# INTERSTITIAL PROSTATE IMPLANT BRACHYTHERAPY USING AN AUTOMATED, 3-D GREEDY HEURISTIC OPTIMIZATION AND I-125 DIRECTIONAL SOURCES

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## ABSTRACT

We present the results of a newly developed automated 3-D greedy heuristic optimization algorithm utilizing the adjoint sensitivity fields of the directional and the isotropic source-seed. Directional brachytherapy is based on use of a partially shielded 0.43 mCi I-125 interstitially applicable brachytherapy source. The dose data for the directional source is taken from the I-125 directional source developed at UW-Madison by Dr. Lin et al. Directional sources along with isotropic sources can be used to provide another parameter in brachytherapy optimization via directional dose delivery. Using this greedy heuristic algorithm, treatment plans are generated for interstitial prostate implant brachytherapy. The treatment plans are mixed source treatment plans utilizing isotropic and directional sources for implantation. The algorithm directs directional sources strategically at positions near the sensitive structures for better shielding, and optimizes their distribution in the bulk of the prostate wherever required for dose compensation. Whereas, directional sources ensure sparing the sensitive structures from overdosing the isotropic sources facilitate in maintaining the desired dose homogeneity.

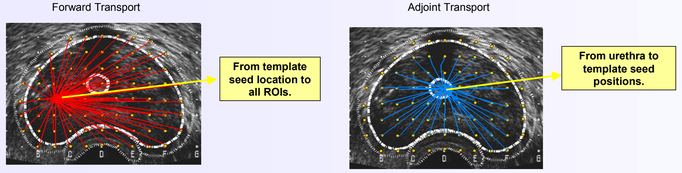
Methods and Materials: The Region of interest volumes from the patient's Ultrasound image are 36cc for the prostate, 1.6cc for the contoured urethra, and 4.3cc for the contoured rectum. The source placement is guided using ultrasound template grid and source-type and seed-position selection is based on sensitivity distribution obtained from adjoint dose matrices of directional and isotropic sources. 0.43 mCi I-125 sources are used. Greedy heuristic algorithm, based on the region of interest adjoint functions, is employed for optimization of the treatment plans. Dose volume histograms and a list of evaluation parameters are quantified to assess the quality of treatment plan generated using directional seeds.

Results: For the mixed source treatment plan, the target coverage as indicated by V100, is 98.44. Dosimetry of urethra indicated by V360, V125 and D90 is 0.00, 7.03, 139.75 Gy respectively. Dosimetry of rectum as quantified by V90 and D90 is 20.54 and 55.37 Gy respectively. the D90 for normal tissue region is 30.11 Gy.

Conclusions: Automated 3-D greedy heuristic optimization based on adjoint sensitivity fields is used to generate optimized mixed source treatment plans utilizing the directional and isotropic sources. Improved urethra and rectum sensitive structure sparing is demonstrated by Interstitially applicable partially shielded directional I-125 sources.

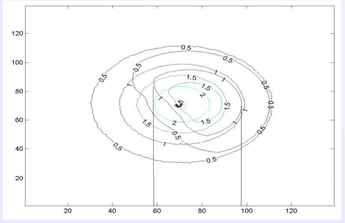
## INTRODUCTION

### Adjoint particle transport in sensitivity profile generation for seed positions




- In Adjoint transport hypothetical tissue response particles emanate at the detector location and are transported in the source field. The tissue response is designated as adjoint particle, $S^+ = E * \mu_{en}(E)/\rho * C$. These adjoint particles deposit response at source locations resulting in Adjoint flux Distribution of $S^+$, $\Phi^+$.
- The adjoint flux distribution is used to predict the response of the receptor to an arbitrary source at any position in the system. Hence, the adjoint distribution acts as an "importance function".

### Directional seed and Greedy Heuristic Optimization



Isodose profile of 0.546 U $^{125}$I isotropic and directional source

The directional dose distribution facilitates placement of directional sources in the regions, which are in close proximity to rectal wall and urethra delivering dose selectively. Notice the matched dose distribution on the unshielded side for easy replacement.

