RESEARCH ARTICLE

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Plan Score Index (PSI): A Tool for Comprehensive Comparative Evaluation of Gamma Knife Treatment Plans

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Abstract

Objectives: 'Plan Score Index (PSI)' has been formulated for GKRS treatment plans that will evaluate the best plan out of two or more than two plans in terms of conformity index (CI), gradient index (GI), coverage, selectivity, number of shots (NOS), and total treatment time (TT). **Methods:** To validate PSI, already treated 54 patients of Gamma Knife Perfexion were retrospectively planned and evaluated. These 54 patients had already been treated with the ideal plan and replanned retrospectively for evaluation of the plans. Two different plans i.e. forward (FP) and inverse hybrid plan (IHP) were created by medical physicist using Leksell GammaPlan® (version10.1.1). The plans were evaluated on the PSI value. **Results:** The mean PSI value for FP and IHP is 0.80±0.66 and 1.38±1.44 respectively. IHP generated plans with higher PSI values because of lesser number of shots and treatment time. The mean PSI difference between both of them is -0.95 showing the superiority of IHP technique (p= 0.00004). **Conclusion:** Plans with higher PSI are better in terms of stereotactic treatment and dosimetric parameters. PSI is a valuable adjunct for comparative evaluation of competitive plans for a single patient.

Keywords: Plan Score Index- Forward planning- Inverse hybrid planning

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Introduction

Stereotactic Radiosurgery (SRS) is a technique for treating intracranial lesions using a combination of stereotactic apparatus and narrow multiple beams delivered through non-coplanar shots (Gamma Knife) or isocentric arcs (Linac based). Accuracy of beam delivery is a crucial requirement of this technique [1]. The main aim of this procedure is to deliver high dose to target while sparing the surrounding normal structures with sharp dose fall off.

The most commonly employed approach in the Gamma Knife Radiosurgery (GKRS) is to generate multiple plans of a single patient and then evaluate these competitive plans to find the best plan for the treatment [2-9]. Plan quality is mainly assessed by evaluating the dose distribution calculated by treatment planning system (TPS). But the evaluation of 3D dose distribution and spatial characteristics is complex. It demands standardization and systematic collection of clinical data and outcomes after treatment.

Unified Dosimetric Index (UDI), a rank system for unified indexes, was utilized by Akpati et al for LINAC based SRS/SRT [10]. UDI is capable of integrating the conformity, coverage, homogeneity, and dose gradient indices. However, the homogeneity index (HI) utilized in this system is not the one that International Commission on Radiation Units and Measurements (ICRU report 62, 1999) recommends [11]. UDI defined the HI as ratio of maximum dose to prescribed dose. They have not taken into account the total treatment time for the evaluation of the given plan. Moreover, most of the studies are for LINAC based SRS/SRT and there is no literature for GKRS technique.

For GKRS, a plan is ideal if it has 100% coverage of target volume, with selectivity index numeric one, gradient Index between 2.45- 2.55 with minimum treatment time [12]. In conventional forward planning [FP] for GammaKnife radiosurgery, multiple shots with varying sizes, locations, and weights are manually placed through trial and error. The Inverse Treatment Planning module [IHP] in Leksell GammaPlan® automates this with two functions: filling, which creates a preliminary dose plan, and optimization, which refines it. This study aims in formulating a Plan Score Index (PSI) to compare any treatment plan's deviation from an ideal plan in terms of conformity index, dose gradient, dose coverage, selectivity

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index, number of shots, and treatment time for forward (FP) and inverse hybrid plans (IHP) of GKRS. PSI helps in deciding the best optimal plans among competitive plans for the patient's treatment.

Materials and Methods

We followed frame based GKRS with Leksell Perfexion (Elekta Ltd. Stockholm, Sweden) and GammaPlan® Software version 10.1.1. The frame is fixed at patient's head with four-point bony fixation under local or general anesthesia. Stereotactic frame defines LGK coordinate system. After collision check, every patient undergoes MR acquisition on 1.5T MRI machine (Philips Insignia, Netherlands) with one mm thin nonoverlapping continuous cuts with MR fiducials. Images are then imported to the TPS. After entering the skull measurements, images are defined on radiosurgical principles. Target and organs at risk (OARs) are marked on relevant MR images. Appropriate grid is decided and treatment dose is prescribed as per the targeted pathology. For this study only single target plans were selected. We excluded functional indications, and multiple targets for the uniformity.

