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Study of Target Volume Effect on Efficiency Index and Paddick Conformity Index for Arteriovenous Malformation Treatment Plans by Gamma Knife

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Abstract:

Background: Since energy is the product of volume times dosage, volumes are given a weighting that is proportionate to the dose that they have received. This is a result that energy is a measure of how much substance has been absorbed.

Aim of the study: The current study aimed to study the fluctuation of the efficiency index and Paddick with differences in the target volume.

Method The efficiency index and conformance index data were computed for each of the thirty scheduled clinical treatments using the Leksell Gamma Knife® Icon™ version (11.1) and compared to the target volume. Data analysis was carried out using the available statistical package for Social Sciences.

Result The value of efficiency index (η50%) for the 30 clinical stereotactic radiosurgery treatment plans ranged from 44% to 84% with a mean value of 63%.and value of conformity was 47% to 82% with a mean value of 60.6%, The study also showed a strong relationship between target volume and this indexes.

Conclusion: Volumes are given a weighting that is proportional to the dose that they have absorbed because energy is the product of volume times dose, where there would be a correlation between efficiency and conformance improvements and an increase in the target volume

keywords: conformity, efficiency index, plan quality, radiotherapy, stereotactic radiosurgery.

Introduction:

The use of stereotactic neurosurgery and its subsequent conceptualization led to the development of a technique known as stereotactic radiosurgery (SRS). The objective is to provide a single, high dosage that is ablative to the lesion while maintaining a steep dose fall-off to prevent any secondary effects on the healthy tissues that are nearby (1,2) All SRS therapy approaches use convergent beam techniques, albeit in very different ways. The majority of the time, when Gamma-Knife (Elekta, Stockholm, Sweden) is used for radiosurgery, the targets fall inside the 50% isodose. Many circular collimated beams converge at a single point (the isocenter) to create numerous isocenters (3)(4). with the aim of enhancing uniformity. using circular collimators of varied diameters (5) or employing several pencil beams in a non-isocentric fashion. (6). Small cerebral arteriovenous malformations (AVM) can be fixed with radiosurgery. For small AVMs smaller than 10–15 cm3 or a diameter of 3 cm, the nidus is destroyed in 70–95% of patients after 3–5 years. Radiosurgery and other types of treatment have had trouble getting rid of larger AVMs of more than 10–15 cm^3 or a diameter of 3 cm (7,8). To keep normal tissue around the lesion from getting risk, radiation dose must be decreased with increasing lesion volume to prevent toxicity of surrounding normal tissue, consequently limiting rates of successful obliteration (9,10). This study's objective was to explore the impact of target volume on treatment planning by comparing it with the Paddick conformity index and the efficacy index. Although SRS is a common manifestation of treatment for brain metastases, the emphasis of this research will be on benign lesions such as arteriovenous malformations (AVMs). Because of their uneven shape, dosimetric planning for these lesions will be more difficult. Since these patients often have a lengthy life expectancy, the dosimetry of benign lesions will also be very important for long-term toxicity (11).

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Method:

Study design and setting:

This cross-sectional study was performed in Dr. Saad Al-Witry Hospital for Neurosciences. The data collection was achieved within 3 months lasting from Oct 2022 to Dec 2022.

Inclusion Criteria:

-This study involved 30 patients diagnosed previously with different single target volumes of brain Arteriovenous malformation (AVM).

- The age of patients was over 12 years old.

- Patients were interviewed to obtain data regarding their clinical manifestations of disease and acceptance of participation in this study

Exclusion Criteria :

1 .Pregnant patients.

