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Comparison between inverse and convolution plan in treatment of cavernous malformations by ICON gamma knife stereotactic radiosurgery

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ABSTRACT

Background: This research aims to evaluate and compare the effectiveness and accuracy of the Inverse and Convolution planning strategies for the treatment of cavernous malformations via the use of ICON Gamma Knife stereotactic radiosurgery.
Methods: A retrospective cohort research was undertaken at the Al-Taj Centre of Gamma Knife in Baghdad, Iraq, spanning the period from January to August 2023. A cohort of forty individuals diagnosed with cavernous malformations were chosen using a random stratified sample method and then underwent treatment use the ICON iteration of the Gamma Knife. Every individual participant got a 3 Tesla Magnetic Resonance iImaging (MRI) scan in order to get comprehensive anatomical mapping. The generation of treatment plans included the use of both Inverse and Convolution methodologies. The assessment criteria included many characteristics, including the Paddick Conformity Index (PCI), Homogeneity Index (HI), treatment duration, Selectivity, Coverage, Gradient Index (GI), and dosage to risk tissues. The statistical analysis was conducted using the software SPSS-28.
Results: The research cohort exhibited an average age of 63.12 years ± 13.42 years, with a little preponderance of female participants. The Inverse planning strategy exhibited improved brain stem protection, higher PCI, and faster beam-on time, but the Convolution plan revealed superiority in terms of Selectivity and GI. There was no statistically significant difference in the integral dose between the two designs, indicating that the total radiation exposure was the same.
Conclusion: This research demonstrates how inverse planning and convulsion methods may be used to treat cavernous malformations using Gamma Knife radiosurgery. While convulsion planning improves selectivity and dosage gradient, inverse planning protects and conforms brain structures better.

Keywords: inverse plan, convulsion plan, cavernous malformations, stereotactic radiosurgery

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INTRODUCTION

Cavernous Malformations (CMs) are abnormalities of the brain's blood arteries that look like mulberries and have a very odd shape [1]. Depending on factors such as tumor size, location, and bleeding risk, these tumors may lead to a variety of neurological symptoms and problems [2]. For CMs located in high-risk or difficult-to-reach brain areas, Stereotactic Radiosurgery (SRS) offers a less intrusive and potentially life-changing therapeutic option [3-14].

Stereotactic Radiosurgery involves the delivery of a high dose of radiation to a precise target within the brain, utilizing multiple beams of radiation that converge at the lesion site. Treatment planning is a critical component of SRS, influencing the efficacy and safety of the procedure. The inverse planning method involves the physician setting a desired dose distribution, with the planning system then calculating the beam weights and configuration required to achieve this distribution. On the other hand, the convolution plan involves the calculation of dose distribution based on a predetermined beam configuration and weights [15, 16].

The ICON Gamma Knife is an exceptional breakthrough in SRS technology, offering exceptional precision and delivering high-dose radiation to the specific lesion of interest, all while ensuring minimal exposure to the neighbouring healthy tissue [17].

Few studies have compared these two strategies for planning ICON Gamma Knife SRS for CMs. Better conformality and dosage homogeneity to the target are two possible benefits of inverse planning that may contribute to better clinical outcomes, according to research conducted in various settings. On the other hand, convolution plans may be simpler to implement and require less time spent on planning, which might be useful in some therapeutic settings [18-20]. The objective of this study is to evaluate and compare the efficacy and safety of two distinct treatment planning approaches utilised in ICON Gamma Knife SRS for the management of cavernous malformations. These approaches include the inverse and convolution plans.

METHODOLOGY

This is a retrospective cohort design of study performed in Al-Taj center of Gamm Knife, Baghdad, Iraq. The study conducted from January 2023 to August 2023. a random stratified sampling technique for patients with brain cavernous malformations diagnosed by neurosurgeon and forwarded to Gamma Knife procedure. Forty patients were involved in this study. Each patient underwent an MRI examination of 3 Tesla for specific anatomical details. Written ethical consent were acquired for each patient.