Worldwide, the routine practice of GKRS follows target cover by PIV ≥ 95%, conformity index ≥ 0.85, and gradient index < 3. The desirable index values are not definite but they seem to provide adequate safe cover and consistent practice. Two plans for each patient were created: one with forward planning (FP) method and second with inverse hybrid planning (IHP) technique generated by Leksell Planner Planning System. In FP, large shots are placed first centrally and then small shots are used to cover the peripheral region or the region near the critical structure. In FP, multiple small shots are required to cover the periphery to achieve better coverage, and conformity. It further leads to increase in number of shots as well as the total treatment time. In IHP, planning system auto generates a plan in which conformity and selectivity may be suboptimal. However, there are lesser number of shots and treatment time when compared to FP. To improve the indices, we either need to add some more shots or modify the original shots, hence called "inverse hybrid planning". With IHP, we initially used optimised settings of coverage as 0.6, GI as 0.3 and beam on time 0.5 to get a best optimised plan (authors have highlighted this strategy in our earlier article) followed by additional shots manually for improvement of coverages [13].

In both the plans, we tried to achieve the coverage of 100%. In some cases, 99% coverage was accepted by visually evaluating the 3D dose distribution to spare the OAR and dose volume histogram (DVH), e.g. cochlea in case of acoustic schwannoma. All the treatments were planned on 50% isodose to allow sharp dose fall off and uniformity. For these plans, following indices were individually evaluated by using Paddick's Formula:

Coverage

It is defined as the percentage of target volume covered by the prescription isodose radiation.

$$C = \frac{TV_{ref,p}}{TV_p}$$

where, $TV_{ref,p}$ is the target volume, TV_p is the volume covered by the reference isodose curve.

Conformity Index (CI)

CI_p [14] is defined as the ratio of the square of PTV_p covered by prescription isodose volume (PIV_p) to the product of PTV and PIV

$$CI_p = \frac{(TV_{ref,p})^2}{TV_p \times PIV_p}$$

Where PIV_p is prescription isodose volume.

Gradient Index (GI)

The GI [15] is the ratio of the volume of half the prescription isodose to the volume of the prescription isodose. The index can be used for any prescription isodose. For a plan normalized to the 50% isodose line, it is the ratio of the 25% isodose volume ($PIV_{25\%}$) to the 50% isodose volume ($PIV_{50\%}$). This index shows the sharpness of dose fall off outside the target.

$$GI = \frac{PIV_{25\%}}{PIV_{50\%}}$$

Selectivity

The selectivity is defined as the ratio of the volume of the target covered by the marginal isodose divided by the total volume of the peripheral isodose volume (PIV_{TV}/PIV). Selectivity is important to see by how much the normal tissue around the target is spared and tends toward numeric one, when the marginal isodose is confined to the target and does not significantly overlap on surrounding normal structures.

Each of the aforementioned indices, or all of them, may or may not individually favour the specific plan when used to evaluate a plan for clinical treatment. Moreover, number of shots and the total treatment time also play an important role while evaluating the specific plan. To achieve better indices, number of shots may increase resulting in significant increase in total treatment time. In order to select a better dosimetric plan, an innovative approach has been introduced as a formula known as Plan Score Index (PSI) defined by

$$PSI = \frac{\text{Conformity Index (CI)}/(\text{Gradient Index (GI)}}{\text{Treatment time (TT)} \times \text{No. of shots (NOS)}}$$

We have not included selectivity and coverage in this formulism as it has already been included in Paddick's Conformity Index. On comparative evaluation, any plan with greater PSI is considered better.

Statistical Analysis

Analysis of normal distribution of the data was done using student 't' test of MS Office v16.0. The skewness and kurtosis values were measured to quantify the normal distribution of the data. The skewness values of lesser than 0.03 and kurtosis values of greater than 2.96 are used to determine the normality of data distribution. To find the difference among the datasets, the paired t-test or Wilcoxon pair test of IBM® SPSS® version 20 were used as a method for determining the null hypothesis i.e. the two datasets are homogeneous, is accepted or rejected. A paired t-test and Wilcoxon pair test are generally used for the situations depending on the parametric or non-parametric data distributions of measured data sets respectively. If the p-value ≤ 0.05, we can conclude that the two paired samples are significantly different. For the plotting of various graphs, OriginLab corporation v9.8 were also used.

