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Gamma Knife Versus Volumetric Arc Modulated Therapy in a Linear Accelerator in Treatment of Multiple Brain Metastasis: Literature Review

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Abstract This literature review introduces the treatment results of Gamma Knife radiosurgery (GKRS) and volumetric arc therapy (VMAT) administered by linear accelerators for patients diagnosed with multiple brain metastases. The present study aimed to compare Gamma Knife radiosurgery with Volumetric Arc Modulated Therapy (VMAT) administered using a linear accelerator for brain metastases and their respective safety profiles and therapeutic results. The review assesses research on treatment precision, local control rates, survival outcomes, radiation necrosis incidence, and post-treatment quality of life. It evaluates technical progress, treatment plans, and physiological effects on brain tissue. Both modalities have the potential for managing brain metastases, with GKRS being beneficial for well-defined lesions and VMAT being a flexible and efficient option for larger or irregular-shaped metastases. The study highlights the unique benefits of each therapy for different types of brain metastases. GKRS and VMAT are effective treatments for brain metastases, using concentrated radiation for localised lesions and advanced imaging techniques for intricate or expanded regions. GKRS offers precise interventions with minimal invasiveness, suitable for patients with lower metastatic burdens or suboptimal surgical tolerance. Both therapies show similar effectiveness in local control and survival but may be better suited for specific patient needs and lesion characteristics.

Key Words gamma knife, volumetric modulated arc therapy, brain metastasis, linac, stereotactic

1. Brain Metastasis

Brain metastases are the most common form of brain tumour and a common complication of cancer. Brain metastases may occur in anywhere from 10% to 26% of cancer patients who ultimately succumb to their disease. Conventional treatments for brain metastases seldom result in a cure, although they may extend life expectancy and alleviate symptoms. The importance of neuro-cognition and quality of life as patient outcomes is becoming more widely acknowledged as survival rates continue to rise [1], [2].

Brain metastases are most often caused by lung, breast, and melanoma malignancies. Prophylactic therapy (cranial irradiation) is the gold standard for small-cell lung cancer due to its high tendency to spread to the brain. Metastases to the brain are uncommon in prostate, head, and neck tumours. It may be challenging to determine which patients would develop brain metastases other than by utilising tumour type and subtype [3], [4]. while there are 17,000 new instances of primary tumours every year. Cancers of the lung(40-50%), breast(15-25%), and melanoma (5%-20%) are the most common cancers to metastasise to the brain [4], [6]. Melanoma has one of the highest rates of brain metastases of all of these tumours; initially, 40–50% of patients are found to have brain metastases, and this number rises by another 30–40% following autopsy. There are six to forty incidences of melanoma per 100,000 people each year. Melanoma accounts for four percent of all skin cancers and seventy-four percent of skin cancer mortality. Intraparenchymal metastases account for 49% of melanoma brain tumours, leptomeningeal for 22%, and dural for 32% [7]. With a five-year survival rate of less than 10%, patients with brain metastases have an extremely bad prognosis. The number of melanoma cases that are diagnosed is consistently rising [8].

A. Epidemiology

Most intracranial tumours are metastases to the brain. There are between 98,000 and 170,000 annual cases in the US. Multiple variables contribute to the rising likelihood of brain metastases. New systemic medicines (such as immunotherapy) are being used, and they have increased survival rates for patients with systemic metastatic tumours. Small, asymptomatic brain metastases are now more easily detected because of the widespread adoption of sensitive magnetic resonance imaging (MRI) and positron emission tomography (PET) scan methods [9].

B. Pathophysiology

Damage to the blood-brain barrier allows metastatic cancer to reach the brain and spinal cord. Invasion, dislocation, inflammation, and swelling result from the subsequent proliferation of clonal cells. Although most brain tumours are found in regions with substantial blood supply, the precise location of each histological subtype varies considerably [10].

