Comparative Assessment of Inverse versus Convolution Treatment Planning Algorithms used in Gamma Knife

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Abstract

Background: This study aims to assess the inverse gamma knife algorithm compared to the convolution planning algorithms for a brain tumor in patients treated with the Gamma Knife Icon®. Materials and Methods: Sixty patients with benign or malignant brain tumors treated with a gamma knife Icon. Cone Beam computerized Scan (CBCT) is used to scan the brain. The patient had a 3.0 Tesla MRI (Philips Achieva model) to get a brain anatomical view. A patient's mask was installed. Neurosurgeons outline the tumor and plan the prescribed dosage. The medical physicist used collimator size, beam angle, radiation weighting dosage, and grid size to optimize the target dose and decrease Organ at Risk (OAR) exposure. First, convolution used, then advanced inverse. The neurosurgeon approves a better patient plan based on tumor and surrounding tissue dosage and evaluation parameters: coverage, selectivity, gradient index (GI), and Paddick conformance index (PCI). Results: The dosage administered to the tumor indicates that the inverse planning method is better than the convolution planning technique. The organs at risk (OAR) engaged in this investigation are the left and optic nerve, brain stem, and pituitary gland. The maximal dosage of the left and right optic nerves reveals no significant variation between the inverse and convolution techniques. While the minimum and mean doses of left and right optic nerves are exposed to radiation much greater in convolution than the inverse planning. The inverse method's maximum and mean brain stem doses were substantially greater than the convolution algorithm, but the lowest dosage was not significantly different. Inverse planning protects the pituitary better than convolution. The convolution algorithm is superior to the inverse algorithm for producing a high selectivity index, the Paddick conformity index (PCI). The inverse algorithms had a higher selectivity, GI, and PCI than the convolution. The convolution shows significantly better coverage and less treatment time. Conclusion: The gamma inverse planning algorithm may be optimum for treatment planning cancers with intact vital tissue such as optic nerve, brain stem, or pituitary glands, whereas the convolution method is preferred for tumors with an appropriate distance from other brain-sensitive structures. It may help cover targets effectively without irradiating OARs.

Keywords: GK, SRS, Inverse, Convolution, PCI

1. Introduction

Gamma Knife radiosurgery (GKRS) is stereotactic equipment designed to treat intracranial pathologies associated with benign, malignant, and functional diseases. It was initially invented by Lars Leksell and the medical physicist Borje Larsson. The gamma knife of Icon versions have 192 perfectly focused Co-60 radiation beams [1].

In most clinical settings, using a trial-and-error approach, convolution (forward) planning is done with gamma knife radiosurgery. As a result, the planner adds and eliminates shots as needed, adjusting their locations and configurations until the PTV and OARs achieve the desired dose characteristics. These require the planner to manually select the number of beams, their directions, forms, dynamic wedge inclusion or exclusion, and relative weightings of each beam type. The computer then uses these beam parameters to determine the resulting dosage distributions. — field [2]. This differs from inverse planning, in which a human treatment planner specifies the intended dose limitations. The computer calculates the required beam intensities and shapes the best to fulfill the dosage constraints. Suppose the resulting dose pattern fails to match pre-planning objectives or is physically impossible to achieve. In that case, the planner adjusts the beam intensities (or weight) and/or field shapes and directions, and the computer calculates the dosage range again. The planner repeats this approach until they obtain a dose distribution that meets the pre-planning defined volume dosage restrictions and is physically feasible [3].

It remains difficult to achieve adequate coverage of the targeted tumor while protecting the critical tissue from harmful gamma radiation in a single fraction [4]. The most common indexes used to show the plan quality are coverage, selectivity (S), gradient index (GI), Paddick conformity index (PCI), and beam-on time (BT). The coverage calculates the volume of the target that is covered by the prescription radiation dose. The selectivity index (SI) is the target volume

doi.org/10.31838/hiv22.02.351 Received: 04.04.22, Revised: 04.05.22, Accepted: 16.08.22

covered by the peripheral isodose. Selectivity is defined by the amount of normal tissue around the target that is spared, and SI is the volume of the target covered by the peripheral isodose. The GI quantified the degree of dosage reduction beyond the target volume [5]. The conformity Index is essential for measuring how closely the prescribed dosage matches the objective. PCI is the squared target volume covered by the prescription isodose volume divided by the target volume and the prescription isodose volume [6, 7]. The beam on time is the amount required to deliver the prescribed dose to the patient's tumor in a single session [8, 9]. This study aimed to evaluate the inverse gamma knife algorithm compared with the convolution planning algorithms of brain tumor patients with the Icon Gamma Knife device.

