Radiation Planning Index for dose distribution evaluation in stereotactic radiotherapy

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SUMMARY

AIM: The aim of this study was to provide a parameter for treatment plan comparisons in clinical practice.

MATERIALS AND METHODS: 21 patients with brain tumours were selected for analysis. Two alternative treatment plans were calculated for each patient. One of the alternative plans was approved while the second one was rejected by the physician. Alternative plans were compared with the parameter RPI. The computer program RPIWin® was prepared to facilitate the calculation process.

RESULTS: Calculations showed that 80% of approved treatment plans had higher RPI than rejected ones. Only 4 cases of approved treatment plans were characterized by lower RPI values than rejected ones.

CONCLUSION: The experiment demonstrated that the Radiation Planning Index formula takes into account the relation between dose distributions calculated for planning treatment volumes and organs at risk and is a convenient tool for treatment plan comparisons in routine clinical practice.

KEY WORDS: stereotactic radiosurgery, quality index, DVH analysis, dose distribution comparison

BACKGROUND

Conformal radiotherapy is a balance between the prescribed dose delivered to the tumour volume and healthy tissue tolerance [1, 2, 3, 4, 5, 6, 7].

Nowadays the choice of the optimal treatment plan among a number of plans calculated for the same patient in modern radiotherapy is challenging and is based on the experience and knowledge of the physician and radiotherapists.

However, such estimation seems highly subjective, and for this reason we believe that an unambiguous index that ranks the dose distribution will benefit the decision-making process [8, 9, 10, 11].

Numerous indices that characterize the dose distribution in the planning treatment volume (PTV) are widely reported in the literature, e.g. the conformal index, which analyzes the relation between the prescribed dose in PTV, and organs at risk (OAR) [12, 13, 14]. However, most parameters take into consideration only the reference dose value and single PTV. None of the parameters takes into account complicated relations between the dose distribution in the set of PTVs and OAR introduced to the plan.

We believe that the Radiation Planning Index (RPI) is a convenient tool for comparison of treatment plans in routine clinical practice.

AIM

The aim of this study was to introduce the RPI formula and to develop a method for comparison of dose distributions calculated in IMRT technique.

MATERIALS AND METHODS

21 patients with brain tumours treated with stereotactic radiosurgery were selected for

analysis. For each patient 2 alternative treatment plans were calculated by the BrainLab BrainScan treatment planning system. Both treatment plans were presented to the physician. One of the alternative plans was approved for treatment while the second one was rejected.

Each pair of treatment plans contained from 1 to 2 PTV contours and from 3 to 6 OAR. The Radiation Planning Index (RPI) was calculated for each analyzed plan.

For the purpose of this study the following RPI formula (Eq. 1) was proposed as an evaluation tool of the decision-making process.

$$RPI = \sqrt[n*m]{\prod_j^n \left[\prod_i^m \left[\left(1 - \frac{w_j \cdot \int_0^{D\max OaR} VjOAR \quad dD_{OaR}}{\int_0^{D\max OaR} VjOAR\ 100\% \quad dD_{Oar}} \right) \cdot \left(\frac{\int_0^{D\max PTV} ViPTV \quad dD_{PTV}}{\int_0^{D\max PTV} ViPTV\ 100\% \quad dD_{PTV}} \right) \cdot (1 - SDev \cdot p_i) \right] \right]} \quad (1)$$

RPI is the Radiation Planning Index, where n is the number of critical structures (OAR) and m is the number of volumes treated (PTV).

Integral doses in RPI are based on the dose volume histograms (DVHs) (Fig 1.) calculated for each OAR and PTV.

$$\int_0^{D\max OaR} VjOAR \quad dD_{OaR}$$

is the integral dose of the j-th OAR, while

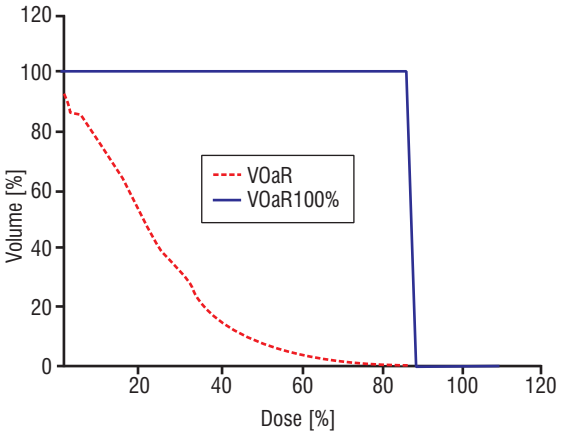

Fig. 1. Dose-volume histogram for OAR represents two dimensional coverage of the irradiated volume. Solid line represents ideal, homogeneous coverage of the irradiated volume with the maximal dose, dashed line is a dose–volume relation assuming realistic, inhomogeneous dose distribution inside OAR.

$$\int_0^{D\max OaR} VjOAR\ 100\% \quad dD_{Oar}$$

is the integral dose of the OAR^j volume, assuming that the whole volume receives the tolerance dose for this critical structure (Fig. 1). Similarly

$$\int_0^{D\max PTV} ViPTV \quad dD_{PTV}$$

is the integral dose of the i-th PTV and

$$\int_0^{D\max PTV} ViPTV\ 100\% \quad dD_{PTV}$$

is the integral dose of the i-th PTV, assuming that the whole volume is homogeneously covered with the prescribed dose value.