Results

Out of total 54 patients included in this study, 7 (FP) and 12 (IHP) patients had 100% tumor coverage while 47 (FP) and 42 (IHP) were treated with 99% coverage respectively. The respective GI ranged from (2.4-3.6; mean 2.7) and (2.5-3.16; mean 2.8) in FP and IHP respectively. The mean number of shots were 42 and 30 in FP and IHP respectively. The mean PSI value for FP and IHP is 0.80±0.66 and 1.38±1.44 respectively. Since the data was not qualified for normal distribution, non-parametric Wilcoxon pair test was used in this study. Wilcoxon pair test shows negative difference of 28 and positive difference of 13 and zero ties of samples. The Z-value for FP and IHP is showing a significant difference ($Z=-2.186$, $p<0.03$). The PSI value of FP and IHP have been shown in Table 1 for all the 54 patients and IHP have higher PSI values than those of FP and the histogram plot of PSI for FP and IHP for all the 54 patients have been shown in Figure 1.

An example has been shown in Table 2 where a patient of Meningioma having target volume of 5.24 cc was treated with a dose of 15 Gy. FP and IHP were compared for the patient showing significant difference in NOS and total TT. Although CI, coverage and GI are comparable for both the plans, the treatment time and number of shots are far more in FP leading to less PSI value for FP than IHP.

In order to see the influences of CI/GI and TT×NOS on PSI, the graphs between CI/GI and PSI values for FP and IHP were plotted in figure 2(a). This shows that mean and range of CI/GI values of FP are smaller as compared to those of IHP due to smaller values of GI of IHP. The range of PSI of IHP are more than FP because optimization in IHP includes TT and NOS parameters. When (TT×NOS) is plotted against PSI in figure 2(b), better PSI was observed for IHP as compared to those of FP. IHP have lesser number of shots and total treatment time than those of FP. The PSI value is mainly affected by the denominator part that is NOS and total TT. Lower the product of NOS and TT, better will be the PSI. All the treatment parameters and dosimetric factors are considered in PSI definition and hence it is a comprehensive treatment plan evaluation index.

Discussion

Today radiation treatment has an ultimate goal of achieving maximum therapeutic dose to target while sparing the critical organs as much as possible. Clinicians are very much dependent upon the traditional approach of slice-by-slice visualization of prescribed isodose line to target volume and dose volume histogram (DVH). It could frequently lead to competing treatment planning methods to create nearly identical dose distribution for the same patient. We can frequently struggle with situations like this because we are unsure of the criteria by which we should approve a treatment plan. This emphasizes the need for something that can easily combine this data and

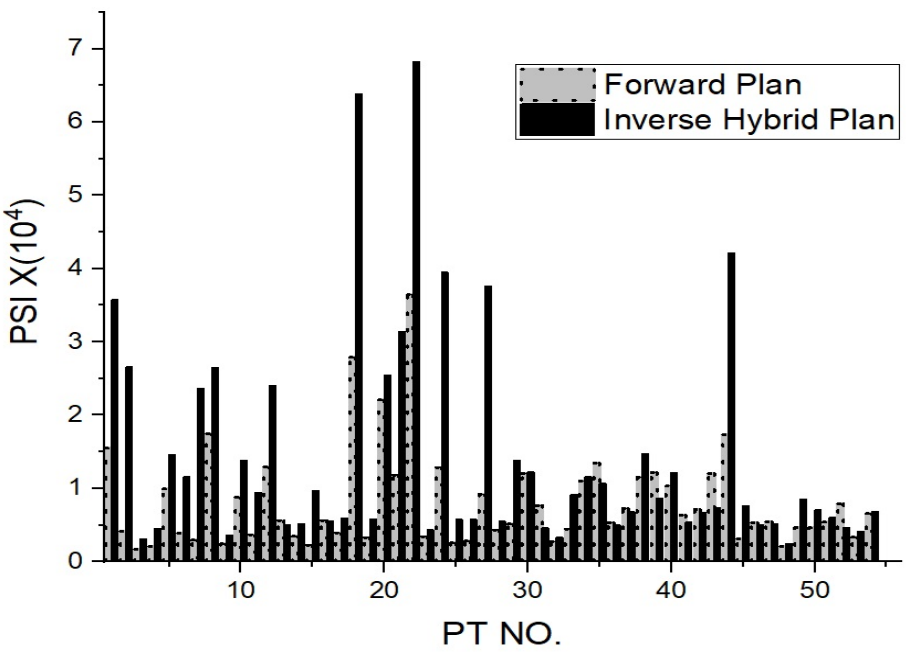

Figure 1. Histogram Plot of FP and IHP against Patient I.D. for All the 54 Patients. Plan Score Index (PSI): A Tool for Comprehensive Comparative Evaluation of Gamma Knife Treatment Plans