2. Patients and Methods

This cross-sectional study was conducted at Al-Taj Gamma Knife Center from January 2022 to June 2022 in Baghdad, Iraq. The IRB approved this research by the college of medicine, Al-Nahrain University. Written ethical consent was acquired for each patient. Sixty patients were diagnosed with a benign or malignant brain tumor and forwarded to gamma knife treatment were involved in this study. The device is the gamma knife Icon version manufactured by Elekta, Sweden. This device is mounted with cone-beam computed tomography (CBCT) to image the brain's anatomical structure. The patient was forwarded to a 3.0 Tesla MRI (Achieva model manufactured by Philips) imaging to acquire the brain's specific anatomical details. The mask was fitted to the head of the patient for fixation. The neurosurgeon delineates the tumor and the critical organs (organs at risk) and sets the dose prescription. The medical physicist performed the two plan to maximize the dose to the target and minimize the dose to the organs at risk (OARs) by selecting the collimator size, beam angle, radiation weighting dose, and grid size. The first plan was done with the convolution algorithm, and the second was performed with the advanced inverse algorithm. The neurosurgeon approves a better plan for the patients depending on the tumor and surrounding tissue dose and the evaluation parameters: Coverage, Selectivity, Gradient Index (GI), and Paddick conformity Index (PCI). The statistical analysis was performed with SPSS 25 at a significant level equal to or less than 0.05.

3. Results

The comparative results of the minimum, maximum, and mean doses reached to the tumor are illustrated in table 1. The dose irradiated to the tumor shows the inverse planning algorithm significantly higher than the convolution planning algorithm, as shown in figure (1). The organs at risk (OAR) involved in this study are the left and optic nerve, brain stem, and pituitary gland. The maximum dose of the left and right optic nerves shows no significant difference between the inverse and convolution algorithms, as shown in figures (2) and (3), respectively. While the minimum and mean doses of left and right optic nerves are exposed to radiation significantly higher in convolution than the inverse planning.

The maximum and mean dose that reached the brain stem in the inverse algorithm was significantly higher than the convolution algorithm, while the minimum dose was not significantly differed between the two studied algorithms, as presented in figure (4). The inverse planning algorithm protects the pituitary gland better than the convolution algorithm, as shown in figure (5)

Table 1. Dose Comparison between the convolution and inverse planning algorithms for tumors and organs at risk.

	Convolution Algorithm	Inverse Algorithm	p-value
Tumor			
Minimum Dose (Gy)	6.18 ± 2.76	10.088 ± 4.49	0.025844
Maximum Dose (Gy)	28.68 ± 10.95	39.364 ± 18.28	0.044654
Mean Dose (Gy)	18.11 ± 6.06	26.14 ± 7.85	0.046738
Rt. Optic Nerve			
Minimum Dose (Gy)	1.74 ± 0.79	0.7 ± 0.11	0.040427
Maximum Dose (Gy)	6.71 ± 1.87	7.29 ± 3.59	0.67743
Mean Dose (Gy)	3.31 ± 2.60	0.89± 0.04	0.045274
Lt. Optic Nerve			
Minimum Dose (Gy)	1.69 ± 0.82	0.9 ± 0.21	0.04279
Maximum Dose (Gy)	7.01 ± 1.90	8.18 ± 3.59	0.92141
Mean Dose (Gy)	2.96 ± 2.88	1.91 ± 0.59	0.03017
Brain Stem			
Minimum Dose (Gy)	1.69 ±0.21	2.1 ± 1.54	0.204522
Maximum Dose (Gy)	14.22 ± 6.29	21.01± 4.14	0.044275
Mean Dose (Gy)	4.97± 1.81	7.53 ± 1.98	0.032151
Pituitary Glands			
Minimum Dose (Gy)	10.85 ± 3.55	9.3 ± 3.04	0.922037
Maximum Dose (Gy)	36 ± 8.1	30 ± 9.52	0.183503
Mean Dose (Gy)	25.25 ± 5.87	19.65 ± 1.75	0.768724

* Significant difference at p – value ≤ 0.05.