Inclusion criteria

- Cavernous malformation confirmed by magnetic resonance imaging.
- Must be above the age of 18.
- SRS was performed using either a backwards or a forward's strategy.
- Available clinical and imaging follow-up data for at least 6 months after SRS.

Exclusion criteria

- The patient has a history of previous cranial radiation treatment.
- The individual presents with many instances of cavernous malformations.
- Individuals who are currently pregnant or in the lactation period.
- Present coexisting cerebral vascular abnormalities.

The patients were prepared with mask and Cone Beam CT (CBCT) fixation and treated with Icon version of Gamma Knife. The prescribed dose was 14 Gy-16 Gy in 50%. The delineation performed by neurosurgeon. The physicist generates two treatment planning techniques for each patient: Convulsion and Inverse. The final approval was done by neurosurgeon. The evaluation of plan depends on: Paddick conformity index (PCI), Homogeneity Index (HI), treatment time, Selectivity, Coverage, Gradient Index (GI), and dose to the tissue at risks.

SPSS-28, a statistical package, will be used to do the analysis. Descriptive statistics will be used to summarise patient demographics and lesion characteristics. Chi-square tests for categorical data and t-tests will be used to do group comparisons. Statistical significance will be assumed at a p-value ≤ 0.05.

RESULTS

The characteristics of patients included in this study were listed in Table 1. The mean age was 63.12 years ± 13.42 years. Most of patients were female (55%), male was 45%, as shown in figure 1. The body mass index was 26.24 kg/m^2 ± 8.11 kg/m^2. The tumor volume shows to be 2.985 ± 0.942.

Tab. 1. Characteristics of cavernoma malformation patients

Age (Years)	63.12 ± 13.42
Gender	Male: 18 (45%)
	Female: 22 (55 %)
Body Mass Index (BMI) (Kg/m^2)	26.24 ± 8.11
Volume (cm^3)	2.985 ± 0.942

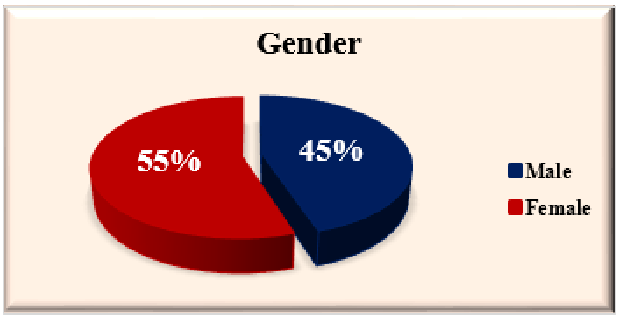

Fig. 1. The prevalence of gender with cavernoma malformation

The distribution of the dose administered to the volume of the cavernoma malformation tumour is shown in Table 2. The research demonstrates a significant disparity in the minimum, maximum, and mean dose between the inverse planning approach and the convulsion planning technique. No statistically significant change was seen in the integral dose.

Tab. 2. The dose distribution of cavernoma malformation

Minimum Dose (Gy)	1.6 ± 0.09	2.87 ± 0.06	0.04432*
Maximum Dose (Gy)	28.15 ± 1.68	29.99 ± 1.09	0.0210*
Mean Dose (Gy)	27.22 ± 2.91	28.34 ± 1.07	0.00129*
Integral Dose (mJ)	14.74 ± 4.29	15.1 ± 2.53	0.05964
*Significant Difference at *p*–value ≤ 0.05			

The brain stem constitutes the vulnerable tissue under investigation in this research. The research indicates that the implementation of an inverted plan offers more protection to the brain stem against excessive radiation compared to the convulsion planning approach. A notable disparity was seen in the maximum, mean, and integral doses. No significant difference observed in minimum dose (Table 3).