Table 1. PSI Values for Forward and Inverse Hybrid Plans (PSI, Plan Score Index)

Pt. No.	Forward Plan					Inverse Hybrid Plan				
	CI	GI	NOS	TT (mins)	PSI (×10⁴)	CI	GI	NOS	TT (mins)	PSI (×10⁴)
1	0.57	3.56	13	79.1	1.55	0.41	3.16	6	59.9	3.57
2	0.88	2.62	54	149.6	0.42	0.82	3.11	20	49.5	2.65
3	0.84	2.63	82	233.5	0.17	0.81	2.58	42	246.6	0.3
4	0.88	2.79	79	191	0.21	0.79	2.77	39	163.8	0.45
5	0.77	2.88	24	112.6	0.99	0.71	2.67	17	108	1.45
6	0.83	2.8	48	159.1	0.39	0.85	2.64	20	139.7	1.15
7	0.66	2.59	47	185	0.29	0.86	2.76	18	73.1	2.37
8	0.79	2.79	24	67.7	1.74	0.73	2.89	16	60	2.65
9	0.83	2.75	56	219.5	0.25	0.79	2.75	36	221.7	0.36
10	0.86	2.76	39	90.8	0.88	0.81	2.69	24	90.6	1.38
11	0.85	2.89	55	145.9	0.37	0.73	3.09	23	109	0.95
12	0.84	2.58	26	96.2	1.3	0.85	2.71	19	68.3	2.41
13	0.9	2.53	56	113.2	0.56	0.87	2.81	48	128.9	0.5
14	0.83	2.67	53	166.9	0.35	0.78	2.74	38	146	0.52
15	0.81	2.72	61	215.5	0.23	0.77	2.79	32	88.5	0.97
16	0.86	2.68	60	95.2	0.56	0.83	2.61	38	153.3	0.55
17	0.92	2.58	83	109.5	0.39	0.87	2.81	40	130.3	0.59
18	0.9	2.68	22	54.6	2.79	0.81	2.85	8	55.5	6.39
19	0.83	2.66	48	197.4	0.33	0.79	2.63	26	197.7	0.58
20	0.72	2.79	10	116.2	2.21	0.66	2.71	9	106.4	2.55
21	0.78	2.98	23	95.9	1.18	0.74	3.02	14	56	3.14
22	0.64	3.15	9	61.9	3.65	0.56	2.99	5	54.9	6.82
23	0.87	2.56	53	187.1	0.34	0.85	2.97	59	112.9	0.43
24	0.83	2.79	25	92.5	1.29	0.82	2.62	13	61	3.95
25	0.83	3.15	64	158.6	0.26	0.77	3.08	35	123.8	0.58
26	0.74	2.98	36	244.4	0.28	0.67	3.11	25	149	0.58
27	0.88	2.69	33	107.8	0.92	0.86	2.74	14	59.6	3.76
28	0.86	2.54	53	147.7	0.43	0.87	2.85	44	125.2	0.55
29	0.86	2.72	53	115.7	0.52	0.79	3.06	21	88.7	1.39
30	0.81	2.65	20	127.1	1.2	0.81	2.71	25	97.3	1.23
31	0.92	2.71	44	100.4	0.77	0.91	2.67	41	179.6	0.46
32	0.77	2.6	44	247.5	0.27	0.77	2.78	49	170.2	0.33
33	0.79	2.7	40	163.8	0.45	0.75	2.76	30	98.9	0.92
34	0.88	2.67	40	75.1	1.1	0.85	3.01	28	87.4	1.15
35	0.78	2.86	32	63.3	1.35	0.76	2.9	27	90.8	1.07
36	0.83	2.53	36	171.9	0.53	0.86	2.78	40	155.8	0.5
37	0.89	2.87	44	97	0.73	0.85	2.88	35	123.4	0.68
38	0.85	2.73	23	117.1	1.16	0.83	3.07	19	96.6	1.47
39	0.81	2.7	26	94.9	1.22	0.78	2.97	26	116.5	0.87
40	0.51	2.83	13	134.4	1.03	0.47	2.72	11	129.6	1.21
41	0.86	2.66	42	121.8	0.63	0.83	2.8	43	128.4	0.54
42	0.92	2.73	58	81.6	0.71	0.88	2.82	42	112.3	0.66
43	0.87	2.7	28	95.3	1.21	0.89	2.81	42	103.6	0.73
44	0.85	2.61	22	85.5	1.73	0.8	2.74	13	53.3	4.21
45	0.86	2.44	57	198.1	0.31	0.84	2.72	41	99	0.76
46	0.83	2.53	36	170.9	0.53	0.86	2.78	40	155.8	0.5
47	0.81	2.92	34	148.4	0.55	0.84	2.95	37	148.9	0.52
48	0.9	2.46	80	216.6	0.21	0.88	2.68	67	205.3	0.24

