Quantitative relationship between seed placement accuracy and dosimetry in PBSI

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Background

- **Permanent breast seed implant (PBSI) brachytherapy** is a single day, outpatient radiotherapy option for qualified early stage breast cancer patients
- Target coverage is not strongly correlated with seed placement accuracy[1,2]: there are many contributing factors

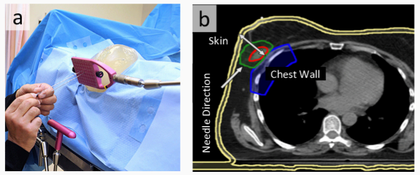

Figure 1: a) PBSI implant showing needle insertion through template. b) Axial CT slice showing the CTV, PTV, and direction of needle insertion.

Purpose: To derive a quantitative relationship between random and systematic seed placement errors and post-implant dosimetry

Methods

- Clinical target volumes were modelled as spheres with volume 1.4, 9.2, and 20.6 cm^3 to span clinical range of volumes, PTV 10 mm isotropic expansion of CTV
- Eight clinically-acceptable treatment plans inverse planned[3] for each CTV
- Monte Carlo simulations performed to produce many potential "delivered dosimetries"

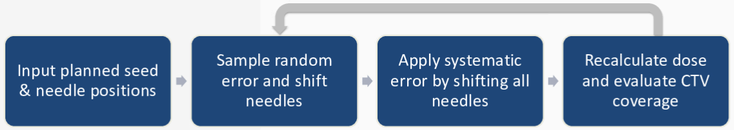

Figure 2: Simulation program structure

- Regression performed to derive two second order polynomial equations relating magnitude of systematic and random error to median CTV $V_{90\%}$ coverage: One with four terms and one with six
- Both equations evaluated for random and systematic errors up to 12 mm. Difference between equations calculated
- Magnitude of difference evaluated for clinically expected uncertainty to determine if the simpler four-term fit sufficiently describes the data

Results: Average CTV

- 1000 simulations per combination of implant uncertainty were performed for the average CTV
- Median CTV V90% related to random error magnitude (r) and systematic error magnitude (s) by:

Six-term equation (R^2 = 0.98):

$$V_{90\%}^{median} = 95 + 1.9r + 0.97s - 0.18r^2 - 0.064\,s^2 - 0.1rs$$

Four-term equation (R^2 = 0.92):

$$V_{90\%}^{median} = 102 - 0.059r^2 - 0.011s^2 - 0.024rs$$

- All simulation data points within 4.0% and 5.6% for six-term and four-term equations respectively

Difference between equations: Impact of fewer terms

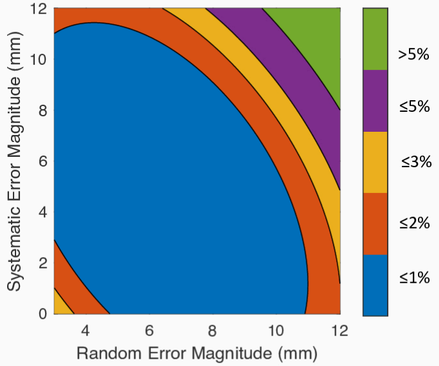

Figure 3: Absolute value differences in CTV $V_{90\%}$ predicted by the 4-term equation vs. the 6-term equation, binned according to the color bar.

- The two fits were evaluated for varied random errors (r) and systematic errors (s)
- The $V_{90\%}^{median}$ from the six-term equation was subtracted from the $V_{90\%}^{median}$ predicted by the four-term equation and a map of the differences is shown in figure 3
- For clinically observed random and systematic errors, the equations are within 2% of each other

Results: Small and Large CTV

- The mean difference between the two fits for the large and small CTV respectively are mean (standard deviation) 0.17% (0.35%), and 0.18% (1.76%)
- Over the clinical range, the two curves are different by less than 1% and 4% for the large and small CTV respectively

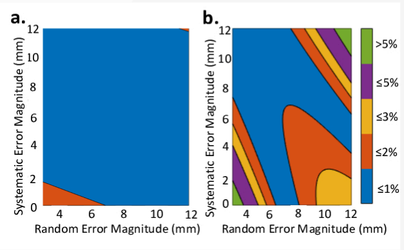

Figure 3: *Absolute value differences in CTV $V_{90\%}$ predicted by the 4-term equation vs. the 6-term equation for large (a) and small (b) CTV.*

Results: Clinical Uncertainty

- For a random error magnitude of 7 mm, and a systematic error magnitude of 8 mm, representing clinical implant accuracy, the differences between the two equations are 0.6%, 0.5%, and 0.3% for the small, average, and large CTV
- For all three CTVs, the simulation data point is within 1.6% of both six and four-term equations at clinical uncertainty

Discussion and Conclusions

- For all CTV volumes, the six-term equation is better fit to the simulation data, however the differences between the CTV $V_{90\%}$ values predicted by the equations are small
- For all six-term and four-term equations, the maximum absolute residual value is less than 6%
- Fit quality decreases for the small CTV, and larger variation is observed
- Over the range of clinically probable uncertainties, the four-term equation is simpler and a good surrogate for the more complex fit

For most situations, the four-term equation provides a simpler alternative to estimate target coverage for a given implant accuracy.

[1]Morton, D., Hilts, M., Batchelar, D., & Crook, J. (2016). *International Journal of Radiation Oncology Biology Physics*, 95(3), 1050–1057.
[2]Watt, E., Skarsgard, M., Roumeliotis, M., Husain, S., & Meyer, T. (2019). *Journal of Contemporary Brachytherapy*, *11*(1), 61–68.
[3]Roumeliotis, M., Yates, B., Watt, E., Frederick, A., & Meyer, T. (2018). *Brachytherapy*, *17*(3), 615–620.

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