2. The patients with ages less than 12 years.

Evaluation of treatment plans by η50% and PCI

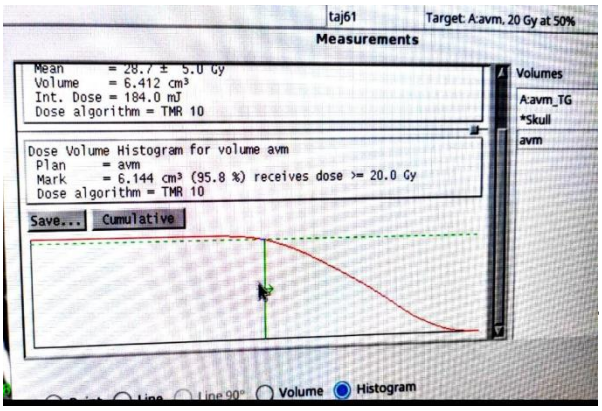
The new index, known as the efficiency index or η50%, is determined by calculating the ratio of the integral dosage of TV to the integral dose of PIV50% (12):

$$\eta_{50\%} = \frac{\text{Useful Energy}}{\text{Total Energy}} = \frac{\text{Integral Dose}_{TV}}{\text{Integral Dose}_{PIV50\%}} = \frac{\int_{Dmin}^{Dmax} TV\ \delta dose}{\int_{PIV50\%}^{Dmax} V\ \delta dose}, \quad \text{---------(1)}$$

Where PIV50% is the volume occupied by 50% of the prescribed dosage, Dmin and Dmax are the lowest and maximum doses to the target volume (TV), and prescription dose (PD). efficiency index(η50%) for a treatment plan with a single target can be calculated using the integral dose to TV and of PIV50%, it can be achieved by using the following equation (12) (13).

$$\text{Integral Dose}_{TV} = \text{Mean Dose}_{TV} \times \text{Volume}_{TV}. \quad \text{----------(2)}$$

This parameter is manually calculated from the Dose -Volume Histogram (DVH) exported from Leksell Gamma Plan (LGP). Where two DVHs were used one for target volume(TV) and the other for prescription isodose volume (PIV50%) (13) as shown in Figure (1).



In addition, calculate the Paddick conformity index (PCI) from the following equation (13)

$PCI = TVPIV^{2} / TV*PIV$ …….. (3)

PIV (prescription isodose volume), TV (target volume). *TVPIV* (volume of the target covered by the prescription isodose).

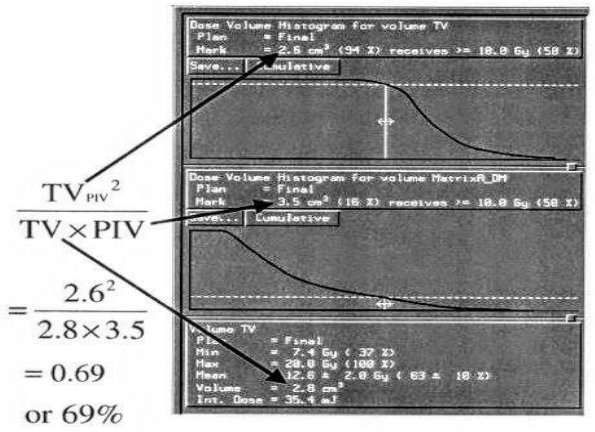


Figure 2: Dose-volume histogram and volume analysis tools are used on the gamma plan to obtain Paddick conformity index constituent parameters (14).

Statistical Analysis

Data analysis was carried out using the available statistical package for Social Sciences (version 25 (SPSS-25)). Data were presented as mean ± standard deviation, and range values (minimum and maximum) for the 30 single-target plans. The significance of the difference between quantitative data was examined using the Pearson correlation coefficient. Statistical analysis was considered significant whenever the P-value was equal to or less than 0.05.

Result

The characteristics of patients treated with gamma knife radiosurgery are presented in Table (1). The age range of patients was 13 to 66 years old. Three common groups of AVM were involved in this study: 10 patients with small volumes ≤3cm^3, 10 patients with middle volumes ≤6 cm^3, and 10 patients with large volumes >6cm^3.

