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Comparative analysis of stereotactic radiosurgery treatment plans in brain cases with one and two tumour changes using conformity indices

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Authors' Contribution:
A Study Design
B Data Collection
C Statistical Analysis
D Data Interpretation
E Manuscript Preparation
F Literature Search
G Funds Collection

Summary

Aim To analyse (quantitatively-statistically) conformity indices calculated for stereotactic radiosurgery treatment plans with one and two isocentres in cases of brain tumour.

Materials/Methods A retrospective study of 33 patients with brain tumours treated between April 2005 and January 2006 was performed in the Radiotherapy Department of the Oncology Centre in Łódź. Stereotactic surgery was performed in all patients. All treatment plans were divided into two groups: plans with one isocentre and plans with two isocentres. For each treatment plan various kinds of conformity parameters were calculated and optimal prescription isodose level was determined.

Results All conformity indices are within ranges and were accepted. Their values are lower in plans with two isocentres in comparison to plans with one isocentre.

Conclusions Conformity indices are very helpful in the analysis of treatment plans, but they do not give real insight into all aspects of plans. Prescription isodose should completely enclose *PTV* volume. Optimal prescription isodose does not cover *PTV*; thus from a clinical point of view it is inapplicable.

Key words **brain tumours • stereotactic radiosurgery • conformity index • optimal prescription isodose**

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Background

Recent years have witnessed very dynamic development of many treatment techniques using ionising radiation. The most often employed treatment techniques, especially in brain tumours, are stereotactic radiosurgery (*SRS*) and stereotactic radiotherapy (*SRT*). These two techniques include irradiation of very small lesions in the brain using many static photon beams. Dose accumulated in the tumour can be delivered in one fraction (*SRS*) or in many fractions (*SRT*). To be able to utilise this technique it is necessary to have a stereotactic frame with instrumentation, multileaf collimator and treatment planning system (*TPS*). The planning system together with computer tomography images and magnetic resonance images allow one to plan in a very precise manner the arrangement of photon beams in relation to reference markers.

The primary aim in planning stereotactic radiosurgery is high homogeneity of dose in the *PTV* volume and steep gradient of dose in healthy tissues. However, this is very difficult to achieve in cases where there are organs at risk near the *PTV* volume which should receive the lowest possible dose. It is especially important as many lesions, which are located in different parts of the brain, are simultaneously irradiated. Then the probability of adverse overdose formation in normal tissues increases. Proper preparation of the treatment plan requires very great precision. It involves both very precise fitting of the leaves of the multileaf collimator to the *PTV* volume and also very precise fitting to the *PTV* volume prescription isodose, which should to a lesser degree cover normal tissues.

Every treatment plan should be subjected to verification. First of all the recommended dose and prescription isodose and then isodose distribution slice-by-slice should be checked. A dose volume histogram for every organ at risk and *PTV* is a very important part of the treatment plan. Exact analysis of this histogram allows one to find dangerous overdosage to the organ at risk and unacceptable underdose to *PTV*. Knowing this, correction of the plan should be made. Additionally, for every treatment plan conformity parameters, which define its quality, should be calculated [1–7].

Aim

The main aim is the comparative analysis (quantitatively-statistically) of conformity indices calculated for plans with one and two isocentres. By calculation of many parameters for many plans in a simple way we can compare them and make deductions. Then it will help to improve planning and treatment.

Materials and Methods

Many parameters defining plan conformity should be calculated for every stereotactic radiosurgery plan for the brain. One of two fundamental indices is the Conformation Number *(CN)* [2,12], which is given by the following equation:

$$CN = \frac{PTV_{PI} \cdot PTV_{PI}}{V_{PI} \cdot PTV} \quad (1)$$

where: PTV_{PI} is the *PTV* volume which is irradiated with prescription isodose *(PI)*, V_{PI} is the total volume of tissue which is irradiated with prescription isodose *(PI)*, *PTV* is the volume of *PTV*, *PTV* is the planning target volume.