C. History and Physical

Symptoms, duration, and severity should all be carefully documented during a thorough history and physical examination. It's important to drill down on specific complaints like these. A thorough evaluation of the nervous system is required. The examination should evaluate the individual's muscular strength, sensory perception, motor control, reflexes, cerebellar function, proprioception, cranial nerve function, cognitive abilities (including language, cognition, and vision), and memory. Papilledema may be detected with an eye examination. Age, performance status, and the presence or absence of a systemic cancer load are all pieces of information that would help doctors better comprehend the progression of the illness and direct future therapeutic action [11]–[13].

D. Evaluation

Although a head CT scan may provide a rapid diagnosis, fine-slice MR imaging of the brain with contrast is the gold standard for neuroimaging when brain metastases are suspected. Using MR, doctors may assess the size, location, and volume of tumors, as well as any accompanying swelling. Complete blood count, metabolic panel, and liver function test are examples of fundamental laboratory assessments [14], [15].

E. Treatment / Management

The initial step in the therapy of newly detected brain metastases is the treatment of cerebral edema. Oral or intravenous steroids (such as dexamethasone) are often utilised. One possible dosage schedule involves administering a loading dose of 10 mg of IV dexamethasone, followed by 4 mg IV every six hours. Many of the negative consequences of long-term high-dose steroid therapy may be avoided if the dosage is gradually reduced after the first clinical response, which can occur rather quickly [16].

Definitive management may begin once steroid treatment has begun. Whole-brain radiation, stereotactic radiosurgery, and removal of surgically accessible lesions (for patients with minimal brain metastases and excellent performance status) are all viable choices for treatment. Daily radiation treatments (often 10 to 15) are administered to the whole brain to achieve whole-brain radiotherapy. Radiosurgery is a targeted kind of radiation that only affects the region of the brain where the metastasis is located. The benefits and drawbacks of each of these options are different. Together with the patient, a multidisciplinary therapy team consisting of a neurosurgeon, radiation oncologist, and neuro-oncologist should develop a treatment strategy [17], [18].

In individuals with a favorable performance status, surgical resection has always been considered the gold standard. One recent analysis found that only 43% of patients who had surgical excision and surveillance were free of local recurrence after 12 months. Post-operative radiosurgery or whole-brain radiation may enhance local control [19], [20]. The amount of non-resected metastases, tumor histology, postoperative follow-up, and patient choice should all be considered when making a therapeutic decision for postoperative therapy. Although whole-brain irradiation after surgical excision of brain metastases may improve intracranial control, it has worse effects on neurocognition than postoperative stereotactic radiosurgery. Stereotactic radiosurgery is a great alternative for managing a small number of intracranial metastases in patients who are either not candidates for, or who want to forego, surgical removal of brain metastases [21].

Stereotactic radiosurgery is now routinely utilised as a standalone therapy, however, it was originally used in conjunction with whole-brain radiation to strengthen local treatment. Single-fraction radiosurgery has excellent local control for brain metastases less than one centimeter in size [22], but final control varies with dosage and lesion size [23]. Multi-fraction treatments are occasionally used for bigger lesions. Individuals with one to four brain metastases are the conventional candidates for stereotactic radiosurgery, but new evidence suggests that patients with as many as 10 brain metastases may also benefit from this therapy [24]. Whole-brain radiation is the gold standard treatment for individuals with a low-performance status or multiple brain metastases [25]. The probability of failure at a new location in the brain is decreased, and individual brain metastases may be controlled, using whole-brain radiation. The possibility for neurocognitive adverse effects, which occur in many individuals to variable degrees, must be evaluated against these advantages. New evidence suggests that whole-brain radiation may provide a little advantage over steroid treatment alone for people with very low-performance status [25]. Therefore, in the management of brain metastases, therapeutic choices will need to be made on an individual patient level, taking into consideration the aims of therapy in a given context as well as the acceptable side effect profile.

F. Differential Diagnosis

Abscess, demyelination, parasite infestation, and original tumor (glioma/ependymoma) are all possible causes of brain metastases [26].

G. Prognosis

Several variables influence the prognosis of brain metastasis, including the patient's age, the number and size of metastases, the location of the main tumor and additional metastatic locations, the existence of the mass effect, and the tumor's radiosensitivity and chemosensitivity [27], [28].

