RESEARCH ARTICLE

Inverse versus convolution treatment planning algorithms for gamma knife radiosurgery

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Abstract

Objective: To compare the convolution and inverse algorithm plans.

Method: The cross-sectional study was conducted from January to May 2022 at the Icon Gamma Knife Centre, Al-Taj Hospital, Baghdad, Iraq, and comprised patients with malignant and benign brain tumours who underwent gamma knife therapy. Each patient's brain was imaged using computed tomography and magnetic resonance imaging. The neurosurgeon prescribed the dose depending on the tumour volume and type, while the medical physicist generated the two plans based on inverse and convolution algorithms. The prescribed dose was delivered to 50% of the isodose line of the tumour. Each plan was evaluated with respect to tumour conformity index, coverage, gradient index, number of shots, and time of treatment.

Results: Of the 30 patients, 17(56.7%) were males and 13(43.3%) were females. The overall mean age was 46.29±15.20 years (range: 10-71 years). The mean dose delivered was 15.86±3.86Gy, and the mean number of gamma radiation shots was 12.56±6.95. There was significant difference between the two algorithm plans for all dosimetric parameters, with the inverse plan providing higher coverage and selectivity than convolution plan, but taking longer time($p<0.05$), while plan was inverse plan better than convolution plan in terms of gradient and conformity ($p<0.05$).

Conclusion: With more extended treatment, the inverse plan was found to have superior selectivity, coverage, gradient index and Paddick conformity index values compared to the convolution plan.

Key Words: Tumour, Algorithms, Brain, Magnetic, Tomography

(JPMA 74: S278 (Supple-8); 2024) **DOI: https://doi.org/10.47391/JPMA-BAGH-16-63**

Introduction

Radiosurgery is a neurosurgical operation in which radiation is supplied using the stereotactic approach, which is a technique that was developed in the 1960s. The term "stereotaxis" is derived from two Greek words; stereos, which means three-dimensional (3D), and taxis, which means organised arrangement[1,2]. It is called surgery because the treatment is carried out in one session, like a surgery. Radiosurgery was first introduced by a young neurosurgeon, Lars Leksell, in 1951. In 1968, Leksell began using cobalt sources for irradiation cases of intractable pain to treat various human diseases. Stereotactic radiosurgery (SRS) is a radiation therapy (RT) focussing high-power energy on a small body area[3–6].

The Gamma Knife (GK) Icon version efficiently treats one or more brain tumours in a single session. It can potentially cure lesions in the orbits, paranasal sinuses and cervical spine, among other locations. In addition to its standard characteristics, the Icon includes extra features that help to enhance the treatment of fractionated stereotactic radiation therapy (SRT). Another feature is an integrated stereotactic cone-beam computed tomography (CBCT) scanner for pre-treatment image guiding[7]. Because of its field size constraint, the Gamma knife can only be used for minor lesions. However, many isocentres may be positioned inside the same target to increase or modify the dose distribution[8].

Using Leksell Gamma Plan (LGP), dosage calculations using Tissue Maximum Ratio 10 (TMR10), a primary homogenous dose method, or a convolution dose approach. After treatment, the convolution technique compensates for changes in relative electron density[9,10].

An inverse planning method for GK radiosurgery has been devised to facilitate the planning process and better use the great degree of freedom available in GK planning. Inverse planning optimisation problems generally include numerous objective terms for clinical or practical factors, including target coverage, selectivity, gradient index (GI), the delivered dose to the organs at risk (OARs)[11,12], and total beam-on time[2,13].

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Prioritisation of these planning goals impacts plan quality. Due to individual anatomical variances, planners must continually engage with the optimisation solver, and alter each patient's objective priorities throughout GK inverse planning to make it clinically optimum[14].

The genetic deoxyribonucleic acid (DNA) material of tumour cells is damaged by radiosurgery. The tumour may progressively decrease as the cells lose their capacity to multiply and die. Small noncancerous (benign) and cancerous (malignant) brain tumours, arteriovenous malformation (AVM), trigeminal neuralgia (TN) and neuroma, acoustic neuroma, and pituitary tumours are the most prevalent conditions treated with GK radiosurgery[3].