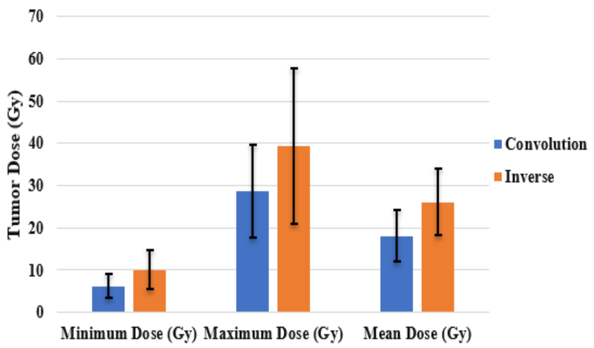

Figure (1): Comparison between the tumor minimum, maximum, and mean doses for the inverse algorithm and convolution algorithm

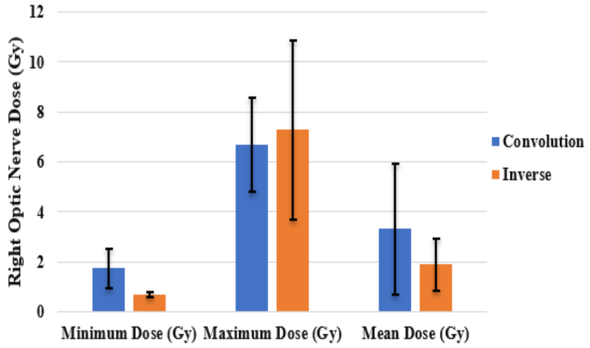

Figure (2): Comparison between the minimum, maximum, and mean doses for the inverse algorithm and convolution algorithm of the right optic nerve

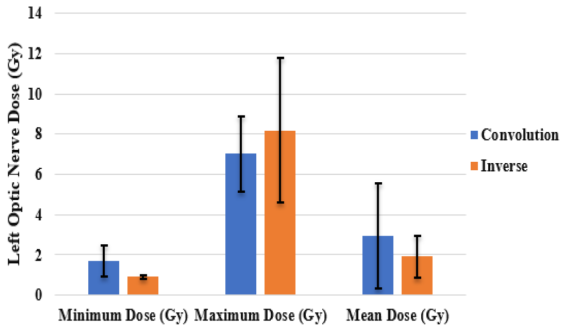

Figure (3): Comparison between the minimum, maximum, and mean doses for the inverse algorithm and convolution algorithm of the left optic nerve

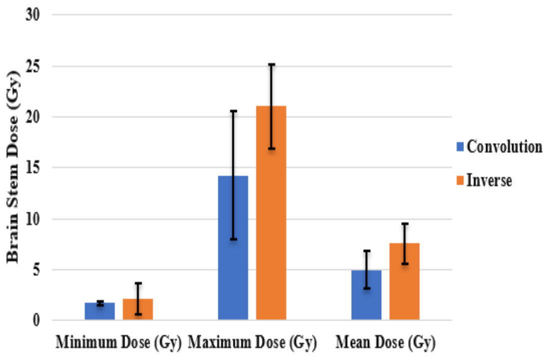

Figure (4): Comparison between the minimum, maximum, and mean doses for the inverse algorithm and convolution algorithm of the brain stem

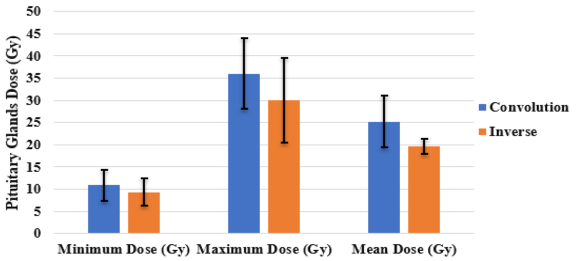

Figure (5): Comparison between the minimum, maximum, and mean doses for the inverse algorithm and convolution algorithm of the pituitary gland

The quality of planning assessment parameters used for gamma knife in this study are tumor coverage, selectivity, dose gradient index (GI), Paddick conformity index (PCI), and treatment time. These parameters are measured for both studied planning algorithms and listed in the table (2). The statistical analysis shows a highly significant difference between the convolution and inverse algorithms: the selectively gradient index and Paddick conformity index (PCI). The inverse algorithms had a higher selectivity, GI, and PCI than the convolution. In contrast, the convolution shows significantly better coverage and less treatment time.

Table (2): Quality of Planning Parameters Comparison between the Inverse and Convolution Algorithms.

Parameters	Convolution Algorithm	Inverse Algorithm	p-value
Coverage	94.62 ± 6.69	93.31 ± 6.55	0.02556*
Selectivity	55.49±24.77	73.05±19.28	< 0.00001
Gradient Index (GI)	2.23±1.43	2.86±2.19	0.02909*
Paddick conformity Index (PCI)	2.15±1.91	1.29±0.49	0.00032*
Time (Minute)	15.99±7.06	21.18±11.62	< 0.00001*

* Significant Difference at p – value ≤ 0.05 level.