The complications of brain metastasis are: mass effect, brain herniation, seizures, hydrocephalus, spread to surrounding tissue, neurological deficit, and death [29].

2. Stereotactic Definition and Overview

Brain tumors and functional abnormalities may be treated using stereotactic radiosurgery (SRS), a non-invasive form of radiation treatment. It may assist in protecting healthy tissue by delivering radiation to a specific target in a lower number of high-dose sessions [30].

When SRS is used, intense doses of radiation are targeted to the afflicted region using three-dimensional imaging, with minimum effect on the surrounding healthy brain tissue. Focused beams of radiation may be generated by devices like the Gamma Knife, linear accelerators (LINACs), and cyclotrons. There is no incision required for SRS, despite its name, therefore it should not be confused with regular surgery. Instead, radiation is used to zero in on the problem location [31].

Depending on the technology used and the specifics of the treatment plan, the process may be done in a single sitting or for many sittings. SRS is used to treat a variety of neurological disorders and malignancies, including brain metastases, arteriovenous malformations (AVMs), trigeminal neuralgia, acoustic neuromas, and pituitary tumors. Its accuracy, efficacy, and shortened treatment duration make it a helpful tool in the care of particular kinds of brain lesions [32].

Through the utilisation of comprehensive imaging techniques, precise dosage planning, and effective immobilisation of the patient's head. This advanced treatment modality enables the delivery of convergent beams of high-energy radiation to a specific volume within the brain, achieving an exceptional level of sub-millimeter precision. Stereotactic radiosurgery (SRS) stands out due to its ability to administer a concentrated dose of radiation to a specific focal point within a patient's body, either in a single session or multiple sessions. This approach differs from conventional radiation therapy, where smaller doses are typically spread out for several weeks [33].

In the realm of stereotactic radiosurgery (SRS), it is crucial to comprehend the fundamental physical principles and components that come into play:

1) **Localisation and Imaging:** The precise localisation of the target tissue is established through the utilisation of stereotactic techniques, which encompass three-dimensional imaging modalities like CT, MRI, or angiography to outline the boundaries of the tumour and adjacent delicate structures [34].
2) **Convergent Beam Radiation:** Multiple beams of ionising radiation are precisely directed toward the target from various angles, ensuring accurate and effective treatment delivery. Each beam exhibits a comparatively low intensity and, as a result, exerts a minimal impact on the surrounding tissues it traverses. Nevertheless, in the focal point where all beams intersect, the collective intensity is sufficiently elevated to cause ablation of the target tissue [35].
3) **Dose Planning and Distribution:** Sophisticated computer algorithms are utilised to determine the most suitable radiation dose distribution, taking into account the tumor's specific geometry and precise location. The objective is to optimise the radiation dosage delivered to the target area while minimising the radiation exposure to surrounding healthy tissues [36].
4) **Radiation Types:** In the field of radiotherapy, we utilise photons generated by linear accelerators or gamma rays emitted from radioactive sources such as Cobalt-60 (as observed in the Gamma Knife) [37].
5) **Collimation:** The shaping and sizing of beams are crucial in radiotherapy, particularly in matching the target's shape precisely. This is achieved through the utilisation of collimators or multileaf collimator systems. These advanced technologies play a vital role in minimising radiation exposure to non-targeted tissues, ensuring their protection during treatment [38], [39].
6) **Patient Immobilisation:** To ensure precise beam delivery, it is imperative to immobilise the patient's head utilising either a frame or a frameless system, employing facial masks or bite blocks [40].
7) **Radiobiology:** At elevated levels of radiation exposure, the DNA within cells is subject to both direct and indirect harm, resulting in cell demise or the disruption of cell division. This mechanism proves efficacious in targeting tumour cells that undergo rapid division [41].