Tab. 3. The dose reached to brain stem as a tissue at risks

Minimum Dose (Gy)	0.64 ± 0.05	0.42 ± 0.02	0.0567
Maximum Dose (Gy)	4.9 ± 0.76	3.7 ± 0.54	0.0408*
Mean Dose (Gy)	2.43 ± 0.55	1.2 ± 0.59	0.00746*
Integral dose (mJ)	1.42 ± 0.02	1.61 ± 0.054	0.03201*
*Significant Difference at *p*–value ≤ 0.05			

The physics of evaluation parameters were presented in Table 4. The parameters were Coverage, Selectivity, Gradient Index (GI), Paddick Conformity Index (PCI), Number of Shots, and Beam on time. The results shown that the convulsion is better than inverse in selectivity. The inverse plan shows better significant Paddick Conformity Index (PCI) and beam on time (minutes). The coverage was higher coverage than convulsion and a smaller number of shots. The convulsion shows better dose gradient than inverse planning.

Tab. 4. The physics of plan evaluation parameters

Coverage	0.91 ± 0.03	0.99 ± 0.02	0.05943
Selectivity	0.89 ± 0.03	0.68 ± 0.07	0.04942*
Gradient Index (GI)	2.34 ± 0.39	2.62 ± 0.48	0.0582
Paddick Conformity Index (PCI)	0.86 ± 0.07	0.92 ± 0.09	0.00892*
Number of Shots	2–10	1 – 4	NA
Beam on time (minutes)	17.43 ± 1.32	13.7 ± 2.19	0.0322*
*Significant Difference at *p*–value ≤ 0.05			

DISCUSSION

The research findings compare two different approaches to radiation therapy planning: the inverse planning approach and the convulsion planning technique. Each of these techniques has its unique methods and principles, which lead to the observed differences in treatment outcomes such as dose distribution, protection of vulnerable tissues, and efficiency [21]. Inverse planning is a commonly used approach that utilises algorithms to optimise the distribution of radiation dosage. This optimisation process is based on a pre-established target, such as a tumour, and takes into consideration various restrictions pertaining to the surrounding normal tissues. The use of this optimisation technique has the potential to enhance the accuracy of tumour targeting, as shown by the significant disparities seen in the maximum and mean doses [22]. The Convulsion Planning method may use a distinct algorithm or strategy that may not achieve the same level of optimisation in dose distribution, resulting in a noticeable divergence [23, 24].

A tumor volume of 2.985 cm^3 ± 0.942 cm^3 was considered typical. How the radiation dose is planned and administered during radiation treatment is greatly affected by the tumor's volume. To achieve sufficient coverage while preserving healthy tissue, more accurate dosage sculpting may be necessary for smaller or irregularly shaped tumors.

The inverse method typically uses advanced algorithms to optimize the radiation dose distribution based on the shape and size of the tumor. The goal is to maximize the dose to the tumor while minimizing exposure to surrounding healthy tissues. The significant disparity in the minimum, maximum, and mean doses suggests that the inverse planning approach might be better at targeting the tumor with high precision, delivering higher doses to the tumor and lower doses to surrounding areas.

The convulsion technique might use a different methodology that does not optimize the dose distribution to the same precision as the inverse planning. It might result in less disparity in the radiation dose across different areas of the tumor. The convulsion planning might focus more on a uniform distribution of the dose rather than intensely targeting specific areas of the tumor.

The integral dose, which measures the overall quantity of radiation energy received by the patient, was comparable between the two methods regardless of these variations. This means that the procedures used to expose the patient to radiation were about equal in terms of total dose. Perhaps the similarity in integral dosage is a result of the delicate balancing act of exposing healthy tissues to the minimum amount of radiation necessary to eradicate the tumor. The overall dosage is balanced by both systems, even though they use distinct ways to dose distribution.

Because it can better tailor the radiation dosage to the tumor, reducing exposure to nearby delicate tissues like the brain stem, the inverse planning method may provide better protection for the brain stem. Contrarily, the convulsion planning method may not be as accurate in avoiding over-irradiation of the brain stem.