Table 1: The TVof arteriovenous malformation patients

Data		Number of patients	Mean ±SD	Min	max
Age (Years)		30	47±8.7	13	66
target volume	Small volume<3cm^3	10	1.9±0.9	0.4	2.93
	moderate volume <6cm^3	10	4.3±0.56	3.22	5.24
	large volume> 6cm^3	10	10.9±3.9	6.2	17.2
Efficiency index		30	63%±5.2 %	43%	84%
Paddick conformity		30	60.6%±3. 7%	43%	82%

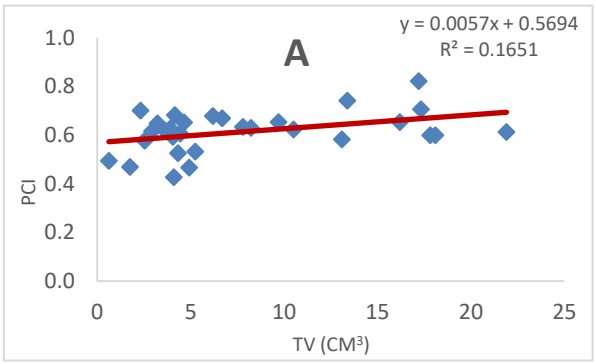
Table 2. It was shown that there was a significant difference between the efficiency index and Paddick conformity with p-value < 0.05, for target volume where mean values and SD for target volume were 1.9±0.9, 4.3±0.56, and 10.9±3.9, of (small, moderate, and large) volume cm^3, respectively

Table 2: The evaluation parameters according to TV groups of arteriovenous malformations patients

Target volume cm^3	Efficiency index Mean ±SD	Paddick conformity Mean ±SD	p-value
Small<3	0.56±0.08(0.44 -0.68)	0.57±0.07(0.47-0.70)	0.000936*
Mid<6	0.59±0.09(0.43 -0.75)	0.577±0.08(0.43-0.68)	0.003639*
Large>6	0.67±0.07(0.59 -0.84)	0.68±0.068(0.62-0.82)	0.003953*

* Significant Difference at*p*–value ≤ 0.05 level.

A substantial association between the target volume and the Paddick conformity index and efficiency index was generated for the 30 different treatment plans for brain arteriovenous malformation as shown in Figure (3). In general, plans that had bigger target volumes also had larger conformity and efficiency indices, but the indexes were essentially constant for plans that had small and moderate target volumes. The conformity index value of 0.82 attained its highest possible level when applied to a plan with a target volume of 17.3 cm^3. The plan with a target volume of 21.9 cm^3 achieved an efficiency index value of 0.84, which was the highest possible value. For the small group of TV lower than 3 cm^3 the average PCI value was found to be (0.57) with an efficiency index value of 0.56. For a group with moderate target volumes smaller than 6cm^3, the mean PCI value was 0.577 with an efficiency index value0.59. For a group with large target volumes greater than 6cm^3, the mean PCI value was 0.68 with an efficiency index value (0.67).



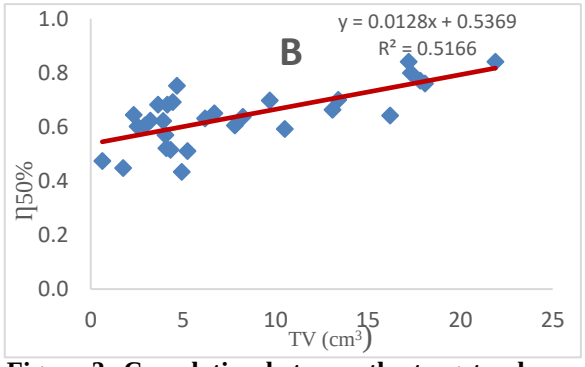


Figure 3: Correlation between the target volume and Paddick conformity (A) and efficiency index (B)

Discussion

In this study, we quantified the range of efficiency index (43%– 84.0%) calculated from eq (1) and Paddick conformity range (48%-82%) calculated from eq (3) for 30 clinical radiosurgery treatment plans and showed correlations to the target volume, note the effect of target volume on quality of SRS plans. The conformance of the set of targets was found to be an average of 55.6% when the conformity index proposed by Paddick was employed to conduct the evaluation. where the conformity worsened for targets smaller than 3 cm3 due to the organ at risk (normal surrounding tissue), As for the smaller, less complex targets, they had a better efficiency and conformity coefficient than the complex targets of the same size. And seen good Paddick conformity with moderate and large target volume (0.43-0.82). also noted that the efficiency index behaved similarly to PCI with respect to large and moderate target volumes. concurred with the findings of this research about the target volume, a prior study done by Julia Stanley and Yesr, where the conformance index recommended by PCI was plotted against the TV for the 170 patients((15) (16)). For this research, the average PCI was similarly 56%. The PCI contains information supplied by both the SALT-Lomax and RTOG conformance indices. In the great majority of the clinical targets investigated, the TV and treated volume overlap, and, consequently, the Paddick index may be lowered to the inverse of the RTOG index, where It has been stated that SRS is used to treat small atypical vascular malformations with a nidus volume of 12 cm3 or a diameter of 3 cm, and an obliteration rate of between 58% and 80% has been reported (16) .