Stereotactic Radiotherapy Application

1) **Fractionation:** In the field of radiotherapy, it is common practice to administer radiation in multiple small doses, referred to as fractions, during a series of treatment sessions. Fractionation is a crucial technique that enables the provision of ample time for healthy tissue to undergo repair between treatment sessions. When dealing with bigger tumors or ones located near sensitive tissues, this becomes more important [42].
2) **Tumor Volume:** SRS is often used for smaller, more clearly defined objectives, so keep that in mind when thinking about treatment volume [43].
3) **Flexibility:** An essential part of stereotactic radiother-

apy, this feature allows for the tumor's size and form to be modified as needed throughout treatment. This flexibility enables us to make treatment plan alterations as required [44].

4) **The technological foundation:** Radiotherapy relies on the use of state-of-the-art technical infrastructure, including specialised gear and software found in linear accelerators (LINACs). The ability to accurately guide beams of radiation from a variety of angles is greatly enhanced by these technologies [45].
5) **Clinical relevance:** Stereotactic radiation is used for more than only brain tumor care; it is also effective in treating lesions in the spine, lungs, liver, and prostate [46].

3. Differentiations between SRS and RT in Stereotactic Radiation Treatment (SRT)

Highly accurate techniques of radiation treatment, stereotactic radiosurgery (SRS), and stereotactic radiotherapy (SRT) differ essentially on how they are administered and how much radiation is given to each patient.

A. Dose and Fractionation

Stereotactic Radiosurgery (SRS) is a treatment technique that involves administering a concentrated dose of radiation in either a single session or occasionally throughout up to five sessions. In the field of radiotherapy, it classifies this treatment as "ablative," indicating its purpose to effectively eliminate the targeted tissue through a single exposure [47].

Stereotactic radiotherapy (SRT) treatment modality entails the administration of multiple smaller doses of radiation, which are carefully distributed over several sessions, a technique commonly known as fractionation. This particular approach is commonly employed in the treatment of larger tumours or those close to sensitive structures. The rationale behind this approach is to provide sufficient time for normal tissue to undergo repair and recovery in between treatment sessions [43].

B. Treatment Volume

The treatment volume refers to the specific area or region of the body that is targeted for radiation therapy. Small, well-defined lesions in the skull may often be successfully treated using stereotactic radiosurgery (SRS) [34].

It's important to remember that stereotactic radiosurgery and radiotherapy aren't only for treating brain tumors. Indeed, it may be put to good use on bigger or irregularly shaped portions of the body [48], [49].

C. Purpose

Small tumors of the brain, arteriovenous malformations, and other neurological disorders are commonly treated with SRS with the hope of a cure. Stereotactic radiation (SRT) is versatile enough to be used for both curative and palliative purposes, allowing it to efficiently treat tumors located anywhere in the body, including the brain, spine, lungs, and liver [50].

D. Equipment

In the field of radiotherapy, we utilise a variety of equipment to deliver precise and effective treatments. Both stereotactic radiosurgery (SRS) and stereotactic radiotherapy (SRT) employ comparable equipment, such as the Gamma Knife for SRS and linear accelerators for SRT. However, it is important to note that the planning and delivery mechanisms may differ depending on the specific technology and intended purpose. The decision between SRS and SRT is contingent upon a multitude of factors encompassing tumour size, location, and type, in addition to the patient's overall health and treatment objectives [51], [52].

4. Gamma Knife Stereotactic Radiosurgery

The Gamma Knife is a device created for the use of stereotactic radiosurgery (SRS), a non-invasive method of treating brain diseases with high-dose radiation. An outline of the context and evolution leading up to 1951 is provided below. Dr. Lars Leksell, a renowned Swedish neurosurgeon, proposed the idea of using radiosurgery to treat complex brain tumors and functional brain diseases, which led to the development of the Gamma Knife [53].

In 1967, the inaugural Gamma Knife procedure took place in Stockholm, Sweden. The initial device employed a solitary beam of cobalt-60 radiation to precisely target and treat localised regions within the brain [54].