With additional parameter of directional seed's orientation introduced into optimization the optimization problem can become very time consuming.

The greedy heuristic (GH) optimization based on ROI adjoint functions offers the advantage of pre-computed sensitivity profile of source-space by the use of adjoint-ratio.

The GH optimization algorithm has been utilized for special applications like generating treatment plans for multi-species interstitial implant brachytherapy.

## METHODS AND MATERIALS

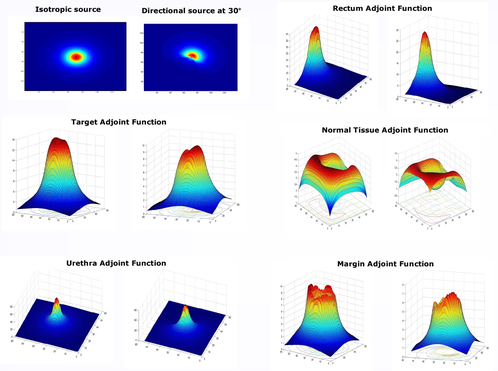
The Greedy Heuristic (GH) algorithm based on ROI adjoint functions is employed to generate the seed and needle configuration for treatment plan utilizing only isotropic seeds and for treatment plan using mixed seed using 0.43mCi I-125 radioactive sources.

The "adjoint function" for a region of interest (ROI) or the importance function, is defined as the sensitivity of the average dose in the ROI to a unit-strength brachytherapy seed at a seed position.

$$D^+_{jROI} = \sum_{i \in ROI} D^+_{ji} / V_{ROI}$$

$D^+_{jROI}$ is in [Gy/Su], where Su designates one source unit of 0.546 U $I^{125}$ permanent seed

Figures below show sensitivity profiles generated using isotropic source and directional source at 30° orientation:




A high adjoint function value of an ROI means high sensitivity for dose delivery to the ROI from the seed at that seed position

An adjoint ratio, for source position j is the ratio of the weighted adjoint functions of the sensitive structures to the adjoint function of the target region.

Isotropic seed adjoint ratio R(j) and directional seed adjoint ratio R(j,θ) are:

$$R(j) = \frac{W_{Ur} \cdot D^+_{j,Ur} + W_{Re} \cdot D^+_{j,Re} + W_{Ma} \cdot D^+_{j,Ma} + W_{No} \cdot D^+_{j,No}}{D^+_{j,Ta}}$$

$$R(j,\theta) = \frac{(W_{Ur} \cdot D^+_{j,\theta,Ur} + W_{Re} \cdot D^+_{j,\theta,Re} + W_{Ma} \cdot D^+_{j,\theta,Ma} + W_{No} \cdot D^+_{j,\theta,No})}{D^+_{j,\theta,Ta}} \quad (\Delta\theta = 30°)$$

Seed positions are ranked from lowest adjoint ratio to highest adjoint ratio prior to start of optimization. The Ranking matrix contains information of preferred orientation and seed type.

Under the "greedy criterion" of minimum adjoint ratio, GH selects a seed position that has a minimum adjoint ratio in the search space.

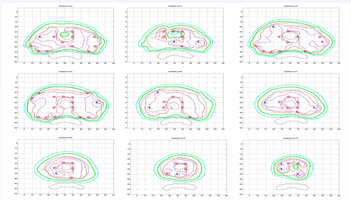
GH is fast because of this immediate decision. Seed positions are selected one-by-one until a termination criterion is reached.

Patient data: The ROI volumes from the patient's Ultrasound image are 36cc for the prostate, 1.6cc for the contoured urethra, and 4.3cc for the contoured rectum.

## RESULTS AND DISCUSSION

Mixed-seeds plans are compared with the isotropic seeds plan. All treatment plans are generated using automated 3D-GH algorithm.

