Application of Monte Carlo algorithms to the calculation of dose and RBE for low energy brachytherapy

Document status and date:
Published: 01/01/2015

DOI:
10.26481/dis.20151118sw

Document Version:
Publisher's PDF, also known as Version of record

Chapter 7:
Valorization addendum

Innovation

This thesis served to address the complexities inherent to dose calculation, dosimetry and radiobiological effectiveness with respect to electronic brachytherapy sources, in particular the Xoft Axxent.

Model-based dose calculation algorithm

The AAPM TG-56, which provides a code of practice for brachytherapy quality assurance, recommends a dose delivery accuracy of 5-10% to a target volume. The recommendations also state that dose distributions calculated using treatment planning software should be accurate to within ±2%. While certain dosimetry protocols (TG-43) assume that the patient can be assumed to be a water-sphere for dose calculation purposes, the complex patient composition and geometry present a challenge for low energy photon sources which are sensitive to composition variations and backscattering. The quantifying of these heterogeneities in chapter 2 and 3 can be used to improve dose delivery accuracy.

The combination of techniques for breast tissue segmentation and CAD-mesh applicator model allows more accurate assignment of heterogeneous tissues to patient geometries as well as modeling of sub-voxel size applicator features. A deformed inflatable balloon applicator would be difficult to model in Monte Carlo platforms using CSG.

Relative biological effectiveness

The low variability of radiobiological effectiveness in low energy brachytherapy for tissues calculated in chapter 5 demonstrate a lack of influence of beam hardening on radiation quality. This may reduce the complexity of low energy brachytherapy sources in terms of radiobiological considerations.
The similarity in RBE for electronic brachytherapy sources for different operating voltages (40kVp and 50kVp) seems to indicate that lower peak voltages does not confer a higher biological effectiveness.

EPR Dosimetry

The difficulties associated with in-vivo dosimetry around brachytherapy sources are well-established. Measurement of absorbed dose for low energy photons present extra challenges due to the material heterogeneities that enhance the dose differences between tissues more than at higher energies.
The results in chapter 4 show the viability of EPR Lithium-formate dosimetry at low energies due to the favourable dose response at distances close to the source. Lithium formate dosimeters are materially-equivalent to water and are sufficiently small, making them suitable for brachytherapy dosimetry.

Clinical Relevance

The techniques for dose calculations and breast tissue segmentation described in chapter 3 can significantly improve dose calculation accuracy and may serve as a foundation for a Monte Carlo-based treatment planning system in the future. The lower-than-expected organ-at-risk dose in certain patients may permit dose escalation in certain patients that would be difficult to predict in TG-43-based planning systems.

Results describing the influence of trace elements on dose distributions for low energy sources can be incorporated into more accurately quantifying dose uncertainty. More accurate elemental tissue composition data may be obtained in the future and allow a further refinement of this uncertainty.

Chapter 5 describes predicts the iso-effectiveness between electronic brachytherapy, in terms of radiobiological effectiveness. While source-based RBE is not yet a criterion for photon radiotherapy (RBE assumed to be 1 for all sources), the various RBE described in tissue may be useful for incorporation into future treatment planning systems.

The clinical benefits of small brachytherapy dosimeters, described in chapter XX, are apparent given the difficulties in accurate dosimetry in low energy brachytherapy. Accurate pre-treatment planning and post-treatment evaluation using CT planning may not be possible, particularly in intra-operative radiotherapy using electronic brachytherapy sources. EPR-based dosimeters potentially offer greater re-usability and accuracy at shorter distances compared to EBT-based film.

Societal relevance

Brachytherapy is a radiotherapy treatment modality, widely used due to advantages it offers in treatment and cosmetic outcome. Brachytherapy treatment planning has not kept up with radiotherapy in terms of dose calculation and has only recently started to move away from water-based models.

The scientific findings discussed in this thesis can be used to improve dose calculation accuracy by properly accounting for applicator and tissue heterogeneities present, in particular, in breast patients. Improved accuracy may be useful for determining the possibility of dose escalation which can increase the dose to clinical relevant regions while maintaining an acceptable dose to organs at risk. The findings also serve to improve/refine dosimetric uncertainty in low energy brachytherapy in general.

Commercial Relevance

EPR dosimetry may become a standard quality assurance evaluator in low energy brachytherapy. The Monte Carlo techniques used may also be incorporated into a future Treatment planning system.