The first prototype Gamma Knife was developed in 1974, and it was a revolutionary step forward in the area. The capacity to give targeted radiation treatment to a specific area was revolutionised by this ground-breaking technique, which focused 179 beams of cobalt-60 gamma radiation onto a single place [55]. The Gamma Knife has undergone several technological upgrades and improvements throughout the years. Targeting brain lesions with the Gamma Knife is now much more precise because of the development of imaging technologies like MRI and CT scans. Because of the extraordinary advancements in computer technology, we are now able to optimise the delivery of radiation to complex targets via the use of more accurate dose-planning methods. Multiple system upgrades have increased the unit's efficiency and efficacy, reduced treatment times, and made patients more comfortable. To improve the accuracy and speed of patient setup and targeting, the Gamma Knife system has been seamlessly combined with several state-of-the-art technologies [56]–[58].

The latest version of Gamma Knife is Icon which represents a major step forward in Gamma Knife technology, in terms of both functionality and design. These modern systems incorporate integrated imaging and software elements that permit real-time motion tracking and dosage control. The Icon's frameless treatment option enhances patient comfort and expands the Gamma Knife's applicability to a broader range of therapeutic applications. The development of the Icon showcases the continuous advancements in radiosurgery, resulting in enhanced patient outcomes. This progress is a result of extensive clinical research, technological advancements, and the accumulation of clinical experience over several decades [59], [60].

5. The History of Stereotactic Volumetric Modulated Arc Therapy (VMAT)

There have been significant advancements in radiotherapy techniques and deliveries worldwide over the past few decades. Our primary objective is to attain dose distributions that are highly conformal, ensuring that the radiation therapy is precisely targeted to the tumour while minimising exposure to surrounding healthy tissues. This approach allows us to enhance the therapeutic ratio, maximising the effectiveness of the treatment while minimising potential side effects [61].

In 1965, Takahashi pioneered the description of arc therapy utilising dynamic field shaping through the use of multileaf collimators (MLCs) [62]. During the late 1990s, the field of radiotherapy saw the introduction of intensity-modulated radiation therapy (IMRT), which was subsequently embraced and implemented in clinical settings. Intensity-Modulated Radiation Therapy (IMRT) is an encompassing name for a family of cutting-edge radiation delivery methods that may include arc therapy [63]. In 1995, Yu presented the revolutionary idea of Intensity Modulation Arc Therapy (IMAT). To accomplish modulation at beam-on time, this novel method entails a smooth gantry rotation and the dynamic motion of the Multi-Leaf Collimator (MLC). Different gantry angles were used in combination with segments to create arcs, as per the concepts of traditional Intensity Modulated Arc Therapy (IMAT) [64].

Since its inception in 2007, Volumetric Modulated Arc Therapy (VMAT) has been widely hailed as a significant advancement in the field of radiation therapy. Rotating the gantry speed and dosage rate simultaneously allows for the delivery of highly conformal dose distributions and the continuous adjustment of multi-leaf collimators (MLCs) for field shaping. With this method, radiation may be administered with little treatment time and a manageable number of monitoring devices (MUs) [65]. It is very impressive to recognise Otto's outstanding contributions to radiotherapy [66] using a custom-built algorithm for treatment planning in the context of single-arc VMAT. Notably, VMAT (Volumetric Modulated Arc Therapy) in radiotherapy has certain benefits that IMAT (Intensity Modulated Arc Therapy) does not (Intensity Modulated Arc Therapy). With VMAT, we have more leeway to adjust the parameters that optimise beam intensity modulation.

[67], released a thorough review study on VMAT in 2011, which offers new and useful perspectives on radiotherapy. An increasingly common kind of radiation therapy is called Volumetric Modulated Arc Therapy. There is evidence that this cutting-edge equipment reduces treatment times and speeds up the distribution of monitoring devices by allowing the user to choose the optimal number of arcs (MUs). This method is unique because it can provide complicated treatments with coplanar or non-coplanar single or multiple arcs, while also distributing modest doses across a large region of healthy tissue. Since fewer monitor units (MU) are used in VMAT compared to traditional fixed field IMRT, the risk of subsequent malignancy is predicted to be reduced. Macchia et al. provided a thorough assessment of the literature in 2017 VMAT's potential therapeutic use across a variety of anatomical locations was examined at length. The research underlined that VMAT has proven substantial success in the treatment of brain tumours, head and neck cancers, thoracic cancers, genitourinary cancers, and gastrointestinal cancers, as well as in the use of stereotactic body radiation therapy (SBRT) for oligometastasis.