Conclusion

The values of the η50% and PCI that were calculated were compared to the target volume The result that was put to the test was that there would be a correlation between efficiency and conformance improvements and an increase in the value target volume. Where the best values of the indicators (η50% and PCI) are at large and medium target volumes because this allows giving the largest amount of energy without affecting the surrounding normal tissues. As for the small and complex targets,

they kept the worst values of the indicators (ɳ50% and PCI) in this study due to the surrounding normal tissues, where the dose must be reduced, preserving the normal tissues, and thus we will get less efficiency for the treatment plan.

Authors' declaration:
Conflicts of Interest: None.-
We hereby confirm that all the Figures and Tables in the manuscript are mine/ ours. Besides, the Figures and images, which are not mine /ours, have been given permission for re-publication attached with the manuscript.-Authors sign on ethical consideration's approval-Ethical Clearance: The project was approved by the local ethical committee in the University of Baghdad College of Medicine, according to the code number (90 in 4\6\2023).

Author contributions:
Arkan M Mhal: study conception, study design, data collection, data analysis, and interpretation.
Nadiya Y Mohammed: study conception, study design, data collection, and interpretation.
Moneer K Faraj: study conception, data analysis, and interpretation, drafting of the manuscript, critical revision

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دراسة تأثير الحجم المستهدف على مؤشر الكفاءة ومؤشر المطابقة لخطط علاج التشوه الشرياني الوريدي بواسطة سكين جاما

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الخلاصة:

الخلفية العلمية نظرًا لأن الطاقة هي نتاج الحجم مضروبًا في الجرعة ، يتم إعطاء الأحجام ترجيحًا يتناسب مع الجرعة التي تلقتها. حيث أن الطاقة هي مقياس لمقدار المادة التي تم امتصاصها. مؤشر الكفاءة عبارة عن إحصائية واحدة يمكن استخدامها لتقييم جودة الخطة بكفاءة من خلال مراعاة التغطية والانتقائية ومؤشر التدرج والهدف ، ومن الممكن استخدام هذه الإحصائية لقياس كفاءة الخطة. مؤشر المطابقة هو قياس مدى توافق حجم توزيع الجرعة الإشعاعية مع حجم وشكل الحجم المستهدف.
هدف الدراسة: تذبذب مؤشر الكفاءة ومؤشر مطابقة بادك مع الحجم المستهدف .
طريقة العمل تم حساب مؤشر الكفاءة وبيانات مؤشر المطابقة ل ثلاثين خطة علاج سريرية والتي تم جدولتها باستخدام خطة ليكسل سكين كاما الإصدار 11.1ومقارنتها بالحجم المستهدف.
النتائج تراوحت قيمة مؤشر الكفاءة η50٪ ل ثلاثون خطة علاجية سريرية من 44٪ إلى 84٪ بمتوسط قيمة 63٪ وقيمة مطابقة بادك من 47٪ إلى 82٪ بمتوسط قيمة 60.6٪ ، حيث أظهرت هذه الدراسة علاقة قوية بين الحجم المستهدف ومعاملات تقييم الخطة .
الاستنتاجات يتم إعطاء الأحجام ترجيحًا يتناسب مع الجرعة التي تم امتصاصها لأن الطاقة هي نتاج الحجم مضروبا في الجرعة ، حيث كان هناك ارتباط بين تحسينات الكفاءة والمطابقة وزيادة الحجم المستهدف.
الكلمات المفتاحية : العلاج الإشعاعي ، المطابقة ، مؤشر الكفاءة ، جودة الخطة ، الجراحة الإشعاعية التجسيمية