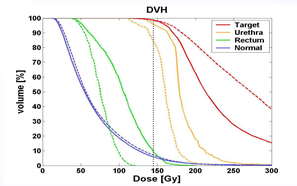
### ISODOSES AND SEEDS DISTRIBUTION



Isodoses:
Green is V100
red is V150
magenta is V200

- GH selects the preferred orientation of directional seed near sensitive structures for efficient sparing. Notice the orientation of the shielded side near the sensitive structures.
- The seed distribution has a marked preference towards the selection of directional seed, thus resulting in increased hot spots in the target. This preference is attributed to the lower dose deposited by the directional seed that results in lower adjoint ratios in comparison to the isotropic seed adjoint-ratio.

### DOSE-VOLUME HISTOGRAM COMPARISON




Bold curves are the isotropic seeds plan dotted curves are the mixed seeds plan.

Prescribed dose is the vertical black dotted line.

Mixed seeds plan results in very efficient sparing of the rectum and urethra sensitive structures. Target irradiation is more than adequate. Normal tissue exposure is similar in both the treatment plans.

Considering Urethra as part of the "central prostate region" the shoulder part of the mixed-seeds-plan urethra DVH should be raised to cover more volume with the prescribed dose.

### DETAILED EVALUATION PARAMETERS

| | Target | | | | | | |
|---|---|---|---|---|---|---|---|
| | V100 [%] | V150 [%] | D90 [Gy] | DNR | CN | NumS | NumN |
| Isotropic seeds plan | 98.3 | 44.08 | 172.98 | 0.45 | 0.69 | 51 | 22 |
| Mixed seeds plan | 98.44 | 71.65 | 185.5 | 0.73 | 0.67 | 79 | 25 |

Both plans result in at least 98% of the target. As indicated by the DNR, dose uniformity in the target degrades in mixed seeds plan. As indicated by the CN, conformity of the dose is comparable in both treatment plans.

## RESULTS AND DISCUSSION

| | Urethra | | | Rectum | | | Normal Tissue |
|---|---|---|---|---|---|---|---|
| | $V360_{Ur}$ [%] | $V125_{Ur}$ [Gy] | $D90_{Ur}$ [Gy] | $V90_{Re}$ [%] | $D10_{Re}$ [Gy] | $D90_{Re}$ [Gy] | $D90_{No}$ [Gy] |
| Isotropic seeds plan | 0.0 | 39.62 | 164.13 | 69.25 | 144.93 | 61.13 | 27.19 |
| Mixed seeds plan | 0.0 | 7.03 | 139.75 | 20.54 | 98.7 | 55.37 | 30.11 |

There is remarkable reduction in irradiation of rectum and urethra.

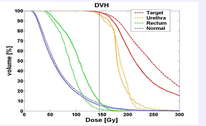
## CONCLUSIONS

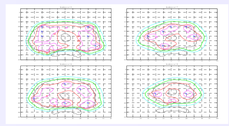
- Used automated 3-D greedy heuristic optimization based on adjoint sensitivity fields along with directional sources for interstitial prostate implant brachytherapy
- Adequate target coverage
- Very efficient rectum sparing
- Improved urethra sparing
- Directional seeds brachytherapy can be used for LDR BT of the prostate.

## FURTHER WORK

### Toward reduction of hot spots

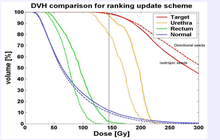
- Adjusting weights on the isotopic seeds adjoint ratio R(j) as Wur=Wno=0.5, Wta=Wre=1.0



### Toward using a faster greedy heuristic (GH)

- GH with a "dynamic greedy-criterion"
- Current version selects the most beneficial seed positions and does not have needle constraints.




| Current Greedy Heuristic | | | |
|---|---|---|---|
| | NumS | NumN | Time |
| Isotropic seeds plan | 51 | 22 | 12.8 s |
| Mixed seeds plan | 79 | 25 | 12.1 m |

| Faster Greedy Heuristic (No needle constraints) | | | |
|---|---|---|---|
| | NumS | NumN | Time |
| Isotropic seeds plan | 66 | 35 | 2.1 s |
| Mixed seeds plan | 89 | 31 | 13.3 s |

Using 1.6GHz Intel Pentium (M) processor

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