Retrospective Evaluation of Thermal Coverage by Thermobrachytherapy Seed Arrangements of Clinical LDR Prostate Implants

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Outline

- Description of thermobrachytherapy (TB) seeds
- Selection and optimization of thermal computation model
- Use of past patient plans to find realistic thermal distributions of TB implants
- Temperature volume histograms obtained from thermal distributions
- Current research directions
- Conclusion

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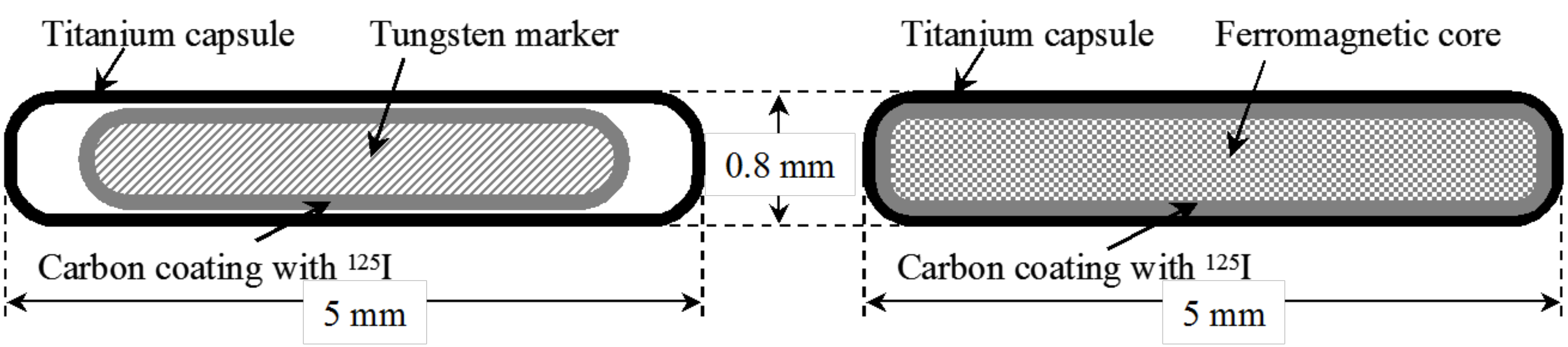
Thermobrachytherapy (TB) seed

- Based on BEST Model 2301 LDR seed
- Tungsten radiographic marker replaced with Ni-Cu ferromagnetic core
  - Curie transition of Ni-Cu alloy for self-regulation
- Several hyperthermia sessions with magnetic coil



BEST Model 2301 Seed

Ferromagnetic core Seed

Towards application in the clinic

- TB seed intended as an alternative to the standard LDR brachytherapy seed
- Fast dropoff of interstitial hyperthermia indicates use of many seeds during implantation
- Retrospective use of plan geometry for patients previously treated with ordinary seeds
  - Seed positions reproduced in finite element analysis solver COMSOL Multiphysics 4.4

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Model optimization

- Variety of algorithms to model thermal distributions of interstitial hyperthermia seeds during a heating session
  - Necessary to balance problem size, simulation time, and solution accuracy
  - Coil current modelling, explicit magnetic field, power vs. temperature, constant-temperature
- Optimization of size of mesh elements

Mesh complexity studies

- Temperature at thermal equilibrium for single seed
- 2D axisymmetric "gold standard" compared against 3D simulations of varying mesh size
- Mesh element size needed in seeds found to be too small for explicit magnetic field modelling
  - Necessary mesh much less stringent for surrounding tissue

Model and seed mesh complexity	% Difference in temperature rise from 2D "gold standard"
Explicit H-field, 2.4×10^2 elements/mm^3	34%
Explicit H-field, 1.0×10^3 elements/mm^3	10%
Explicit H-field, 5.7×10^4 elements/mm^3	0.01%
Power vs. temperature, 1.0×10^3 elements/mm^3	4.4%