The volumetric modulated arc therapy with simultaneous infusion of drugs (VMAT-SIB) approach is often employed in radiotherapy. VMAT technology allows for the effective implementation of the simultaneous integrated boost (SIB) method. By utilising VMAT, we can deliver highly biologically effective doses to the target area while minimising the dose to the surrounding normal tissues. This approach not only improves treatment efficacy but also helps reduce toxicity According to Macchia et al. [61], it has been concluded that the clinical utilisation of VMAT is relatively less documented. However, it has been found that VMAT-SIB and VMAT-SBRT are effective and safe techniques for treating different types of cancers in the body.

According to Hanna et al. [68], VMAT-SRS is considered a dependable therapeutic modality for SRS, supported by extensive dosimetric research that highlights its safety and advantages, especially in cases involving multiple brain metastases. In terms of treatment plan acceptability, conformity, and heterogeneity, VMAT was found to be comparable to the non-VMAT approach. It also demonstrated effectiveness in treating multiple lesions and providing frameless radiosurgery treatments with the aid of image guidance.

Dr. Shahid Hameed has made significant contributions to the field of modern radiotherapy in Pakistan. He initiated the implementation of Intensity-Modulated Radiation Therapy (IMRT) treatments at the esteemed Shaukat Khanum Memorial Cancer Hospital and Research Centre (SKMCH & RC) in 2005. SKMCH & RC Lahore holds the distinction of being the pioneering institution where the development of modern radiotherapy took place. In 2008, the esteemed Prof. A. Sattar M Hashim, a renowned neurosurgeon, established a state-of-the-art Gamma Knife and Linac-based Stereotactic Radiosurgery/Radiotherapy setup at the esteemed Neurospinal & Cancer Care Institute (NCCI) in Karachi. A group has been at the forefront of introducing and advancing the practice of stereotactic radiosurgery (SRS) and stereotactic body radiotherapy (SBRT) in Pakistan. In the beginning, we have been utilising different forms of IMRT in our practice as radiotherapist lecturers. These include fixed beam, step, and shoot, as well as forward and inverse IMRT, which were implemented between 2008 and 2013. Subsequently, we obtained the necessary license to utilise VMAT technology in our practice. Since 2014, we have been utilising VMAT (Volumetric Modulated Arc Therapy), VMAT-SIB (Simultaneous Integrated Boost), and VMAT-SRS/SBRT (Stereotactic Radiosurgery/Stereotactic Body Radiation Therapy) techniques as part of our routine practice [69].

6. Gamma Knife vs. VMAT: Comparative studies

The utilisation of stereotactic radiosurgery (SRS) in patients presenting with 1–4 intracranial metastases has been widely acknowledged as a recognised therapeutic approach (70). Recent studies have shown that stereotactic radiosurgery (SRS) is a safe and effective therapy option for patients with 5-10 brain metastases. Moreover, the study reveals that patients who undergo this treatment for multiple brain metastases experience comparable survival rates to those who are treated for 2-4 brain metastases [71].

