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Dose gradient based algorithm for beam weights selection in 3D-CRT plans

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ABSTRACT

Aim: In this work we test the usage of dose gradient based algorithm for the selection of beam weights in 3D-CRT plans for different cancer locations. Our algorithm is easy to implement for three fields technique with wedges defined by planner.

Background: 3D-CRT is usually realized with forward planning which is quite time consuming. Several authors published a few methods of beams weights optimization applicable to the 3D-CRT.

Materials and methods: Optimization is based on an assumption that the best plan is achieved if dose gradient at ICRU point is equal to zero. Method was tested for 120 patients, treated in our clinic in 2011-2012, with different cancer locations. For each patient, three fields conformal plan (6 MV and 15 MV X-ray) with the same geometry as proposed by experienced planners was prepared. We compared dose distributions achieved with the proposed method and those prepared by experienced planners. The homogeneity of dose distributions was compared in terms of STD and near minimum and near maximum doses in the PTV.

Results: Mean difference of STD obtained by the proposed algorithm and by planners was 0.1%: 0.1% for prostate cancer, 0.3% for lung cancer, −0.1% for esophagus cancer, 0.1% for rectum cancer, −0.1% for gynecology cancer, −0.1% for stomach cancer.

Conclusions: Applying the proposed algorithm leads to obtain the similar dose distribution homogeneity in the PTV as these achieved by planners and therefore can serve as a support in creating 3D-CRT plans. It is also simple to use and can significantly speed up the treatment planning process.

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1. Background

Conformal therapy (3D-CRT) is still in common use. Simplicity of beam arrangement is one of the parameters of the plan quality. It is very important especially for palliative cases, patients with pain or respiratory problems. That is why three beams geometry is used very often. Usually beam weights are chosen by trial and error process. Sherouse[1] described mathematical formalism of 3D-CRT radiotherapy planning based on dose gradient analysis for open beams. He noticed that mathematical gradient analysis "holds promise as the basis of a technique for automatic selection of wedge angles, collimator angles, and relative beam weights as a part of a clinical treatment design system." Algorithm based on dose gradient analysis applied to two and three beams therapy was proposed by Dai.[2]

2. Aim

Few authors made some effort to shorten 3D-CRT treatment planning time. Simulated annealing,[3,4] genetic algorithms,[5] omni-wedge technique,[6,7] and other methods[8–11] were tested. To the best of our knowledge none of these methods is in common use. Therefore in this work we developed a method based on dose gradient analysis. It was tested for 120 three fields technique plans for patients with different cancer locations.

3. Materials and methods

Treatment techniques

Our method was tested for 120 plans, realized in our clinic in 2011–2012. We have chosen plans with six different cancer locations: prostate, lung, esophagus, rectum, gynecology, stomach – 20 plans for each location. Each treatment plan consists of three coplanar fields. Each field was set to 6 MV or 15 MV X-ray depending on a tumor depth. The shape of the fields was obtained with multileaf collimator. We calculated field weights with our algorithm for the same geometry as prepared by experienced planner.

3.1. *Optimization of beam weights*

According to Sherouse we assumed that the most homogeneous dose distribution in the PTV is obtained if dose gradient at ICRU point is zero. In order to find field weights we had to solve following set of equations:

$$\begin{cases} \sum_{i=1}^{3} w_i \cdot D_i(\mathrm{ICRU}) = D_p(\mathrm{ICRU}) \\ \sum_{i=1}^{3} w_i \cdot \nabla D_i(\mathrm{ICRU}) = 0 \end{cases} \quad (1)$$

where w_i are beam weights. In our model beam normalization is calculated with formulae: $(\mathrm{PDD}(d)/\mathrm{PDD}(\mathrm{ICRU})) \cdot (D_p/n)$, where $n = 3$ and d is depth of the ICRU Reference Point for the n beam. This means that weights are proportional to the dose delivered from each single beam to ICRU point. We decided to use isocenter, chosen by planner, as an ICRU point. The first equation of formulae (1) guarantees that the dose at ICRU point would be equal to prescribed dose D_p. Second equation sets the dose gradient at ICRU point to zero. This set of equations has exactly one solution. We had considered two possible ways of calculating $PDD(d)$. One way was to look into the tables and measurement and second (easier one) was to use formulae described by Gerbi[12]:

$$\mathrm{PDD}_{\mathrm{SDD}}(d) = 10^{[p_1 + p_2 \cdot d + (p_3 + p_4 \cdot d)\log(A/P)]} \quad (2)$$

In Eq. (2) p_i are factors which depend on beam quality index ($\mathrm{TPR}_{20/10}$), d stands for depth, A and P are field area and periphery, respectively. PDD was recalculated from one SSD to another with the formulae:

$$\mathrm{PDD}_2(d, A_s, \mathrm{SSD}_2) = \mathrm{PDD}_1(d, A_S, \mathrm{SSD}_1)\frac{\mathrm{TAR}(d, A_{d_2})}{\mathrm{TAR}(d, A_{d_1})} \cdot \left(\frac{\mathrm{SSD}_2 + d_{\max}}{\mathrm{SSD}_2 + d}\right)^2 \cdot \left(\frac{\mathrm{SSD}_1 + d_{\max}}{\mathrm{SSD}_1 + d}\right)^{-2} \quad (3)$$

The factor $\mathrm{TAR}(d, A_{d_2})/\mathrm{TAR}(d, A_{d_1})$ is very close to 1, and therefore was neglected.