Power vs. temperature approximation

- Use of power of each seed component as a function of temperature
- Single 2D axisymmetric seed with finest practical meshing modelled with explicit magnetic field, and P vs. T for each component extracted
  - Process repeated for each magnetic field strength used
  - Equations for P vs. T at each H-field empirically found
- Uniform blood perfusion considered
  - Range of 10 – 20 mL per minute per 100 g

Patient selection

- 3 past UTMC patients chosen with volumes covering a range typically seen in the clinic
  - Patient 1: 37 cm^3
  - Patient 2: 44 cm^3
  - Patient 3: 24 cm^3
- Further patient plans currently under study
- Study done these patients' implant geometries with varying blood perfusion rates

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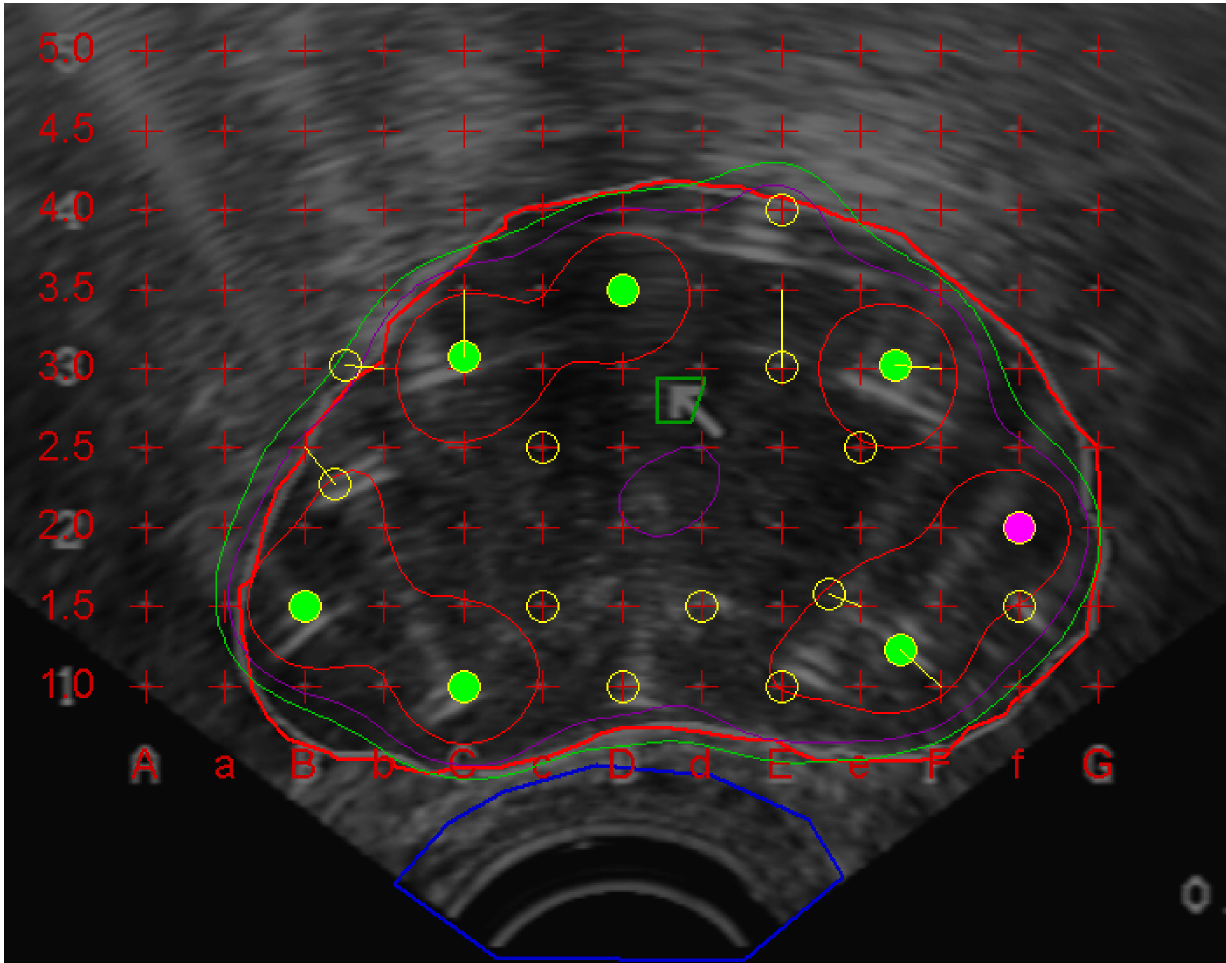
Original treatment plans

