A STUDY OF HOMOGENEITY PARAMETERS IN LOW DOSE RATE INTERSTITIAL BRACHYTHERAPY

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ABSTRACT

Purpose: In this work we investigate four homogeneity parameters to determine a suitable parameter for dose homogeneity optimization.

Method and Materials: A new version of the Adjoint-based Greedy Heuristic (GH) 3D optimization algorithm is used to generate treatment plans for low dose rate prostate brachytherapy. Treatment plans are generated for seed-strengths varying from range 0.2mCi to 1mCi for I-125 BEST 2301 seed model. Each plan is designed for 98% target coverage. Four main homogeneity parameters -Conformation number (CN), Dose non-uniformity ratio (DNR), Uniformity index (UI) and Homogeneity index (HI) are quantified and analyzed against varying seed strengths. The local homogeneity parameter is defined as the value of a homogeneity parameter at any instant as the seeds are added during the treatment plan optimization process.

Results: An analysis of the final values of the homogeneity parameters using varying seed strengths reveal a strong relation between the CN and the seed strength used in an implant. The HI, UI and DNR parameters fluctuate greatly. Using a fixed source strength, a study of the local CN reveals that, as seeds are added, the CN increases to a maximum value and then decreases as more seeds are added.

Conclusion: Based on our study, homogeneity parameters such as HI,UI or DNR can be useful in a dose homogeneity-optimization routine using a pre-decided source-activity. An optimization routine can also aim at searching for optimum activity of the seeds to be used in an implant. For such an optimization routine CN based parameter (viz. CN/DNR) can be useful.

MOTIVATION

Optimization codes for interstitial brachytherapy are based on the aims of adequate target coverage and maximum sparing of sensitive structures. These two aims define the basic way in which the seeds should be implanted in a tumor. It is time to look at optimization routines that try to achieve additional aims for improving the quality of an implant. One of these additional secondary aims can be maximizing the dose homogeneity in an implant. This work is conducted to find out the best suitable homogeneity parameter for progression (step-wise addition of the seeds) of such optimization routines.

METHODS AND MATERIALS

Greedy Heuristic based on adjoint functions:

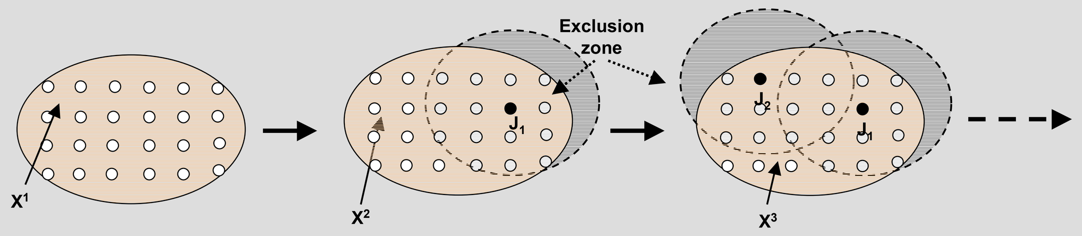
The adjoint sensitivity based Greedy Heuristics (GH) optimization scheme for interstitial implant brachytherapy was developed at UW-Madison. The first version of the GH-algorithm[1] utilizes adjoint ratio based rankings of seed positions to effectively distribute the seeds inside the target region. The adjoint ratio, R(j), is defined by the equation below

$$R(j) = \frac{w_{urethra}\cdot D^{+}_{j,urethra} + w_{rectum}\cdot D^{+}_{j,rectum} + w_{normal}\cdot D^{+}_{j,normal}}{D^{+}_{j,target}}$$

Where, $D^{+}_{j,ROI}$ is the "adjoint function" for a region of interest (ROI) or the importance function, defined as the sensitivity of the average dose in the ROI to a unit-strength brachytherapy seed at a seed position. W_{ROI} is the weighting factor for an ROI.

METHODS ...contd

The GH employs the method of exclusion zones to distribute seeds in the tumor volume. In this method, a region around the placed seeds is selected as exclusion zone for further seed placement. Highest ranking seed is selected for seed placement from the region available outside the exclusion zones.



When the available space diminishes, a smaller region is selected for exclusion and the seed placement restarts.

Greedy Heuristic based on a dynamic metric:

GH optimization code based on a dynamic metric has a cumulative-dose-based sensitivity coupled with the ROI-based-sensitivity (adjoint ratio) for sorting of the seed positions.