The dosimetric parameters include target coverage, selectivity, and GI[15]. Coverage is the proportion of the target volume (TV) that the prescribed isodose volume covers, and this fraction is called prescription isodose volume (PIV) coverage. The proportion of PIV that is contained within the TV is described as the selectivity of PIV inside the TV[16–22]. The GI measures how steep the dosage fall-off is, which is the ratio between the half-PIV and tumour size[23]. The sum of the shooting timings for all shots on a target is the beam-on time[24].

The maximum dose for the treatment is reduced to limit the risk of problems while retaining a suitably high dose to TV. Maintaining an adequate target dosage with a reduced maximum dose in clinical practice is problematic because numerous doses limit how high-value isodose lines are covered (e.g., 90% and 70%) inside the targets, which is the primary difficulty[23].

The current study planned to assess and compare inverse and convolution treatment planning algorithms for patients undergoing GK radiosurgery.

Materials and Methods

The cross-sectional study was conducted from January to May 2022 at the Icon Gamma Knife Centre, Al-Taj Hospital, Baghdad, Iraq, after approval from the ethics review committee of the College of Medicine, Mustansiriyah University, Baghdad. The sample was raised using convenience sampling technique. Those included were patients of either gender with malignant and benign brain tumours who underwent GK therapy, and written informed consent was obtained from all the subjects. Those not willing to participate were excluded.

Each patient's brain was imaged using computed tomography (CT) and magnetic resonance imaging (MRI) to work out the brain's anatomical details. The neurosurgeon specified the prescription dose depending on tumour type and shape, and delineated the tumour and OARs. The medical physicist generated the two plans with a GK Icon version (Elekta Systems, Sweden). The first plan used an inverse algorithm, while the second used a convolution algorithm. The prescribed dose was delivered to 50% of the isodose line of the tumour. Each plan was evaluated using the parameters that included Paddick conformity index (PCI)[25], coverage, Gradient Index (GI)[26], number of shots, and time of treatments. The neurosurgeon selected the better plan, depending on the evaluation parameters, and approved the plan. The plan was exported to a GK workstation to prepare the patient for irradiation.

Results

Of the 30 patients, 17(56.7%) were males and 13(43.3%) were females. The overall mean age was 46.29±15.20 years (range: 10-71 years). Meningioma was found in 16(53.4 %) patients, vestibular schwannoma in 7(23.3 %) and metastasis 7(23.3 %) in (Figure 1). The mean dose delivered was 15.86±3.86Gy, and the mean number of gamma radiation shots was 12.56±6.95 (Table 1).

Table-1: Characteristics of the patients treated with gamma knife.

Characteristics	
Mean Age (Years)	46.29 ± 15.20 (10 – 71)
Gender	Female: 13 (43.4%)
	Male: 17 (56.6%)
Tumour Type	Meningioma: 16 (53.4 %)
	Vestibular Schwannoma: 7 (23.3 %)
	Metastasis: 7 (23.3 %)
Dose (50%) Gy	15.86 ± 3.86 (9 – 20)
Number of shots	12.56 ± 6.95 (2 – 29)

There was significant difference between the two algorithm plans for all dosimetric parameters, with the inverse plan providing higher coverage and selectivity than the convolution plan, but taking longer time, while the convolution plan was better in terms of GI and PCI values (Table 2).

Table-2: Comparison between inverse and convolution algorithms of gamma knife plans..

Parameters	Convolution Algorithm	Inverse Algorithm	*p*-value
Coverage	92.55 ± 5.36	95.10 ± 2.39	0.0438*
Selectivity	68.10 ±16.97	77.48 ± 5.87	0.0096*
Gradient Index (GI)	0.274 ± 1.16	0.233 ± 0.95	0.04906*
Paddick conformity Index (PCI)	1.50 ± 0.48	1.23 ± 0.38	0.0375*
Time (Minute)	18.23 ± 0.82	25 ± 3.83	0.0171*