SDev determines the standard deviation of the dose distribution in PTV, while p_i is a weight factor of the dose distribution homogeneity for the PTVi. Each OAR is characterized by the importance factor w_j. The importance factor was introduced to RPI to rank organs sensitive to irradiation. Its value is established individually for each patient based on the physician's and dosimetrist's experience, organ's radiosensitivity and patient's history of irradiation.

D max *OaR* is the maximal dose value, which should not exceed the tolerance dose for the selected anatomical structure.

When

$$w_j * \int_0^{D\max OaR} VjOAR \quad dD_{OAR} = \int_0^{D\max OaR} VjOAR 100\% \quad dD_{OAR}$$

then

$$\left(1 - \frac{w_j * \int_0^{D\max OaR} VjOAR \quad dD_{OAR}}{\int_0^{D\max OaR} VjOAR 100\% \quad dD_{OAR}} \right) = 0$$

It results in *RPI* = 0 because the whole OAR is covered with the maximal tolerance dose. If the integral dose in PTV is much lower than the prescribed reference dose then

$$\frac{\int_0^{D\max PTV} ViPTV}{\int_0^{D\max PTV} ViPTV 100\%} -> 0$$

which results in *RPI* – > 0.

For S_{Dev} = 0 the whole tumour volume is covered homogeneously with the reference dose.

When the critical structures receive 0% of the reference dose and the whole tumour volume is covered by 100% of the isodose and the dose distribution inside PTV is homogeneous (*SDev* = 0) then RPI = 1.

RPI = 0 when each OAR volume is covered with the homogeneous maximal dose or standard deviation *SDev* is equal to 1.

In clinical practice RPI values are in the range of 0 to 1. RPI depends on the particular clinical situation and therefore it is a convenient tool for comparison among alternative treatment plans prepared for the same patient. Treatment plan comparison among different patients is inefficient when using RPI values.

RESULTS

For better understanding of the RPI concept the analysis of two alternative treatment plans A and B for selected patient is presented. Treatment plans were calculated for one PTV contour and five critical structures. Dose volume histograms A and B were generated for each delineated structure (Fig. 2). RPI values for plans A and B were 0.328 and 0.403 respectively. Importance factors were the same value for all OAR. According to RPI plan B is assumed to be preferable; however, the dose received by the chiasma optica and neuromyelitis optica are higher in comparison to plan A. In contrast, the doses delivered to right and left eyeballs are lower in plan B.

In both plans, doses delivered to the eyeballs are below 1.6 Gy (20% of the reference dose), which is an acceptable dose value for this structure.

Therefore, in this particular situation, importance factor wj (Eq. 1) for this structure is equal to 0. RPI values are now 0.519 for plan A and 0.493 for plan B. According to the new estimated RPI values plan A is recommended for treatment.

Similar calculation of RPI value was performed for the pair of treatment plans for 21 patients. 17 plans, approved by the physician, had higher RPI values compared to rejected ones. The mean difference in RPI between approved and rejected plans was 6.3%. Only for 4 cases were approved treatment plans characterized by lower RPI values than rejected ones. In this group the mean difference between RPI values was 7.3%. It can be concluded that 80% of the approved plans had higher RPI than rejected ones. Non-parametric analysis performed with the test of agreement demonstrated statistically significant differences between groups (p = 0.0013).

The computer program *RPIWin*® was prepared to facilitate the calculation process. The program, created in C++ language, operates under Windows system. *RPIWin*® enables DVHs to be transferred from the treatment planning systems Eclipse Varian and BrainScan BrainLab and RPI values to be calculated for the reference treatment plan and alternative one (Fig. 2).