This index is a combination of two others indices. The first was introduced in 1993 by the Radiation Therapy Oncology Group [1,12] – Conformity Index *(PITV)*, expressed by following equation:

$$PITV = \frac{V_{PI}}{PTV_{PI}} \quad (2)$$

This parameter determines the overdosed volume of normal tissues. In most cases its value is above 1.0 because prescription isodose covers not only *PTV* but also a small volume of normal tissue around *PTV*. In the ideal plan this parameter is equal to 1.0; however, in most plans it is between 1.0 and 2.0, which is acceptable and in agreement with the procedure. Every other value above or below this range implies low conformity of the plan and requires comprehensive analysis.

The other index is the Volume-Related Target Coverage *(vTC)* [8,12], which is expressed as:

$$vTC = \frac{PTV_{PI}}{PTV} \quad (3)$$

It is the ratio of *PTV* volume enclosed by prescription isodose to total *PTV* volume. This parameter represents *PTV* volume with underdose. Its theoretical value is in the range of 0.0–1.0 but acceptable values are in the range of 0.8–1.0.

By precise analysis of both parameters it can be found that the value of *CN* represents volume with

an overdose to normal tissues and underdose to *PTV*. Its ideal value is 1.0 and values from 0.0 to 0.5 indicate the low conformity of the plan.

The second important parameter quantitatively describing the plan is the Dose-Related Conformation Number *(dCN)* [12], which is expressed as:

$$dCN = \frac{PTV_{PI} \cdot PTV_{PI} \cdot D_{min}}{V_{PI} \cdot PTV \cdot PI} \quad (4)$$

It is a combination of the Conformation Number (CN) and the Dose-Related Target Coverage *(dTC)* [12]:

$$\mathrm{dTC} = \frac{D_{min}}{PI} \quad (5)$$

where D_{min} is the minimum dose in *PTV*.

The *dTC* parameter represents the volume of *PTV* with a dose much higher than the prescription isodose and does not represent the volume of *PTV* where there is an underdosage. Its optimum value is 1.0. It is fulfilled when prescription isodose fully encloses *PTV*. But in other cases when *PTV* is not completely enclosed by this isodose, its value will be lower than 1.0. A reasonable range for this parameter is from 0.9 to 1.0.

The *dCN* parameter describes quantitatively the same aspects as *CN* does and gives information about the overdosed volume of *PTV* which indicates the gradient in this volume. The acceptable value is 1.0 and every lower value shows deviation from the plan.

Over the last six months in the Radiotherapy Department of the Oncology Centre in Łódź patients with small brain tumours have been treated using stereotactic radiosurgery. This method was applied to 15 patients with metastatic tumours and to 18 patients with primary tumours. An immobilizing mask, made of thermoplastic material, was prepared for every patient before treatment. Computer tomography images were taken with step of 2mm. Additionally, when any problems with delineation of *PTV* occurred, images using nuclear magnetic resonance (*NMR*) were recorded. A series of images from *CT* and *NMR* superimposed in *TPS* made definition of *PTV* easier. Every treatment plan was prepared using the BrainScan planning system (BrainLab, Munich Germany). Varian 600D linac with multileaf microcollimator *m3* from BrainLab and stereotactic frame for exact patient positioning were applied. Only patients with one or two tumours were treated (maximum of 2 isocentres were used). For every treatment plan many parameters (*vTC, dTC, CL_x, CN, dCN*) were calculated and together with comprehensive verification of *DVH's* and dose distributions they make the plan acceptable or not.

Optimal prescription isodose

Every treatment plan of stereotactic radiosurgery prepared in the Regional Oncology Centre in Łódź was analysed mathematically. For every isodose from 80% to 100% parameters of conformity indices were calculated (*CN, dCN*). Figure 1 shows parameters' value as a function of isodose. The curve in this figure has a characteristic maximum, and the isodose that is responsible for this maximum does not enclose any normal tissues, has the highest values of conformity parameters and mathematically is the best prescription isodose.

