overall responses but also higher rates of trigeminal neuropathy. Despite conflicting early results, recent studies highlight that dose rate influences outcomes, with higher dose rates potentially leading to quicker pain relief and lower recurrence rates. The debate continues over using single versus multiple isocenters, with no identified benefit for multiple isocenters. Prognostic factors for better outcomes include typical TN pain features, older age, visible vascular compression on MRI, and no prior surgical treatments, while sensory changes post-GKRS correlate with better pain relief. GKRS stands out as a primary treatment for TN and a salvage treatment post-failure of other procedures.[13] Its least invasive nature among surgical options, lower risk of procedural complications, and relative insensitivity to neurosurgeon experience or patient-specific anatomical variations make it a favorable choice. However, it does have a latency period before pain relief and is less predictable compared to other modalities like Microvascular Decompression (MVD).[14] The impact of dose rate and Biologically Effective Dose (BED) in GKRS remains a critical research area. Studies like those by Balamucki et al. and Arai et al. found no significant association between dose rate and pain control, while more recent findings by Lee et al. and Tuleasca et al. suggest that specific BED ranges can optimize long-term pain relief and minimize sensory complications. However, further research is required to solidify these correlations.[15,16] Diffusion Tensor Imaging (DTI) provides a non-invasive method to assess trigeminal nerve microstructures, potentially serving as biomarkers for TN diagnosis and treatment response. Studies indicate that specific DTI metrics can differentiate responders from non-responders and might predict successful pain relief post-GKRS. For patients undergoing repeat GKRS due to TN recurrence, the efficacy and complications of repeat procedures are key considerations. Repeat GKRS shows favorable outcomes, though with increased rates of trigeminal nerve dysfunction, particularly with higher cumulative doses. Studies indicate that good initial GKRS outcomes and facial numbness post-procedure are positive predictors for repeat GKRS success.[17]

COMPARISON OF GAMMA KNIFE RADIOSURGERY WITH MICROVASCULAR DECOMPRESSION (MVD)

Both Gamma Knife and MVD offer effective treatment for trigeminal neuralgia, but they differ in their approach and suitability for patients. Gamma Knife is a non-invasive procedure, delivering radiation through a machine without any scalpels or incisions. MVD, on the other hand, is an open surgery requiring an incision in the skull to access the trigeminal nerve.[18] Gamma Knife boasts a much shorter recovery time due to its non-invasive nature. Patients typically go home the same day after the procedure. MVD, being an open surgery, involves a longer hospital stay and a more extensive recovery period. MVD generally carries a higher risk of complications compared to Gamma Knife. These may include facial numbness, hearing loss, or cerebrospinal fluid (CSF) leak. While Gamma Knife can also cause facial numbness, the risk is generally lower. Studies suggest both MVD and Gamma Knife offer high initial success rates in terms of pain relief. However, MVD may provide a more definitive cure for some patients, with a lower chance of recurrence.[19]

REVIEW OF LITERATURE

In a study led by D. Kondziolka, radiosurgery demonstrated notable efficacy in alleviating facial pain, with 60% of patients achieving complete relief and 77% maintaining significant pain reduction at last follow-up. Recurrence of pain was low, affecting only 10% of initially relieved patients. While 10% developed new or increased facial paresthesias post-treatment, no cases of anesthesia dolorosa or other procedural morbidities were reported,