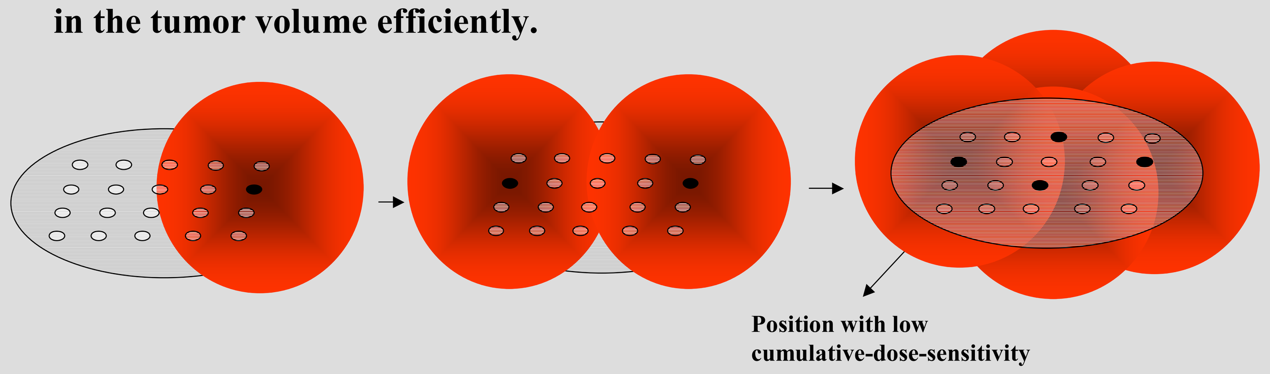
The cumulative-dose-based-sensitivity S_{dose}, is defined as the proneness of a voxel to adopt the dose based on the *hypothesis* that the lower the dose to a target voxel the more prone it is to adopt a seed. To account for the doses added by the seeds in the tumor at any time, we define S_{dose} as:

$$S_{dose} = \sum_{i=1}^{n} D_{ij} / D_{p}$$

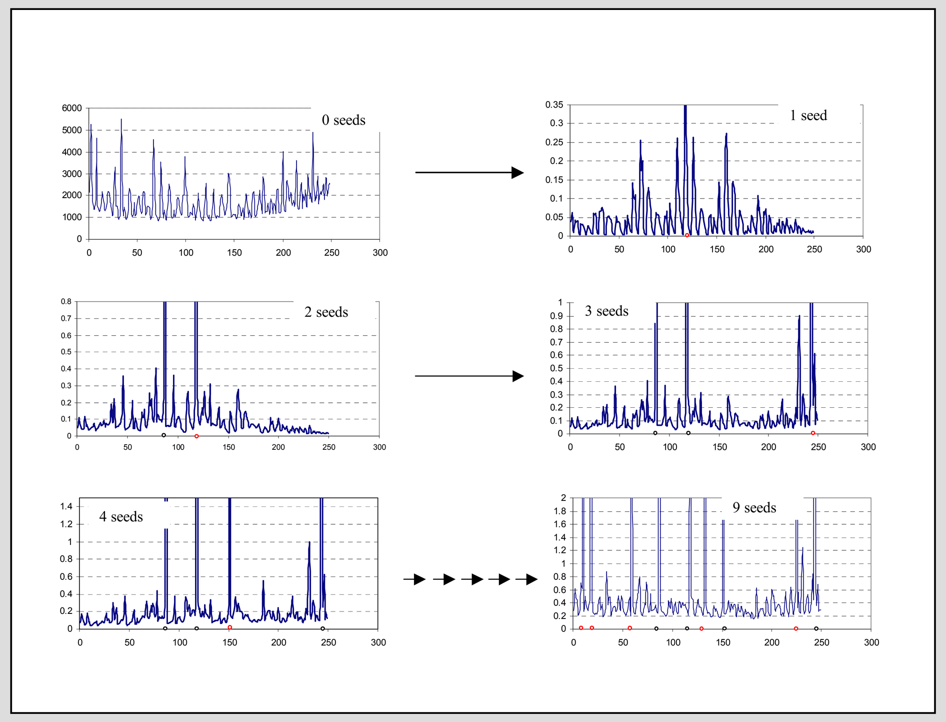
Where Dij is the dose to the jth receptor voxel from all the seeds at ith voxels and Dp is the prescribed dose. Hence, the new coupled metric, Rdj, is comprehensive of the dynamic dose changes in the receptor-field and the constant ROI-based-sensitivity at any instant:

$$Rdj = R(j) * \sum_{i=1}^{n} Dij/Dp$$

Whenever a seed is added, the new metric-values are sorted to prepare the new ranking matrix. Whereas R(j) helps select the seed-position with maximum impact for optimized dose delivery, S_{dose} helps dispersing the seeds in the tumor volume efficiently.