RESULTS

A retrospective analysis of 33 patients with brain tumours treated between April 2005 and January 2006 was performed in the Radiotherapy Department of the Oncology Centre in Łódź. Stereotactic surgery was performed in all patients. All treatment plans were divided into two groups: plans with one isocentre and plans with two isocentres.

For every single isocentre 6 to 8 static photon beams were used. The treatment technique depended on size of the tumour and its location in relation to the organ at risk [9,10]. The prescribed dose for PTV was 10–20Gy for prescription 80% isodose and was dependent on size of the tumour. The 80% isodose had to cover minimum 99.5% of *PTV*.

The main parameters that helped to determine the optimal prescription isodose were *CN* and *dCN*. For 80% isodose for one isocentre values of *CN* were between 0.51 and 0.80 (average 0.66) and values of *dCN* were between 0.47 and 0.70 (average 0.64). Optimal prescription isodoses evaluated on the basis of *CN* and *dCN* were between 86% and 92% and for them the value of *CN* was 0.68 to 0.94 (average 0.80) and the value of *dCN* was 0.62 to 0.93 (average 0.77). The *PTV* volume was enclosed by 80% isodose in 99.88% and 92.33% of *PTV* volume was enclosed by optimal prescribed isodose.

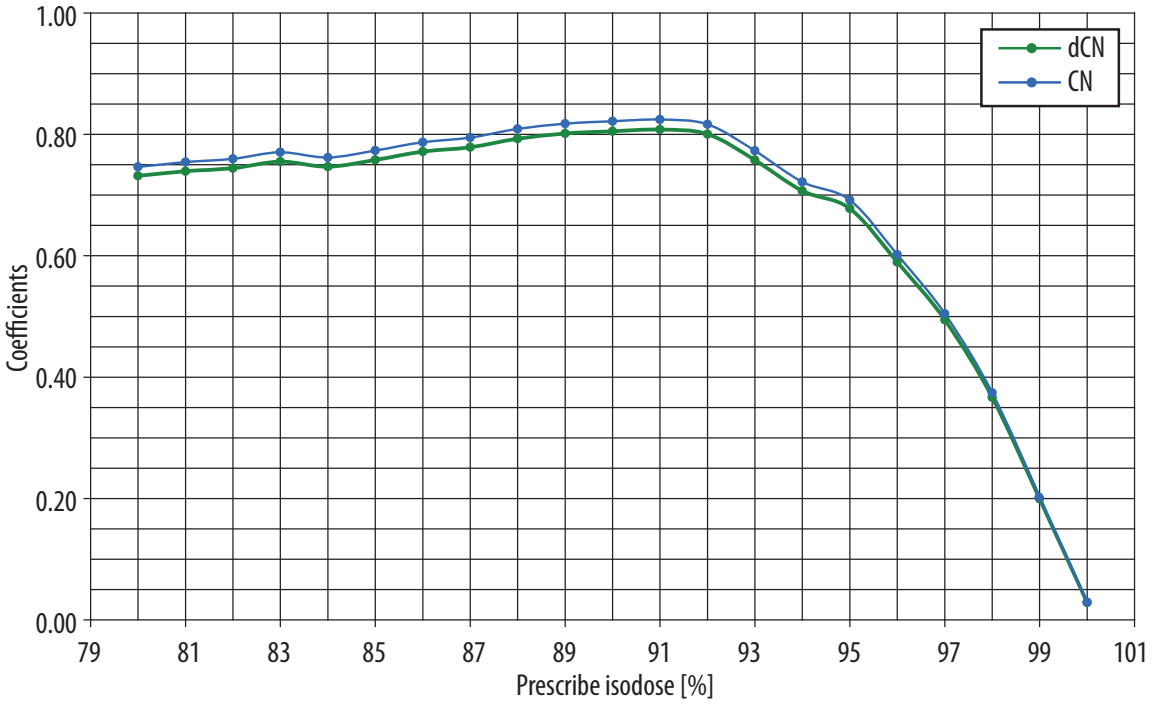

Figure 1. Example graph of a dependence coefficient to isodoses.

Table 1. Analysis coefficients for plans with one isocentre.

