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Fast automated multi-criteria planning for HDR brachytherapy explored for prostate cancer

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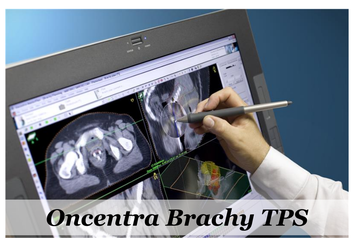
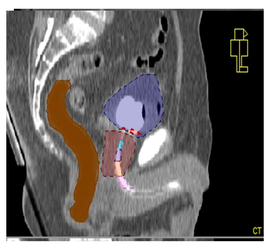
Introduction

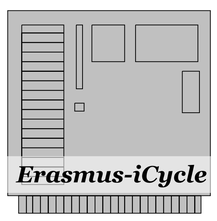
We developed an automated multi-criteria treatment planning workflow for high dose rate (HDR) brachytherapy, compatible with our clinical treatment planning system (TPS). The aim is to establish planner-independent, enhanced plan quality and short optimisation times, allowing daily online plan generation.

Workflow



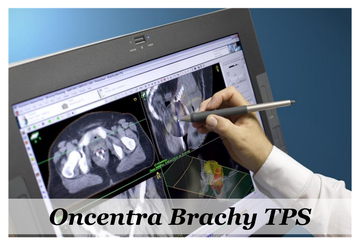


Export CT + contours + dwell positions from Oncentra to Erasmus-iCycle



Automatically optimise dwell times

Export dwell times to Oncentra TPS



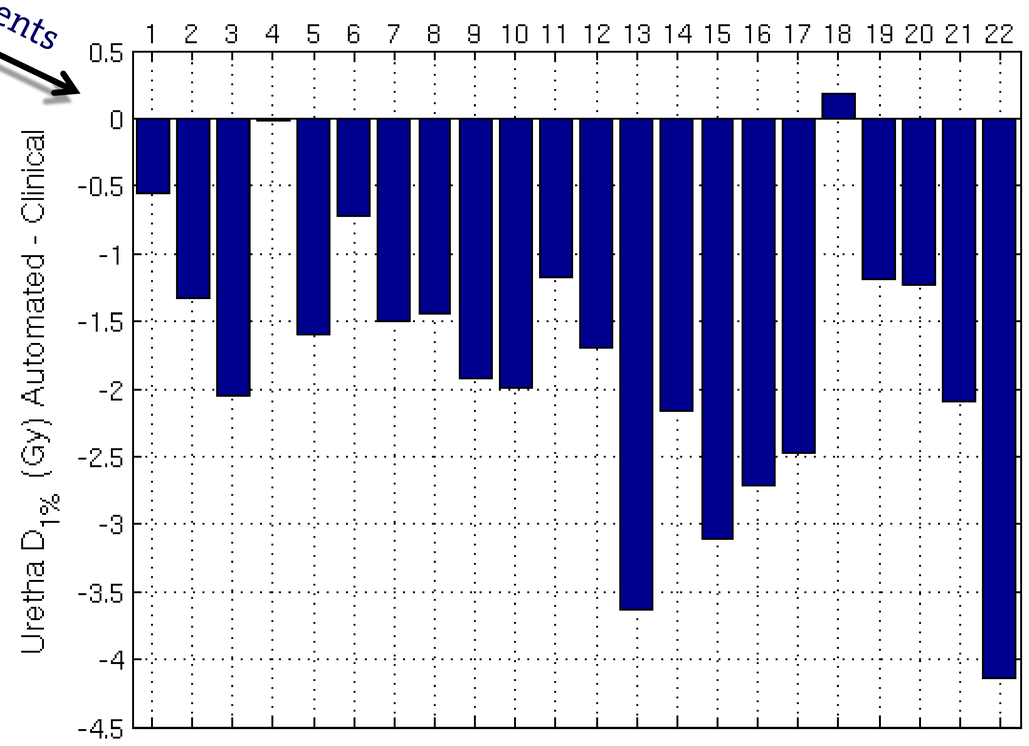
Forward dose computation, obtain DVHs and evaluate plan