- Planned in Variseed 8.0
- BEST 2301 seeds, 0.398 to 0.476 U
- Modified peripheral loading



Patient plan conversion

- Geometry of previous treatment plans with ordinary seeds imported into COMSOL with TB seeds
- US images of previous plans recontoured in MIM 6.2.2, and contours exported as a DICOM file
- Custom in-house software used to combine COMSOL output and contour data to generate temperature volume histograms (TVHs)

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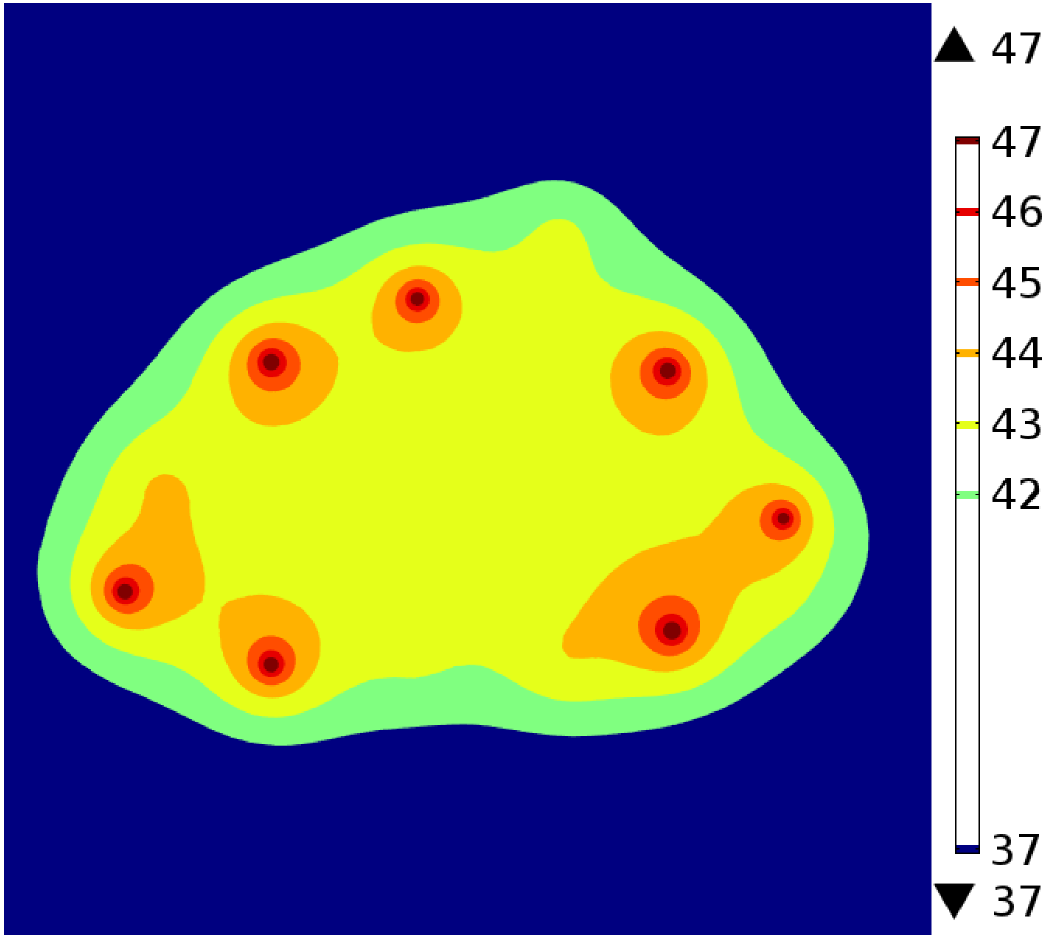
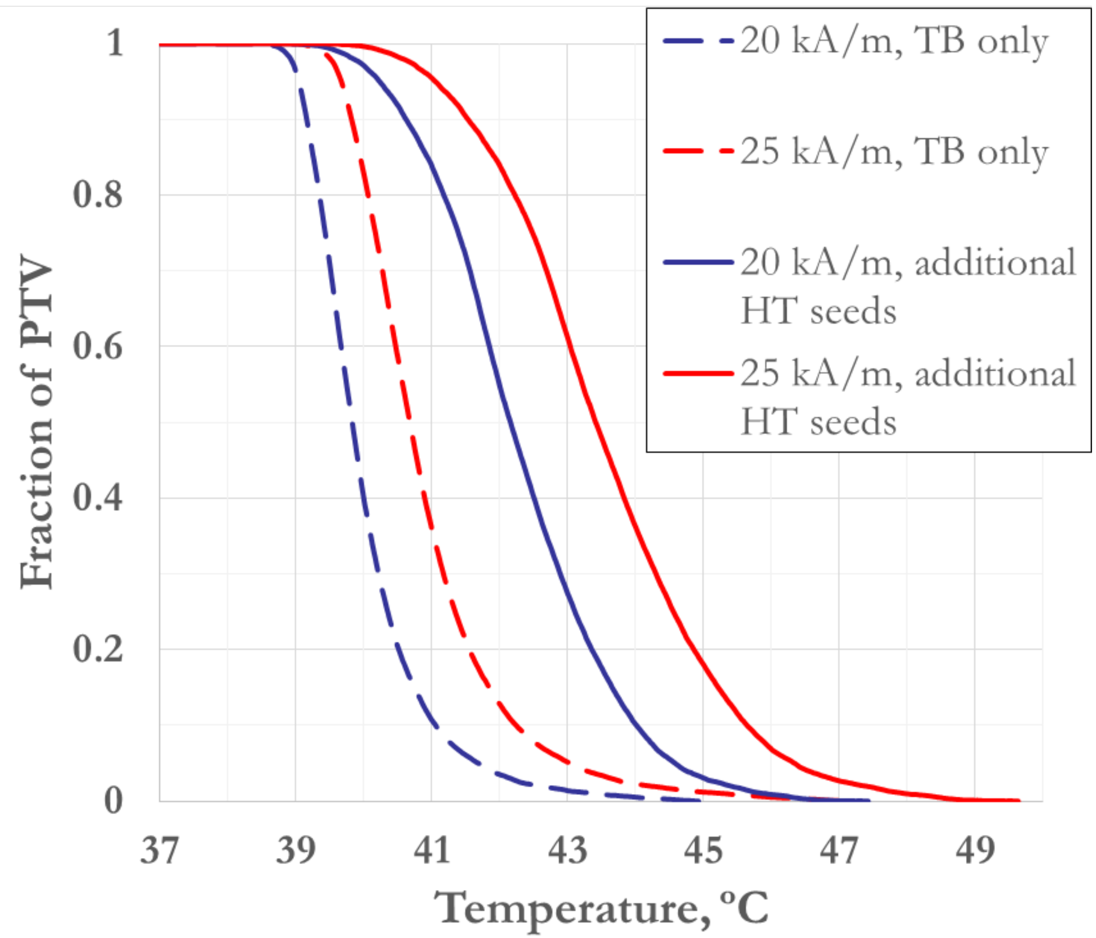
Patient 1, thermal distribution

- With low blood perfusion, use of only TB seeds adequate
  - Figure: H-field amplitude = 20 kA/m, Perfusion rate = 3 mL / minute / 100 g
- More seeds needed for blood perfusion rates typical for prostates
  - ~15 mL / minute / 100 g
- Solution: use of HT-only seeds in unused positions in implantation needles