Dose gradient component (∇D_i) parallel to central axis has to be calculated, at particular depth, from depth dose curve. Dose gradient component perpendicular to central axis has to be calculated from the dose profile (in the transversal axis direction) at depends mostly on wedge angle. Finally the dose gradient is a vector sum of these two gradients.

In order to calculate dose gradient component transversal to beam axis we fit line to the dose profile for wedged beams in the surrounding of the central axis in the distance ±1 cm from the axis. Linear fitting was done with the least square method. We have checked how the slope is changing with the depth for depths from 6 cm to 24 cm (see Fig. 1). Mean standard deviation

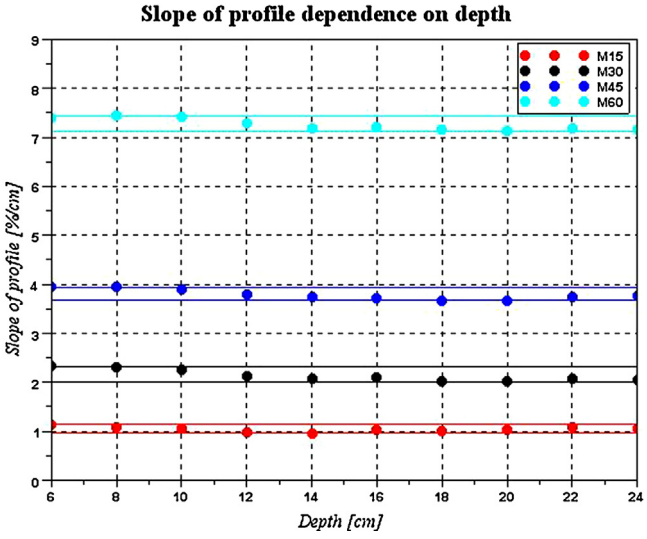

Fig. 1 – Comparison of slope value for different depths and different wedges.

of slope for different depths was equal 3% of the mean slope value.

To calculate beam weights the following parameters were introduced: depth of ICRU point along the central beam axis, field size, wedge angle (represented by the slope of central part of profile), depth of maximum dose (d_{max}) and beam quality index ($TPR_{20/10}$).

3.2. *Implementation of a model for cancer patients*

After calculating beam weights and wedge angles, which was done by solving the set of Eq. (1) in an analytic way with a help of computer program, they were introduced into TPS (Eclipse v.8.9: Varian Medical Systems, Palo Alto, CA with Anisotropic Analytical Algorithm 10.0.28). We compared statistical parameters of dose distribution achieved with beam weights optimization method and by experienced planners. We compared dose distribution homogeneity in terms of: dose standard deviation (STD), near minimum and near maximum dose in target volume. In our opinion D98% and D2% serve better as an estimation of dose distribution than D_{min} and D_{max} which are point doses.

3.3. *Calculations*

All calculations were carried out with homemade program prepared in the free Python language.[13]

4. Results

Mean difference of STD obtained by the proposed algorithm and by planners (with trial-and-error forward planning process) was 0.1% (see Fig. 2 for details).

For prostate cancer 1 plan prepared with algorithm had smaller STD than that prepared by planner (−0.25% of prescribed dose), for 7 plans no difference was observed, for other plans STD in plan prepared with algorithm was higher (up to 1.5% of prescribed dose). Mean D98% difference was −0.2% (range −2.1% to 0.4%) and mean D2% was 0.3% (range −0.8% to 2.8%).

For lung cancer 2 plans prepared with algorithm had smaller STD than that prepared by planner (up to −0.5% of prescribed dose), for 4 plans no difference was observed, for other plans STD in plan prepared with algorithm was higher (up to 1.75% of prescribed dose). Mean D98% difference was −0.4% (range −2.8% to 0.7%) and mean D2% was 0.9% (range −1.2% to 3.3%).

For esophagus cancer 5 plans prepared with algorithm had smaller STD than that prepared by planner (up to −0.75% of prescribed dose), for 7 plans no difference was observed, for other plans STD in plan prepared with algorithm was higher (up to 0.5% of prescribed dose). Mean D98% difference was 0.2% (range −1.7% to 1.6%) and mean D2% was −0.1% (range −1.8% to 1.6%).