IOI	Dose [%]	Dose [cGy]	Volume [%]	Volume [ccm]
ITVB	100.00	150.00	90.11	1.85
Cervix	100.00	150.00	100.03	19.06
ITVD	100.00	150.00	96.22	28.92
dR-CTV	100.00	150.00	99.22	18.99
R-CTV	100.00	150.00	71.08	55.59
Bladder	75.00	112.50	2.52	1.13
Rectum	75.00	112.50	3.41	0.83

Do for 22 patients

Result: Urethra $D_{1\%}$ dose reduction

Difference in Urethra $D_{1\%}$ between the clinical and the automated plan



Conclusion

Fast, automated multi-criteria treatment planning for prostate HDR brachytherapy is feasible. For 21/22 patients, the autoplan met the coverage condition for the prostate with consistent reduction in near-maximum urethra dose (most important clinical objective). Plan optimisation took less than 10 seconds on average.

Background and protocol

The test cohort consisted of 22 planning CTs with catheter reconstructions and delineations for low-intermediate risk prostate cancer patients who were previously treated with 4 x 9.5 Gy HDR brachytherapy. Data of 5 patients was used to configure the autoplanning system, Erasmus-iCycle[1].

The fixed configuration was then used to also automatically generate treatment plans for the other 17 patients. Automatically generated plans were compared to the corresponding clinical plans. All evaluations were performed in the clinical TPS.

Clinically applied hard constraints were used for automated planning: D_{1cc} < 80% of the prescribed dose (PD) for rectum and bladder, and $D_{1\%}$ < 120% of PD for the urethra. The objectives in order of priority were to 1) prostate $V_{100\%}$ = 95%, 2) minimise urethra $D_{1\%}$, 3) improve conformality.

The dwell times for the autoplan are then exported to Oncentra, and the dose is recomputed for evaluation. For comparison, both the clinical and automated plans were rescaled to exactly match 95% coverage, unless one of the other constraints were met first.

Convex problem solving

The automated planning configuration was embedded in our non-linear convex optimisation framework[2], which has the advantage of fast convergence to a globally optimal solution. Hereto, the dose-volume constraints (D_{1cc} < 80%) on the rectum and bladder were reformulated to a convex approximation, using the LTCP[3] cost-function with parameters 30.6 Gy and cell sensitivity of -0.6.

For the objectives, the urethra $D_{1\%}$ was optimised by stepwise reducing the urethra maximum dose, followed by maximising the prostate coverage. When the coverage reached 95%, the urethra maximum and prostate coverage are kept as a constraint, followed by a minimisation of the dose at 7 mm distance of the prostate to improve conformality.

Results

Automated plan optimisation took on average 9.8 seconds (range: 2.7 – 21.6 seconds), including computation of the dose kernels. Computations were performed on an Intel Core i7-7700.

The autoplans of 21/22 patients showed 95% tumour coverage within the imposed hard constraints. Coverage of patient 4 was lower than desired (94.8%), though slightly higher than in the clinical plan (94.5%), both due to the urethra constraint. For 21/22 patients the autoplan showed a reduction in the most important OAR objective, urethra $D_{1\%}$ (see figure above). The absolute mean and maximum reductions were 1.8 Gy and 4.1 Gy, respectively.

References

1. Breedveld S., Storchi P. Voet P. & Heijmen B. (2012) iCycle: Integrated, multicriterial beam angle, and profile optimization for generation of coplanar and noncoplanar IMRT plans Med. Phys. 39 951-963 (DOI)

2. Breedveld S., Van den Berg B. & Heijmen B. (2017) An interior-point implementation developed and tuned for radiation therapy treatment planning Comput. Optim. Appl. 68 209-242 (DOI)

3. Alber M. & Reemtsen R. (2007) Intensity modulated radiotherapy treatment planning by use of a barrier-penalty multiplier method. Optim. Methods Softw. 22 391-411 (DOI)