Table 1. Continued

Pt. No.	Forward Plan					Inverse Hybrid Plan				
	CI	GI	NOS	TT (mins)	PSI (×10⁴)	CI	GI	NOS	TT (mins)	PSI (×10⁴)
49	0.78	2.7	42	147.3	0.47	0.75	2.6	21	162.5	0.85
50	0.86	2.52	45	164.1	0.46	0.82	3.16	43	92.4	0.7
51	0.78	2.57	35	161.2	0.54	0.8	3.11	30	171.5	0.6
52	0.9	2.96	34	113.1	0.79	0.87	2.58	38	180.5	0.46
53	0.85	2.82	45	199.5	0.34	0.87	2.77	47	172.8	0.41
54	0.75	2.57	31	143.2	0.66	0.85	2.67	37	120.3	0.68

Plan Score Index (PSI): A Tool for Comprehensive Comparative Evaluation of Gamma Knife Treatment Plans

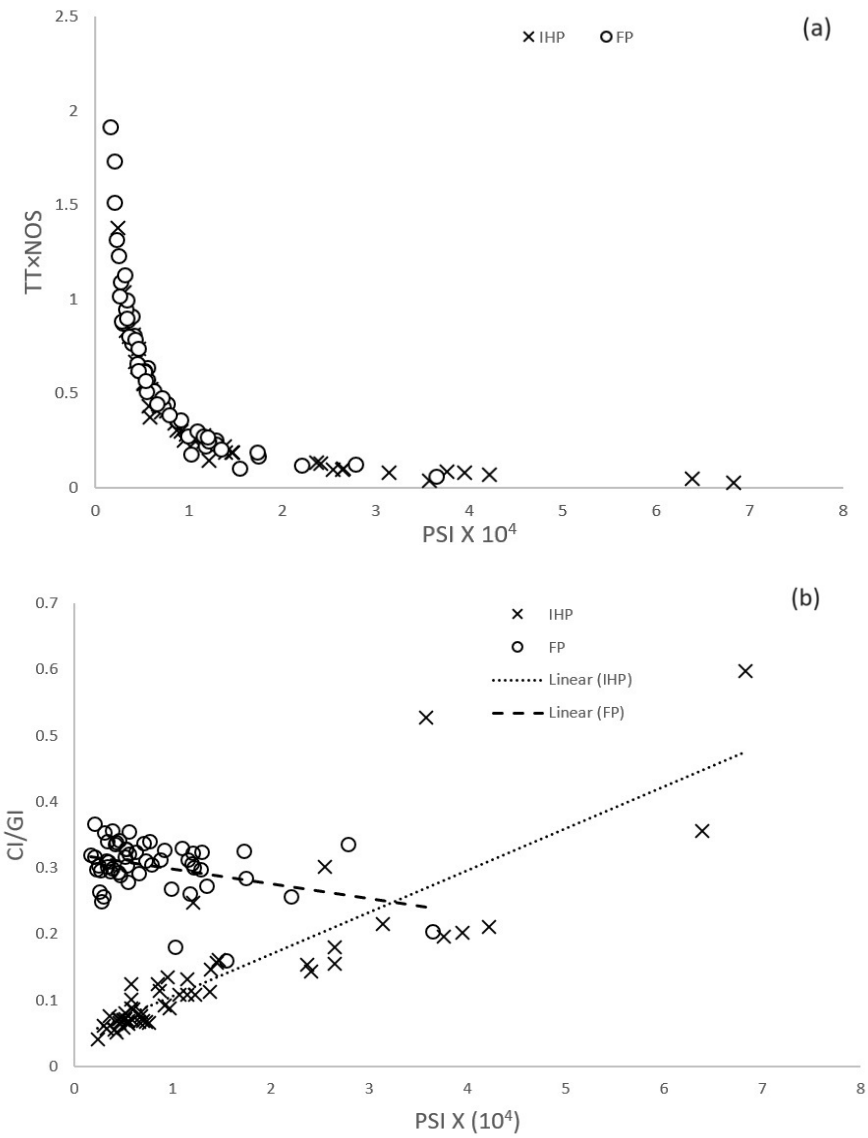

Figure 2. (a). Plot of ratio of multiple of TT to NOS vs PSI of Inverse Hybrid Plan and Forward plan for all the 54 patients. (b). Plot of ratio of CI to GI vs PSI of Inverse Hybrid Plan and Forward plan for all the 54 patients.