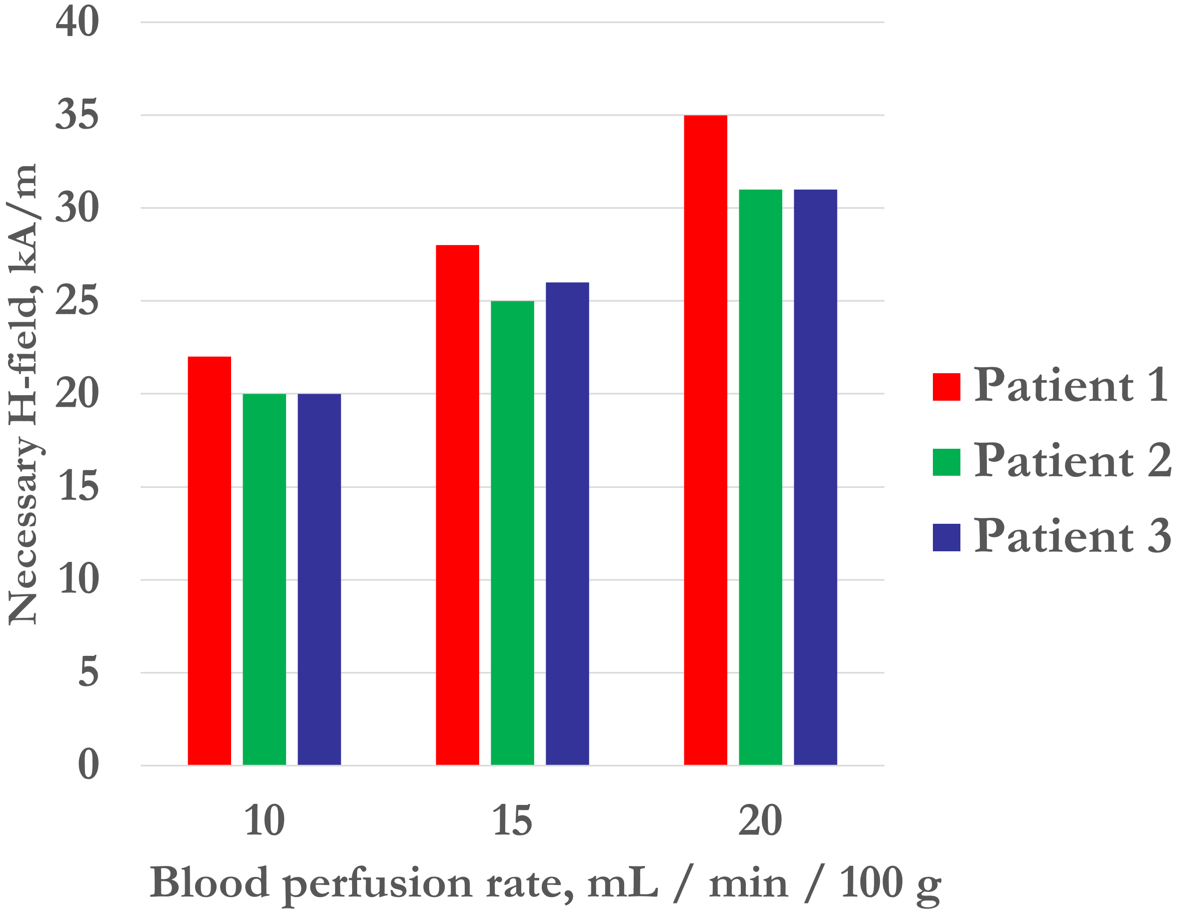
TB and hyperthermia-only seeds

- Proposed hyperthermia-only seeds identical to TB seeds, but non-radioactive
  - Same design to simplify manufacturing process
- Greater number of seeds considerably improves coverage and heating efficiency
  - Figure: Patient 1, blood perfusion rate of 15 mL / minute / 100 g