No	PTV volume [cm³]	Prescribed isodose [%]	Optimal isodose [%]	Percent PTV volume [%]	VTC	dTC	CLx	CN	dCN
1	2.02	80		100.00	1.00	1.00	0.58	0.58	0.58
			87	96.16	0.96	1.00	0.84	0.81	0.81
2	5.24	80		99.91	1.00	0.99	0.64	0.64	0.63
			88	94.75	0.95	0.99	0.83	0.79	0.78
3	13.78	80		99.94	1.00	1.00	0.75	0.75	0.75
			91	87.75	0.88	1.00	0.94	0.82	0.82
4	27.38	80		99.91	1.00	1.00	0.70	0.70	0.70
			89	96.61	0.97	1.00	0.85	0.82	0.82
5	6.98	80		99.90	1.00	0.99	0.64	0.64	0.63
			90	91.54	0.92	0.99	0.86	0.78	0.77
6	2.20	80		99.80	1.00	0.98	0.65	0.65	0.63
			87	95.41	0.95	0.98	0.84	0.80	0.78
7	30.73	80		99.95	1.00	0.95	0.67	0.67	0.63
			91	94.04	0.94	0.95	0.83	0.78	0.74
8	44.14	80		99.93	1.00	0.93	0.72	0.72	0.67
			92	92.70	0.93	0.93	0.89	0.82	0.76

Table 1 cont. Analysis coefficients for plans with one isocentre.

No	PTV volume [cm³]	Prescribed isodose [%]	Optimal isodose [%]	Percent PTV volume [%]	VTC	dTC	CLx	CN	dCN
9	1.31	80		99.80	1.00	0.91	0.51	0.51	0.47
			90	83.52	0.84	0.91	0.82	0.68	0.62
10	6.42	80		99.91	1.00	0.99	0.73	0.73	0.72
			88	88.65	0.89	0.99	0.87	0.77	0.76
11	5.00	80		99.72	0.99	0.96	0.62	0.61	0.59
			87	93.91	0.94	0.96	0.77	0.72	0.70
12	5.45	80		99.50	0.69	0.90	0.65	0.45	0.40
			89	92.92	0.64	0.90	0.84	0.54	0.49
13	11.96	80		100.00	1.00	1.00	0.75	0.75	0.75
			90	98.83	0.90	1.00	0.92	0.82	0.82
14	12.70	80		99.81	1.00	0.90	0.62	0.62	0.55
			91	91.94	0.92	0.90	0.85	0.78	0.70
15	1.37	80		99.90	1.00	1.00	0.55	0.55	0.55
			88	90.49	0.90	1.00	0.82	0.74	0.74
16	24.06	80		99.83	1.00	0.93	0.63	0.63	0.58
			90	97.64	0.97	0.93	0.81	0.78	0.72
17	1.47	80		99.93	1.00	0.99	0.80	0.80	0.79
			86	93.67	0.94	0.99	1.00	0.94	0.93
18	6.75	80		99.94	1.00	0.98	0.68	0.68	0.67
			89	93.83	0.94	0.98	0.88	0.82	0.80
19	1.84	80		99.73	1.00	0.94	0.70	0.70	0.66
			88	85.64	0.86	0.94	1.00	0.86	0.80
20	3.39	80		99.90	1.00	0.95	0.66	0.66	0.62
			91	80.20	0.80	0.95	1.00	0.80	0.76
21	5.71	80		100.00	1.00	1.00	0.63	0.63	0.63
			87	96.22	0.96	1.00	0.83	0.80	0.80
22	21.64	80		99.96	1.00	0.99	0.70	0.70	0.69
			90	94.86	0.95	0.99	0.86	0.82	0.81
23	9.52	80		99.98	1.00	0.99	0.68	0.68	0.67
			90	93.70	0.94	0.99	0.90	0.84	0.83

Table 2. Analysis coefficients for plans with two isocentres.