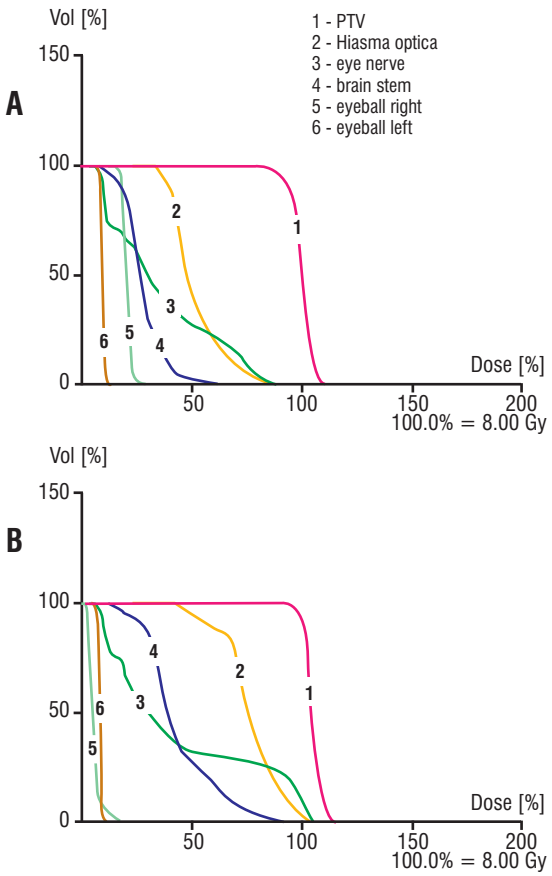

Fig. 2. DVHs for alternative treatment plans A and B prepared for the same patient. Dose to volume relations were calculated for all delineated structures introduced to the plans. RPI for plan B demonstrates higher value than for plan A when weight factors were the same for each delineated structure.

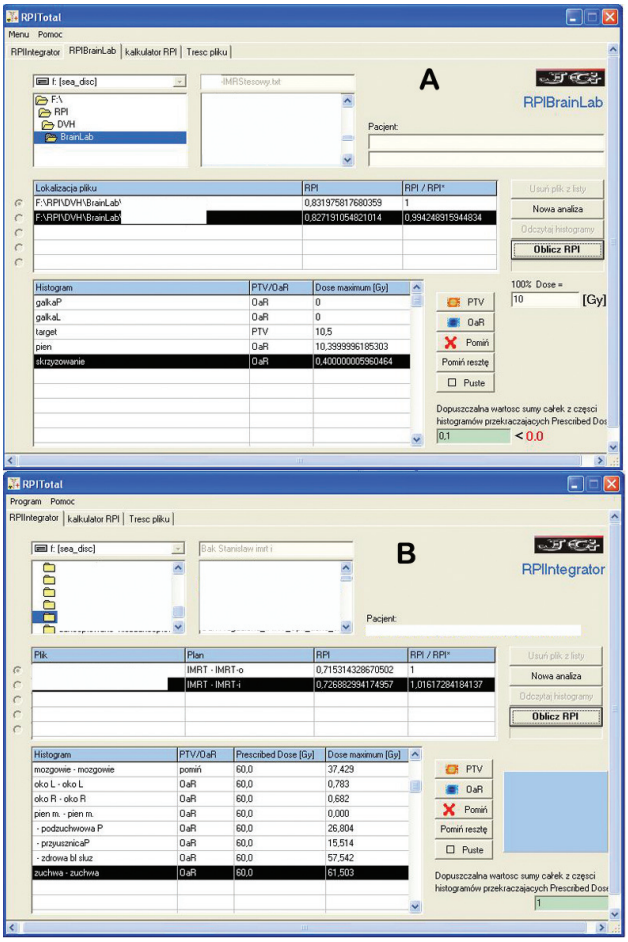

Fig. 3. C++ programming language was used to create the RPIWin® application which operates under Windows system. DVHs are transferred from TPS versions A – BrainLab and B – Eclipse to RPIWin®. RPI values are calculated for dose distribution for chosen anatomical structures and PTVs.

DISCUSSION OF RESULTS

The RPI formula, implemented to the *RPIWin®* algorithm, takes into account relations between dose distribution in treated volumes and critical structures. The number of DVHs for calculation is optional. Only physical dose values were analyzed; parameters that influence the radiobiological effect (overall treatment time and fraction size) were ignored in the *RPIWin®* algorithm. However, the purpose was to analyze only physical parameters (dose value) since they are the background for the treatment planning process. The RPI formula describes the relation between integral doses and dose distributions calculated for the same patient and may be helpful in the decision-making process. The results confirm that the value of RPI is in agreement with physician's and dosimetrist's knowledge and provides an objective tool for ranking the treatment plans for the same patient.

The COIN index proposed by Baltas et al. [15] became a prototype for the RPI. Unlike other parameters widely reported in the literature [16], COIN and RPI take into consideration the complex relations between PTV and OAR. In a review by Feuvret L. et al. [16], a number of indices were presented for treatment plan evaluation. In our study, we did not compare the results acquired from RPI calculations with results for other indices because, based on our calculations [17], the evaluation of the treatment plan quality is determined by the choice of conformity index. Moreover, this work was focused on the relative comparison between RPI values for alternative plans for the same patient rather than establishing absolute RPI levels, which indicate whether the dose distribution is in compliance with the treatment protocol.

CONCLUSION

The Radiation Planning Index formula takes into account the relation between dose distributions calculated for planning treatment volumes and organs at risk.

The experiment showed the potential role of the RPI index for the comparison of alternative treatment plans calculated for the same patient and introduces a convenient tool for treatment plan selection in clinical practice.

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