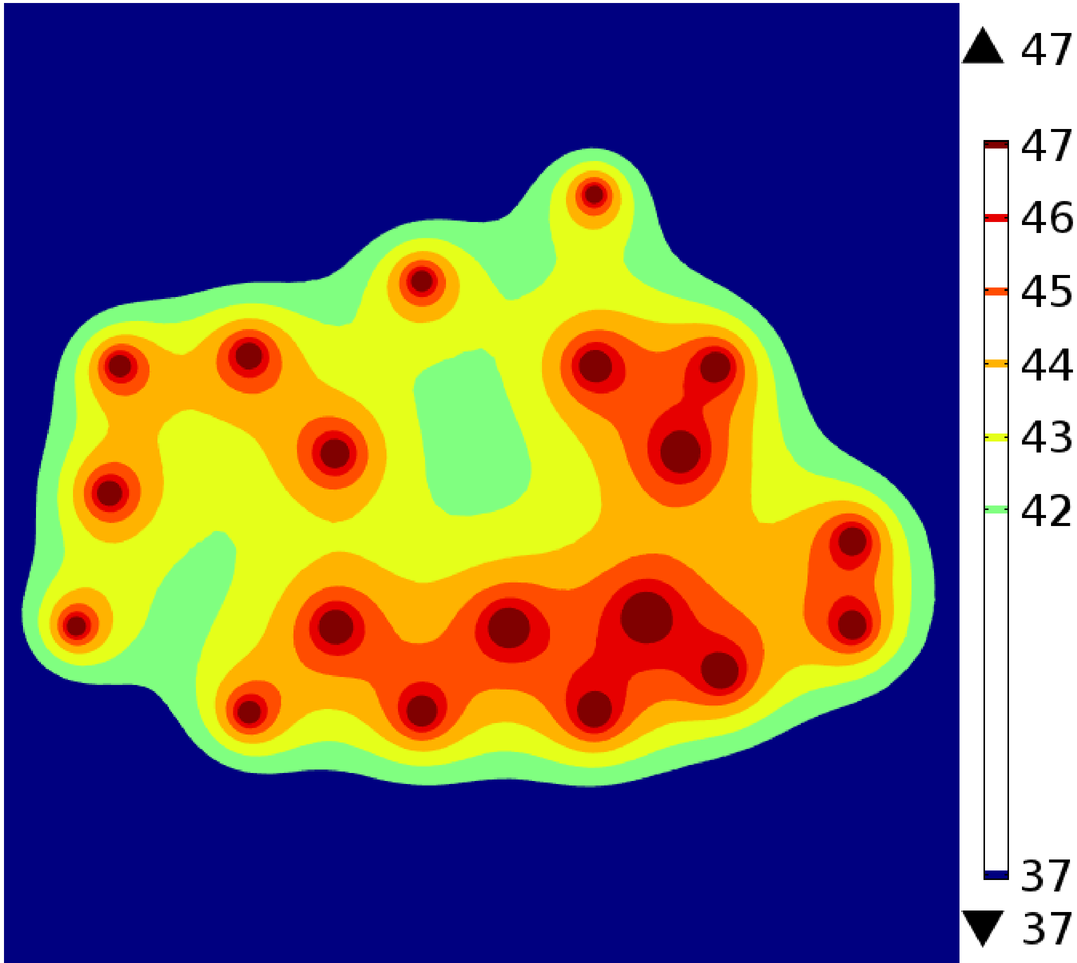
TVHs of patients studied

- Determination of necessary H-field amplitude to obtain T90 of 42°C
  - 42 °C considered a radiosensitizing temperature
  - Also provides a significant thermal dose



Addition of extra needles

- Calculated thermal distribution indicates that patient 1 can use additional needles for better thermal coverage
- Use of 1 or 2 extra needles decreases the necessary magnetic field amplitude
  - 15 mL/min/100g:
    - 28 kA/m to 26 kA/m for 1 additional needle
    - 28 kA/m to 25 kA/m for 2 additional needles
- Improvement in coverage should be weighed against trauma of additional needle



Current research directions

- Accurate measurements of magnetic relative permeability at magnetic fields used
- Modelling of discrete vasculature
- Acquisition of thermal distributions and TVHs for more past patients
- Analysis of effects of seed movement/migration
- Monte Carlo study of increased interseed effect on radiation dose
- Animal studies

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Conclusion

- Patient-specific thermal distributions generated by a novel dual-modality implant have been characterized for the first time
- A semi-automated system has been developed to obtain thermal distributions and TVHs from given LDR brachytherapy plans
- Potential issues in the clinical application of this implant have been identified and addressed

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Thank you

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