GammaKnife (GK) radiosurgery has traditionally been the favoured choice in the field of radiotherapy. Nevertheless, when it comes to treating more than five brain metastases using the Gamma Knife (GK), the duration of the treatment tends to be extended, typically ranging from 1 to 3 hours, particularly when utilising aging Co-60 sources. Moreover, it is important to note that an extended GK treatment can result in the allocation of significant clinical resources within a radiation oncology department. This is primarily due to the necessity of physical supervision mandated by regulatory bodies, which involves the presence of both a radiation oncology physicist and a radiation oncologist [72]. Linear accelerator-based stereotactic radiosurgery (SRS) is becoming more commonly used as a viable option to Gamma Knife (GK) due to its broader accessibility and the ability to administer treatment quickly (within 20 minutes) using high-intensity flattening filter-free (FFF) modes. Liu et al. [73] have provided evidence that the quality of treatment plans achieved with GK Perfexion and single-isocenter, multiple noncoplanar VMAT techniques are similar. However, it is important to note that the VMAT approach may result in a slightly higher volume of low-dose radiation (<3 Gy) to the normal brain. Nevertheless, it is important to note that this particular study solely focused on a limited sample size consisting of six cases, each presenting with 3-4 small brain metastases. Additionally, the evaluation of dosimetry was exclusively conducted using 6-MV FFF plans. In their study, Thomas et al. [74] presented findings that showcased comparable conformity, dose fall-off, V12 Gy, and low dose spill between Gamma Knife (GK) and single-isocenter Volumetric Modulated Arc Therapy (VMAT) techniques. These results were obtained using the 10-MV Flattening Filter Free (FFF) beam model for a total of 28 cases, with a median number of three targets per case. One limitation of their study was the analysis of dosimetry using the older GK Model C instead of the more advanced GK Perfexion. The GK Perfexion has the potential to offer a dosimetric improvement when compared to its predecessor. This improvement is achieved through the convenient delivery of hybrid shots, which are produced by an inverse-planning algorithm. This algorithm optimises various factors such as target coverage, selectivity, and gradient index to enhance the treatment outcomes [75]. In contrast, it was determined by McDonald et al. [76] that in the context of radiotherapy, single-isocenter VMAT resulted in a notably higher dose to the normal brain in comparison to GK Perfexion across all examined dose levels. Nevertheless, our research focused on analysing cases involving a limited number of brain metastases, ranging from 2 to 5. Additionally, we did not utilise the 6-MV FFF or 10-MV FFF beam models in our study. According to a recent study conducted by Zhang et al. [77], which focused on hippocampal-sparing in cases with 3-10 brain metastases (with a median of six metastases per plan), it was found that GK Perfexion plans exhibited significantly reduced irradiated brain volume in terms of V12 Gy, V8 Gy, and V4 Gy, as compared to single-isocenter VMAT. Nevertheless, it is important to note that this particular study failed to differentiate between cases with a small number of metastases (3) and cases with a larger number of metastases (10). Additionally, the study did not conduct a comparative analysis of the dosimetry outcomes between the VMAT 6-MV FFF and 10-MV FFF beam models.

7. Conclusion

The Gamma Knife radiosurgery (GKRS) and volumetric arc modulated therapy (VMAT) in the treatment of numerous brain metastases have yielded significant findings on the most effective approach to managing this disease. Both techniques have unique benefits and have shown efficacy in enhancing patient outcomes when customised to certain therapeutic situations. The GKRS technique is notable for its accurate administration of concentrated radiation to localised and well-defined lesions and is supported by a substantial body of empirical research. The safety and efficacy of this therapeutic practice have been confirmed by the accumulation of data over an extended period of time, accompanied by a well-described profile of adverse effects. This method is a great option for individuals with a modest burden of metastatic lesions or those who may not tolerate surgical treatments well because of its ability to give precise therapeutic interventions with little invasiveness. The modern approach presented by VMAT, on the other hand, makes use of advanced imaging and treatment planning tools to more precisely deliver radiation to complex or enlarged areas of the body. This option to GKRS is competitive because of the flexibility and efficiency with which therapy may be delivered, particularly in cases involving larger or irregularly shaped metastases or where a short treatment term is required. As far as I can tell from the literature at hand, both treatments are equally beneficial in terms of local control and survival. While both therapies have the potential to improve patient outcomes, they may be more effective in treating different types of patients and lesions. This means that the size and location of the tumor, the patient's current condition, and the available resources must all be taken into consideration when making judgments in clinical practice.

Conflict of interest

The authors declare no conflict of interests. All authors read and approved final version of the paper.

Authors Contribution

All authors contributed equally in this paper.

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