No	PTV volume [cm3]	Prescribed isodose [%]	Optimal isodose [%]	Percent PTV volume [%]	vTC	dTC	CLx	CN	dCN
1	11.18	80		99.71	1.00	0.95	0.65	0.65	0.62
			93	87.40	0.87	0.95	0.90	0.78	0.74
	1.30	80		99.79	1.00	0.96	0.63	0.63	0.61
			88	90.96	0.91	0.96	1.00	0.91	0.88
2	31.18	80		99.82	1.00	0.95	0.69	0.69	0.66
			91	93.76	0.94	0.95	0.87	0.82	0.78
	7.87	80		99.78	0.99	0.93	0.75	0.74	0.69
			88	88.92	0.89	0.93	0.89	0.79	0.73
3	5.53	80		99.82	1.00	1.00	0.67	0.67	0.67
			86	94.76	0.95	1.00	0.80	0.75	0.75
	17.69	80		99.77	1.00	0.96	0.68	0.68	0.65
			91	90.37	0.90	0.96	0.86	0.77	0.75
4	34.21	80		99.91	1.00	0.94	0.61	0.61	0.57
			91	89.71	0.90	0.94	0.76	0.68	0.64
	4.30	80		99.90	1.00	1.00	0.63	0.63	0.63
			91	85.03	0.85	1.00	0.91	0.77	0.77
5	8.25	80		99.35	0.98	0.86	0.63	0.62	0.53
			92	81.96	0.82	0.86	0.84	0.69	0.59
	22.42	80		99.56	0.99	0.94	0.53	0.53	0.49
			94	84.80	0.85	0.94	0.78	0.66	0.62
6	5.71	80		100.00	1.00	1.00	0.63	0.63	0.63
			87	96.22	0.96	1.00	0.83	0.80	0.80
	24.06	80		99.83	1.00	0.91	0.63	0.63	0.57
			90	95.51	0.97	0.91	0.81	0.78	0.71
7	3.39	80		99.90	1.00	0.95	0.66	0.66	0.62
			91	90.50	0.80	0.95	1.00	0.80	0.76
	19.29	80		100.00	1.00	1.00	0.73	0.73	0.73
			87	95.35	0.97	1.00	0.82	0.80	0.80
8	8.26	80		99.81	1.00	0.98	0.87	0.87	0.85
			87	95.74	0.96	0.98	0.94	0.90	0.88
	1.01	80		100.00	1.00	1.06	0.58	0.58	0.62
			88	95.52	1.00	1.06	0.73	0.73	0.77
9	1.45	80		99.87	0.99	0.96	0.56	0.55	0.53
			87	90.87	0.94	0.96	0.83	0.78	0.75
	6.43	80		99.41	0.99	0.93	0.71	0.71	0.66
			89	90.89	0.93	0.93	0.91	0.85	0.79
10	8.07	80		100.00	1.00	1.00	0.72	0.72	0.72
			87	96.20	0.96	1.00	0.84	0.81	0.81
	1.39	80		100.00	1.00	1.00	0.61	0.61	0.61
			90	95.43	0.95	1.00	0.80	0.76	0.76

In the case of two isocentres for isodose 80% values of *CN* were between 0.53 and 0.87 (average 0.65) and values of *dCN* were between 0.49 and 0.85 (average 0.63). Optimal prescribed isodoses evaluated on the basis on *CN* and *dCN* were between 86% and 94% and values of *CN* and *dCN* related to them were between 0.66 and 0.91 (average 0.78) and 0.59 and 0.88 (average 0.75) respectively. The *PTV* volume was enclosed by 80% isodose in 99.76% and 91.49% was enclosed by optimal prescription isodose.

Performing comparative analysis of plans with one and two isocentres one finds that the average values of parameters *CN* and *dCN* are higher for plans with one isocentre by about 0.35% (p=0.925) and 0.15% (p=0.970) for 80% isodose, respectively and 0.88% (p=0.750) and 1.3% (p=0.686) higher for optimal isodose. The average percentage value of *PTV* volume covered by 80% is higher by about 0.07% (p=0.946) and covered by optimal isodose is higher by about 0.97 (p=0.513) for plans with one isocentre.