The superior selectivity of the convulsion technique may be attributed to its ability to concentrate on the dose more precisely, although potentially deviating from the tumor's shape compared to the inverted plan. The superior performance of the inverse plan in these specific locations implies that it exhibits more efficiency in providing a conformal dose within a reduced timeframe. The inverse plan's ability to provide higher coverage with fewer shots may be attributed to the use of advanced optimisation algorithms. These algorithms efficiently ensure comprehensive tumour coverage while minimising the necessary amount of radiation beams or shots. The convulsion plan has a superior dose gradient, suggesting its potential to provide a more pronounced decline in radiation dose beyond the tumour site, hence safeguarding adjacent tissues.

The research conducted by Fallows et al. represents a notable progress in the comprehension of convolution-based treatment planning for Gamma Knife radiosurgery [25]. The results suggest that this approach provides enhanced precision, particularly in diverse tissues, in contrast to the conventional TMR10 algorithm. The greater accuracy highlighted in this context calls for a reassessment of existing dose recommendations and emphasises the possibility of enhanced treatment results in real-world medical settings. This paper makes a substantial contribution to the dynamic field of radiation therapy, emphasising the need of ongoing adjustment and enhancement of treatment planning methods in light of technological progress.

The objective of the study by Ghanim et al. is to evaluate the inverse gamma knife algorithm in relation to the convolution planning algorithms for patients with a brain tumour who have had Gamma Knife Icon treatment [26]. Sixty people who had gamma knife surgery for benign or malignant brain tumours were analysed. The process of scanning the brain is called a Cone Beam CT scan (CBCT). The patient had an MRI of the brain using a 3.0 Tesla magnet (a Philips Achieva). The mask of the patient was put in place. The neurosurgeon will draw a diagram of the tumour and decide on a treatment strategy. In order to reduce exposure to Organs at Risk (OARs), the medical physicist optimised the target dose by adjusting collimator size, beam angle, radiation weighting dosage, and grid size. In the beginning, convolution was utilised, and later on, sophisticated inverse was used. The neurosurgeon recommends a superior patient plan based on tumour and surrounding tissue dose and assessment parameters: coverage, selectivity, Gradient Index (GI), and Paddick Conformance Index (PCI). The researchers concluded that the inverse planning approach outperformed the convolution planning method in terms of the dosage delivered to the tumour. In this study, the pituitary gland, brain stem, and both optic nerves are considered OARs. There is no discernible difference between the inverse and convolution approaches with regards to the maximum dose of the left and right optic nerves. Contrast this with inverse planning, where minimum and mean dosages to the left and right optic nerves are much lower. Maximum and mean doses to the brain stem were considerably higher with the inverse approach than with the convolution algorithm, whereas the minimum dose was not significantly different. The pituitary is better protected by inverse planning than by convolution. When it comes to generating a high Paddick Conformity Index (PCI), the convolution approach is preferable than the inverse algorithm. The inverse algorithms exhibited a greater selectivity, GI, and PCI than the convolution. Better coverage with less time spent treating is what the convolution demonstrates. They found that the convolution method was best for tumours at a reasonable distance from other brain-sensitive structures, while the gamma inverse planning algorithm was best for tumours near intact vital tissue like the optic nerve, brain stem, or pituitary glands. Targets might be successfully covered without exposing OARs to radiation.

CONCLUSION

In conclusion, the study provides evidence that both convulsion and inverse planning methodologies provide unique benefits in the context of Gamma Knife radiosurgery for cavernous malformations. Inverse planning has been shown to provide more protection to vulnerable brain areas and greater conformance. On the other hand, convulsion planning has demonstrated superior selectivity and dosage gradient. The results indicate the possibility of requiring personalised treatment strategies that take into account the unique qualities of each patient and the parameters of their tumour. The present work provides significant contributions towards the optimisation of Gamma Knife radiosurgery in order to improve patient outcomes.

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