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

Gregory R. Warrell
Diana Shvydka, PhD
E. Ishmael Parsai, PhD
University of Toledo
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
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

![Diagram of BEST Model 2301 Seed vs 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
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

<table>
<thead>
<tr>
<th>Model and seed mesh complexity</th>
<th>% Difference in temperature rise from 2D “gold standard”</th>
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<tbody>
<tr>
<td>Explicit H-field, 2.4 × 10^2 elements/mm³</td>
<td>34%</td>
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<tr>
<td>Explicit H-field, 1.0 × 10^3 elements/mm³</td>
<td>10%</td>
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<tr>
<td>Explicit H-field, 5.7 × 10^4 elements/mm³</td>
<td>0.01%</td>
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<tr>
<td>Power vs. temperature, 1.0 × 10^3 elements/mm³</td>
<td>4.4%</td>
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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
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)
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
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
Selected references


Thank you