Analysis of results

In comparative analysis of conformity parameters for plans with one and two isocentres Student's t-test [11] was used. On its basis one can find differences between two groups of plans (one and two isocentres). For analysis level of significance was set at α=0.05. For every analysis for every group level of probability *p* was calculated. All values α<p show us that these two groups do not differ significantly. In all cases described above the level of significance α is lower than the level of probability *p*.

Tables 1 and 2 show whole volume of *PTV* together with parameters of conformity and values of optimal isodose and percentage volume of *PTV* covered by this isodose. A detailed analysis of *PTV* volume and value of optimal isodose does not show any correlation between these quantities [11]. For plans with one isocentre the value of the correlation parameter is R^2=0.40 and for plans with two isocentres is R^2=0.18. There is also no direct dependence between the value of the *PTV* volume and the correlation parameters which are near zero.

The value of conformity parameters and value of the optimal isodose depend on the value of volume of normal tissues covered by the optimal isodose. Outline of the *PTV* volume and its position in relation to the organ at risk have a great influence on these values. It is known that when the *PTV* volume is more irregular and positioned close to organs at risk or a second tumour it is more difficult to set the number of fields to provide optimal values of conformity parameters. In such a case there is a high possibility of overdosage in normal tissues, which is a problem when making a plan and affects values of conformity parameters. In the abovementioned analysis all parameters for plans with two isocentres have lower values than in plans with one isocentre. For plans with one isocentre we have much more freedom in setting the fields because there is no second tumour. But it does not mean that conformity parameters calculated for treatment isodose can differ significantly in these two groups. Differences for this isodose are low: 0.35% and 0.15% respectively. Noticeable differences between plans with one and two isocentres can be noticed for conformity parameters calculated for optimal isodose. This is natural because a large number of fields in plans with two isocentres and limits in setting them increase the probability of irradiation of a larger volume of normal tissues and of covering minimum 99.5% *PTV* volume by treatment isodose (the difference in coverage of *PTV* volume by treatment isodose between the two plans is minimal and is 0.07%). As was stated above the value of optimal isodose and parameters calculated for it essentially depend on the volume of normal tissues irradiated by treatment isodose. This means that differences between plans for optimal isodose are higher than for treatment isodose, being 0.88% and 1.3%.

Conclusions

The determination of conformity indices for every plan is a routine operation performed at the end of treatment planning and before final audit by a physician. However, it gives us information only about the present, and not what could cause problems. Making any decisions concerning the plan relying only on mathematical parameters can result in fundamental faults. Only an overall view of all aspects of the plan can guarantee correct realization. It is the main policy in safe treatment course. Not all plans with parameters below acceptance level are unacceptable. In some cases, although its value is not reasonable, the plan is accepted because of other important facts (clinical, ethical). Prescription isodose should be changed as a logical consequence of the aforementioned analysis and in particular the determination of optimal prescription isodose.

From a mathematical point of view it is reasonable because values of conformity parameters for many but not all isodoses above 80% are higher than those for 80% isodose. Assigning dose to optimal prescription isodose leads to better output in conformity parameters for every plan and makes the dose lower at the isocentre point which is normalized to 100%. This approach is mathematically correct but does not meet criteria for enclosing 99.5% volume of *PTV* by prescription isodose. The average volume of *PTV* enclosed by optimal prescription isodose in plans is 91.9% and 88.8% with one isocentre and with two isocentres, respectively. This means that about 10% of *PTV* volume is underdosed, which cannot be accepted in stereotactic radiosurgery because this failure will not be possible to rearrange. Such sophisticated and exact analysis of every plan is a major part of quality assurance. It allows for fast and convenient comparison of plans prepared using different stereotactic techniques and in different oncology centres. It is very useful and ensures high quality assurance and steady improvement in planning. Meticulous analysis of the dose distribution in every image and the dose volume histogram of *PTV* and organs at risk are crucial parts of the planning process. They can guarantee successful treatment through eliminating the possibility of irreversible mistakes.

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