4. Discussion

The algorithm planning analysis of patients' tumors in this study was treated with an Icon gamma knife depending on the site regardless type of tumor. It was found that the dosage administered to cancer indicates the inverse planning method much greater than the convolution planning technique. The organs at risk (OAR) engaged in this investigation are the left and optic nerve, brain stem, and pituitary gland. The maximal dosage administered to the left and right optic nerves does not change significantly between the inverse and convolution methods. While the minimum and mean doses of radiation exposure to the left and right optic nerves are much greater in convolution than inverse planning, the minimum and mean doses are significantly lower. In the inverse method, the maximum and mean doses that reached the brain stem were much larger than in the convolution technique. However, the lowest dosage did not change significantly between the two examined algorithms. The inverse planning method better protects the pituitary gland than the convolution technique.

To evaluate the relative advantages of competing for stereotactic radiosurgery treatment plans, a medical physicist planner must acquire enough knowledge and consider a tremendous amount of three-dimensional dosage information. Given the radiation dose distribution in three dimensions in the vicinity of the target, the planner must determine how well the prospective plan achieves the treatment goals of uniformly irradiating the target to a high dose level while sparing non-target tissue from the effects of a large radiation dose [10].

This research uses tumor coverage, selectivity, dosage gradient index (GI), and Paddick conformance index (PCI), and treatment duration as planning factors for gamma knife. The statistical study indicates that the convolution method and the inverse algorithm vary relatively significantly. Paddick conformance index, the selectively gradient index (PCI). The inverse algorithms were superior to the convolution in selectivity, GI, and PCI. In comparison, convolution provides substantially higher coverage and requires less processing time.

The inverse planning approach has the disadvantage of taking a long time. The capacity to construct a simple with a small-dose variation inside the tumor volume is beneficial. The convolution technique uses the electron density within each voxel to account for tissue heterogeneities. This technique computes the primary and dispersed doses to calculate the overall dose deposition. This technique adds both direct and dispersed doses [11].

Wieczorek et al. [12] compared inverse plans optimized by GK Lightning to convolution or forward plans on 115 lesions. It revealed that, in terms of plan quality measures, inverse plans were equivalent to or better to forward plans. Spaniol et al. [13] Conducted comparative studies on the methods of 38 patients and analyzed the inter-operator variability of a single plan for each pathology category. In addition, they demonstrated increased plan quality with GK Lightning while operator experience had negligible effect. The research performed by Cui et al. [14] categorized plan quality comparisons into distinct diagnoses with a wider variety of treatment locations and examined planner reliance for all forty plans. Our research presents an impartial assessment of the inverse planning technology and compares GK plans made by skilled and novice users for various illness locations treated clinically using GK. They discovered that the plan quality of inversely optimized plans generated with inverse planning technology was at least comparable to those manually created by experienced planners across all disease types, with the PCI of the inversely optimized plans being significantly higher.

Due to the large degrees of freedom inherent in a GK plan, standard convolution planning for GK is often complicated and nonintuitive. Due to the size of the search space, the quality of a manually constructed GK plan is diminished. Due to the large degrees of freedom inherent in a GK plan, standard convolution planning for GK is often complicated and nonintuitive. Due to the size of the search space, the quality of a manually constructed GK plan is diminished [15].

It should be noted that the proportion of isodose line prescription is implicitly established during optimization. While the lower limit of the prescription % of a target is directly associated with the target's maximum dosage, which may also be defined in the optimization, the upper bound of the prescription percentage can only be altered indirectly by raising the penalty for low dose leakage. Controlling the homogeneity of a target dosage is hampered by the inability to directly manipulate the prescription proportion [16]. It has been argued that the internal hotspot created by prescribing to a lower percentage would increase the response of the central hypoxic region of the tumor, resulting in greater local control. On the other hand, it has been reported that prescribing a percentage of 70% or higher would not affect local control [17].

It could be argued that the use of the better planning algorithm depends on the nature of the malignancy type of lesions and the large distance between the targets and critical organs, so large shots were frequently used in planning for multiple brain metastases cases to shorten the duration of the overall treatment.

5. Conclusion

The gamma inverse planning algorithm may be an optimal choice for treatment planning tumors that show an intact location with the critical tissue such as optic nerve, brain stem, or pituitary glands. In contrast, the convolution algorithm is preferable in the tumor with an acceptable distance from the other brain-sensitive structures. It may aid in attaining the objective of effective target coverage without exposing OARs to radiation.

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