Table 2. Comparison of Different Indices & PSI of Forward and Inverse Hybrid Plan for a Case of Meningioma Patient

	Coverage	Conformity Index (CI)	G. I	T.T (mins)	NOS	CI/GI	TT×NOS	PSI (×10⁴)
Forward Plan	0.99	0.83	2.7	166.9	53	0.31	8845.7	0.35
Inverse Hybrid Plan	0.99	0.78	2.7	146	38	0.29	5548	0.52

C, Coverage; CI, Conformity Index ;GI, Gradient Index; NOS, number of shots; PSI, Plan score index; TT, treatment time quantify the effectiveness of treatment plans.

An unanimously approved GKRS plan is a result of complex measurements that form the basis of treatments. An important aspect is to know the distribution of the radiation in relation to the target as radiosurgery is a delicate yet powerful and irreversible knife. This very activity is known as 'dose plan'. In gamma knife a plan is determined by isocentres on which radiation beams are directed. A good dose plan then ensures that the radiation field remains conformal to the target area. To ensure the same there are multiple indices which help in objective assessment of the best possible plan.

Krishnan J et al have given a formula for Plan Quality Index (PQI) in which they have taken into account the quality of organs' sparing as well as various dose volume constraints in the plan evaluation collectively for LINAC platforms. Still, the importance of treatment time was not considered. In the current times of debatable value of Biologically effective dose and dose output rate, short treatment time is an important factor to consider. Moreover, all these studies that we found in literature are for LINAC based SRS/SRT but there is no study on Gamma Knife Treatment.

In our present study, we formulated an evaluation tool Plan Score Index (PSI) which included all the indices i.e. coverage, CI, selectivity along with number of shots and the total treatment time of plan. Higher PSI suggests that a plan with lesser number of shots and shorter duration is a better plan. For an individual patient, PSI can be used for evaluation of multiple plans on competitive basis.

Limitations

The study has only been evaluated for single target volume. Functional targets are usually single shot personalised radiosurgery that do not need complete coverage and contouring, it cannot be used for their evaluation. For the uniformity in this article, authors have prescribed the radiation dose at 50% isodose curve. It has been noticed by Paddick and Lipitz in 2006 that for a single target radiosurgery, the steepest dose gradient outside the target is achieved with prescription isodose of 50%. Smaller the target volume, larger the values of GI and for steepest dose gradient, prescription isodose line ranges from 40 to 50 percent as recommended by Zhao et al. [16]. Indices are just some tools with the main task to provide competitive advantage while controlling the pathological processes and minimising the complications. For many intracranial pathologies, there remains discrepancy between ideal radiological indices and a biologically better dose plan. At present, the study is a comparative evaluation between FP and IHP method. However, the same is also useful for comparative evaluation by two independent operator's plans. The study is conducted on Gamma Plan® version (10.1.1) best available at the centre. Moreover, there is a significant upgradation of the software and hardware over last one decade. The study is a proof of concept at present, which needs further evaluation on multitarget module and the latest software.

In conclusion, PSI is a useful method for competitive evaluation of multiple plans. Although both FP and IHP plans are comparable and good enough for the treatment of the patient but this study suggests that we can use PSI to evaluate the both the plans. The plan with higher value of PSI can be considered better on stereotactic principles and dosimetry. From this study, we can conclude that the 'Inverse Hybrid Plans have better PSI as it is having less treatment time and lesser number of shots when compared with the forward planning. In this study we have not compromised with the dosimetric parameters, so we are taking into account the treatment time and total number of shots for evaluation. PSI can be used and inculcated in day to-day practice in GKRS treatment for the evaluation of multiple plans on competitive basis.

Author Contribution Statement

Conception and design: Satinder Pal Kaur and Arun S Oinam; Data collection: Satinder Pal Kaur; Data analysis and interpretation: Satinder Pal Kaur, Arun Oinam, Manjul Tripathi; Final approval of manuscript: Arun Oinam, Manjul Tripathi, J S Shahi, Renu Madan, GY Srinivasa

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How the ethical issue was handled (name the ethical committee that approved the research)

Institutional ethical clearance has been taken.

Any conflict of interest

None.

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