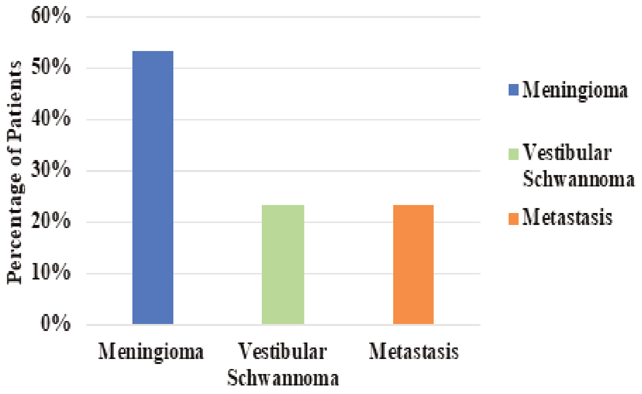

Figure: Tumour type distribution.

Discussion

The current compared conventional and inverse algorithms on the basis of dosimetric parameters, including coverage, selectivity, GI, PCI values and treatment time[25,27].

The inverse plan algorithm achieved all the markers described in literature [21].

Pan et al. and Hasegawa et al. reported that multiple shots in dose distribution for GK were required to cover TVs, especially for treating large targets. It is important to achieve a better PCI values, but large or irregularly shaped targets are at an increased risk of radiation-induced complications because more normal tissues inside or surrounding the targets are irradiated[28,29]. The current results were in agreement.

The GK collimation system provides a more conformal treatment to the target and an alternative way of lowering the normalising impact via composite shots. The fraction of higher isodose lines that cover the objective may be increased by reducing the normalisation impact. This improves the homogeneity of the high-dose zone within the target and the mean dose to target if the marginal dosage is kept constant. Because of this, homogeneous high-dose and conformal target irradiation may raise a given dosage while preserving target coverage[30,31]. At least 95% of the TV was covered by the prescribed dose in the treatment plans.

As a result, the maximum dosage supplied to the target centre may be lowered while maintaining an adequate mean target dose. In theory, by decreasing the maximum dosage, the surrounding normal tissues should get less radiation, minimising the chance of complications[32].

Conventionally, the recommended dosage to the target margin is set at 50% of the isodose level due to the dose's fast decay outside the target margin. When a critical organ is near a target, clinicians must evaluate the relative relevance of target coverage and organ sparing in the patient's overall health status[33].

Many rounds are sometimes required to cover TVs thoroughly when treating large objects. Repeated rounds improve target conformance for objects with irregular curves[26]. This is due to the higher quantity of normal tissue irradiated within or around large or irregular targets [28,29].

In a typical phase in the inverse planning process, numerous planning goals are considered, such as when inverse planning for intensity-modulated radiation treatment (IMRT) and volumetric-modulated radiation therapy (VMAT) are involved. Most of the GK inverse planning articles did not address this fine-tuning procedure, but studies claimed that they quantitatively established the priority of the goals[34]. Furthermore, Ghobadi et al. pointed out that if beam-on time is included in optimisation, the trade-off between beam-on time and plan quality must be balanced depending on the users' prioritisation[35].

In the current study, just two planning techniques were employed in the design process; ensuring that the target gets at least the minimum prescribed dosage level, minimising the amount of dose spread outside the target. As a result, the preference was achieved by imposing soft and hard restrictions on the target function, respectively, on these two techniques.

In a study, the PCI ranged from 0.66 to 0.77, the GI ranged from 2.59 to 3.94, and the heterogeneity index (HI) ranged from 0.18 to 0.84, indicating data variability[26].

More conformal and adequate doses delivered to the target for successful therapy should be achieved. The maximum dose to the surrounding tissue should be decreased to minimise and eliminate radiation toxicity. Lowering the normalisation effect during treatment planning may assist in achieving dosage distribution.

Limitation: The current study has limitations as the sample size was not calculated which could have affected the power of the study.

Conclusion

The inverse plan showed better selectivity, coverage, GI and PCI values with more time treatment than the convolution plan.

Acknowledgement: We are grateful to the administration of the Gamma Knife Centre, Al-Taj

Hospital, Baghdad, Iraq, for facilitating the study.

Disclaimer: None.

Conflict of Interest: None.

Source of Funding: None.

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