For rectum cancer 1 plan prepared with algorithm had smaller STD than that prepared by planner (−0.5% of prescribed dose), for 8 plans no difference was observed, for other plans STD in plan prepared with algorithm was higher (up to 1% of prescribed dose). Mean D98% difference was −0.1% (range −1.1% to 0.4%) and mean D2% was 0.3% (range −1.2% to 1.9%).

For gynecology cancer 4 plans prepared with algorithm had smaller STD than that prepared by planner (−0.75% of prescribed dose), for 7 plans no difference was observed, for other plans STD in plan prepared with algorithm was higher (up to 0.5% of prescribed dose). Mean D98% difference was 0.1% (range −0.9% to 1.3%) and mean D2% was 0.3% (range −1.6% to 1.8%).

For stomach cancer 7 plans prepared with algorithm had smaller STD than that prepared by planner (up to −1% of prescribed dose), for 3 plans no difference was observed, for other plans STD in plan prepared with algorithm was higher (up

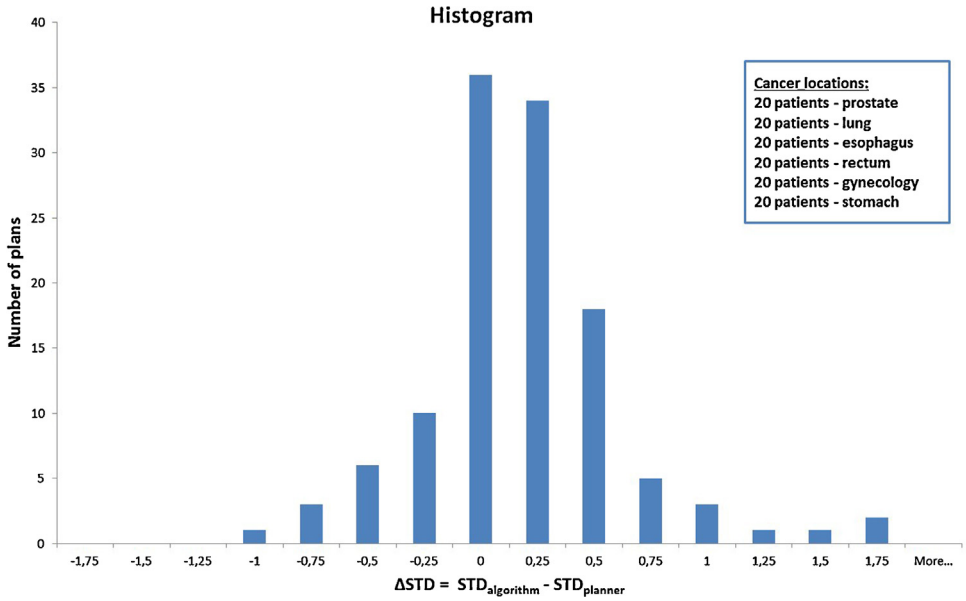

Fig. 2 – Histogram of dose standard deviation difference between plans prepared by planners and with our algorithm.

to 1% of prescribed dose). Mean D98% difference was 0.2% (range −1.1% to 1.6%) and mean D2% was 0.2% (range −1.8% to 3.0%).

5. Discussion

STD differences which have been obtained in most plans should not lead to significant change in TCP [14]. For more than 50 patients STD was equal or even better for our algorithm.

Possible reason for higher STD for plans prepared with algorithm can be patient body shape. Dai and Zhu[6] also noticed a problem in accounting a patient's body shape and tissue inhomogeneity. In our previous work we proposed the solution of this problem. We identified influence of patients body shape on open beams profiles as an additional wedge. We showed that introducing these profiles into our set of Eqs. (1) is sufficient enough.

In forward 3D-CRT planning the planner must choose the appropriate fields geometry, beam energy, wedges, beam weights and of course number of beams. The most important are the number of beams and their positions (for isocentric techniques angles of beams) with respect to target volume and sensitive structures. Several parameters of beams may be defined automatically, the isocenter, the shape of each single beam. The simplicity of a plan, especially in palliative treatment has an important role. Therefore quite often two opposed beams are used. Our method allows a more complicated geometry for easy planning, e.g. three fields technique. The method ensures that dose distribution in the target volume is quite homogenous.

6. Conclusion

Nowadays the main effort in TPS development is directed on searching optimization methods for IMRT and VMAT techniques. One cannot forget that 3D-CRT would be used in clinical practice as well, also because we do 3D-CRT plans for many palliative cases, what was not done before. In most countries more than 40% of patients have palliative treatment. Therefore using 3D-CRT instead of standard 2D treatment is time-restricted. Our work shows that it is possible to create very easy and effective methods of dose distribution optimization for 3D-CRT plans.

Conflict of interest

None declared.

Financial disclosure

None declared.

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