Figures below depict dynamically changing metric profile at each step. Seed position with lowest metric is selected for seed deposition. Cluttering of seeds is avoided as the metric values at and near a seed position are increased in magnitude proportional to the doses received. Red dots depict most recently added seed; black dots represent all the prior seeds that are added.



RESULTS

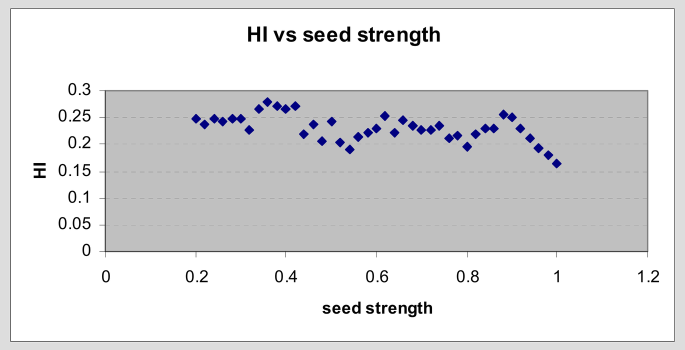
We performed a detailed analysis on homogeneity parameters. Four main homogeneity parameters – Conformation number, Dose non uniformity ratio, Homogeneity index and Uniformity index.

Using the GH algorithm with the dynamic dose metric and dose data for I-125 seed BEST model 2301, dose distributions were generated for seed strengths varying from 0.2mCi to 1mCi with a step of 0.02 mCi.

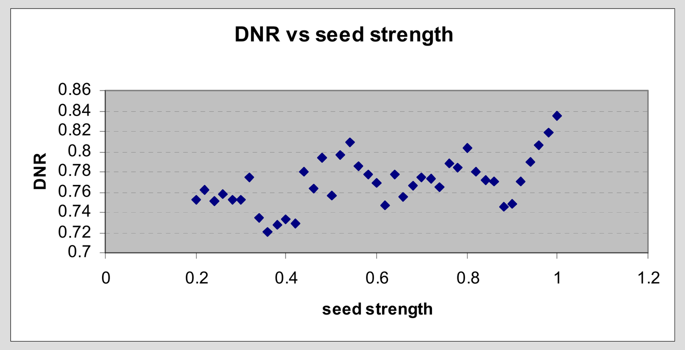
Final homogeneity parameters are quantified.

The local homogeneity parameter is defined as the value of a homogeneity parameter at any instant as the seeds are added during the treatment plan optimization process. Local homogeneity parameters are quantified.

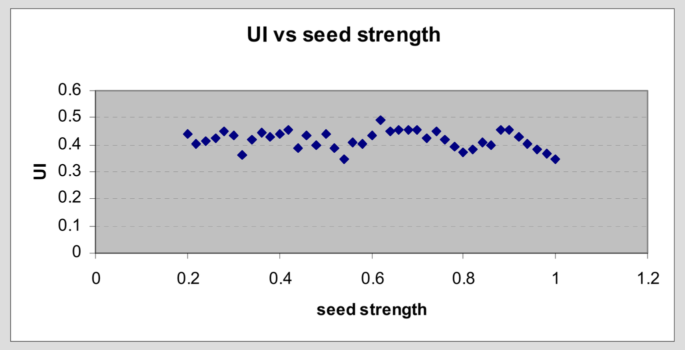
For 98% coverage of the target in each case the variation of Dose-non-uniformity ratio (DNR), Conformation number (CN), Homogeneity index (HI) and Uniformity index (UI) are given in figure below:



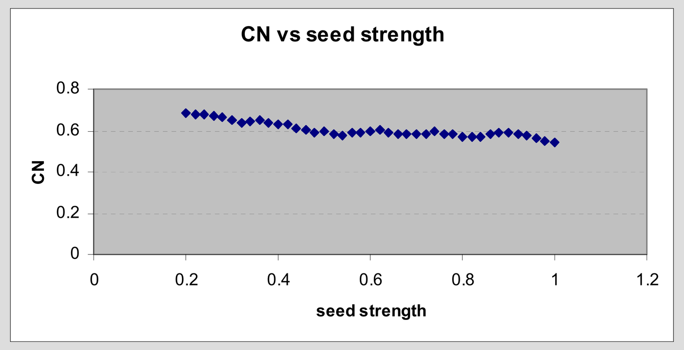
$$HI = \frac{V_{100,ta} - V_{150,ta}}{V_{100,ta}}$$



$$DNR = \frac{V_{150,ta}}{V_{100,ta}}$$

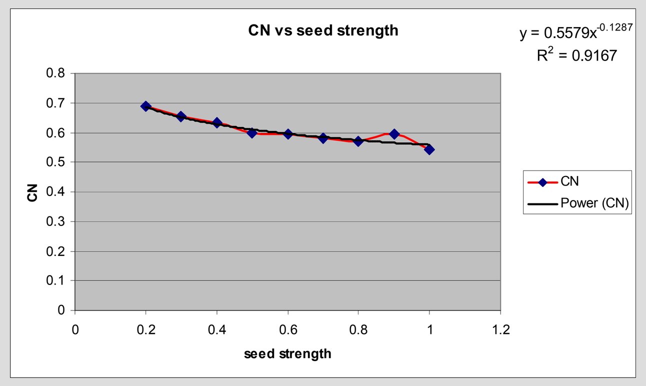


$$UI = HI \times \left(\frac{D_{100ta}^{-3/2}}{D_{100ta}^{-3/2} - HD^{-3/2}}\right)$$



$$CN = \left(\frac{V_{100,ta}}{V_{ta}}\right) \times \left(\frac{V_{100,ta}}{V_{100}}\right)$$

An analysis of the final values of the homogeneity parameters using varying seed strengths reveal a strong relation between the CN and the seed strength used in an implant. The HI, UI and DNR parameters fluctuate greatly.



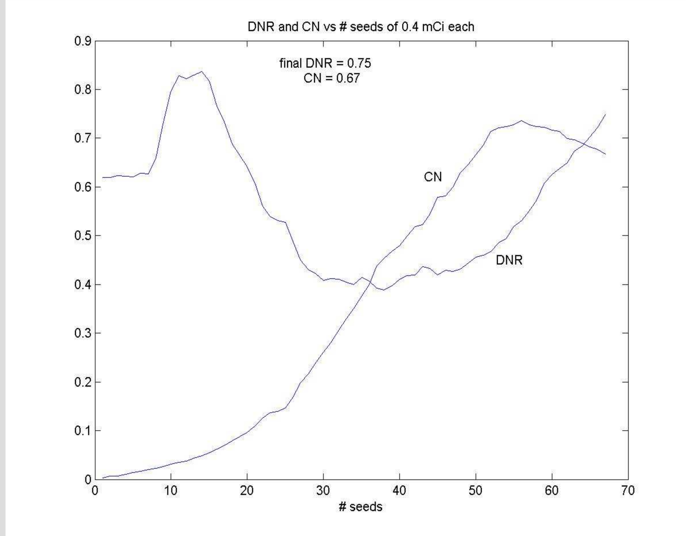
A power fit to the CN curve shows conformity of the dose to the target has a strong relationship with the activity of seeds incorporated to make the treatment plan.

Other homogeneity parameters do not depict such behavior.

RESULTS ...contd

A plot of behavior of local CN and local DNR

Variation of CN and DNR in an under-construction treatment plan as seeds are being added. The plot is for 0.4mCi I-125 seeds.



Whereas the CN monotonically improves as the seeds are distributed in the target the DNR shows a random behavior depicting the changing hot spots in the target.

As the seeds are added to a system the CN increases mostly and towards last few seeds the value degrades. However, since a good CN value is already established this degradation does not bring the final CN value down to an unacceptable limit.

CONCLUSIONS

The study of local homogeneity parameters demonstrates an improvement in CN as seeds are added. So, progression of a dose homogeneity optimization routine using a fixed seed strength should be based on HI,UI or DNR parameters.

The study of final homogeneity parameters of a treatment plan using varying seed activities for each treatment plan, demonstrates a strong relationship between the CN and the seed activity used.

An optimization routine can aim at searching for optimum activity of the seeds to be used in an implant. For such an optimization routine CN or CN based parameter (viz. CN/DNR) will serve as more reliable parameter.

REFERENCES

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