suggesting radiosurgery as a generally safe and effective option for managing facial pain. In two separate studies, the efficacy of gamma knife radiosurgery (SRS) in treating trigeminal neuralgia (TN) was evaluated.[20] In the study by Jelena Filipović, early efficacy was assessed, revealing a trend of decreased effectiveness within the first year post-procedure, likely due to limited monitoring and assessment duration.[21] Conversely, Ajay Niranjan's study, involving a retrospective review of 503 patients, showcased promising results: 449 patients experienced initial pain relief within a month after SRS, with 73% remaining pain-free and 80% achieving pain control at the one-year mark. Overall, SRS provided significant pain relief ranging from 60-90%, highlighting its potential as an effective intervention for TN. Early SRS intervention was particularly emphasized for its ability to deliver faster, better, and longer-lasting pain relief.[22] In the study by Sean, Gamma Knife radiosurgery demonstrated durable pain relief in 61% of patients, with recurrence reported by 23% of patients, occurring at a mean time of 9.6 months post-procedure.[23] In contrast, Oscar Zorro's study revealed even more promising outcomes, with 62.1% of patients achieving complete pain relief and 97.3% experiencing reasonable pain control.[24] Both studies underscore the effectiveness of Gamma Knife radiosurgery in managing pain associated with various conditions, highlighting its potential as a viable treatment option. In Patrick Han's study, 43 patients underwent stereotactic radiosurgery with positive outcomes.[25] Meanwhile, Raj Kumar Badam's research concluded that Gamma Knife surgery (GKS) offers a low-risk option with 80% pain relief and low recurrence rates, positioning it as a less invasive alternative to other neurosurgical treatments.[26,27] Ronald F. Young's study found even more promising results, with 81.7% of patients experiencing complete or nearly complete pain relief.[28,29] In Susan's study, Gamma Knife radiosurgery (GKRS) demonstrated low complication rates, high success rates, and reported patient satisfaction, indicating its efficacy and safety.[30,31] Additionally, Felipe Constanzo's research found GKRS to be effective, providing pain reduction ranging from 75-95% in patients.[32] J. H. Kang's study further supported GKRS's effectiveness, particularly for medically refractory idiopathic trigeminal neuralgia, with a pain response rate of 92.7% and no serious complications reported.[33] These findings collectively highlight GKRS as an increasingly utilized and successful primary intervention for appropriate trigeminal neuralgia patients, offering significant pain relief with a favorable safety profile. In Jin Woo Chan's study, Gamma Knife radiosurgery demonstrated a notable pain response rate of 86.7% in patients with idiopathic trigeminal neuralgia, with no serious complications reported, albeit mild facial sensory changes in two patients.[34] Ming-Chien's paper similarly highlighted positive outcomes, with 85.6% of patients achieving complete or partial pain relief at one year.[35] Halil's study reported a significant decrease in pain for 76% of patients with few complications.[36] Additionally, Toru Koyama's research underscored the effectiveness of Gamma Knife radiosurgery for idiopathic refractory trigeminal neuralgia, with 75.8% pain relief at one year and 55.6% at five years.[37] These findings collectively emphasize the efficacy and safety of Gamma Knife radiosurgery as a viable treatment option for trigeminal neuralgia, offering substantial pain relief with relatively low complication rates over both short and long-term durations.

In various studies, Gamma Knife radiosurgery (GKS) has emerged as an effective and minimally invasive treatment for trigeminal neuralgia, offering significant pain relief with relatively low risk. Leland Rogers' study reported effective treatment with a small risk of mild facial hypesthesia, positioning GKS as the least invasive nonpharmacologic therapy for the condition.[38] Bradley's research highlighted the efficacy and safety of a 90 Gy dose, achieving complete pain relief in 73.8% of patients.[39] However, Shinji Matsuda's study noted some complications, including dry-eye issues, post-GKS in a subset of patients.[40] Ronald Brisman's study emphasized GKS as a primary management option, with better relief observed in certain patient groups.[41] Yang Weizhon's research demonstrated a high percentage of patients experiencing pain relief post-GKRS, albeit with some recurrences and numbness reported.[42] Abiodun Idowu's study found a high proportion of patients reporting satisfactory responses at 6 months post-GKRS, reinforcing its effectiveness.[43] Similarly, Ali Mansour's study reported varying rates of pain relief and recurrence, ranging from 73.8% to 96% and 2% to 26.3%, respectively.[44] These collective findings underscore GKS as a valuable therapeutic option for trigeminal neuralgia, offering effective pain relief with manageable risks and recurrence rates.

CONCLUSION

The Gamma Knife radiosurgery is the safest and most effective form of treatment which is currently available for trigeminal neuralgia and is recommended once the diagnosis is clearly established. Compared to other minimally invasive treatments like glycerol rhizotomy, balloon compression, and radiofrequency thermocoagulation, GKRS offers a favorable balance of efficacy and safety. It is particularly beneficial for patients with multiple sclerosis-associated TN, who may have a lower success rate with other treatments. Gamma Knife Radiosurgery represents a significant advancement in the management of trigeminal neuralgia, offering high rates of pain relief with minimal invasiveness. While long-term effectiveness can diminish, the procedure remains a valuable option for patients seeking alternatives to conventional surgery. Ongoing research aims to optimize dosing strategies and improve long-term outcomes for patients.

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