Optimisation Planning for Photodynamic Therapy

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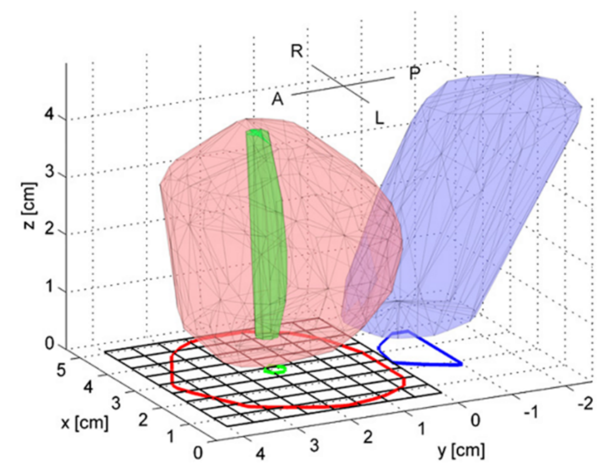
Challenge

Photodynamic therapy (PDT) has been successfully used as a light-based treatment for superficial cancers of the skin, oesophagus, upper respiratory tract, head and neck, and other locations where surface illumination is possible. However, treating deep-seated tumours that require interstitial light delivery has been hampered by the very steep attenuation of light. New light delivery technologies providing greater penetration depths have prompted a rebirth in the field of interstitial PDT. Ideally the light dose delivered is tailored to match the size and shape of the targeted tumour, in order to maximise treatment of tumour tissue while minimising impact on healthy tissue. Optimization of treatment plans has to consider numerous factors, including optical properties and response of the tissue, temporal changes in the shape of the target tissue, variations in blood volume and oxygenation, and placement of the light diffuser. Understanding the implications of uncertainties in such factors would help inform treatment planning, whether it is done before or during the treatment.

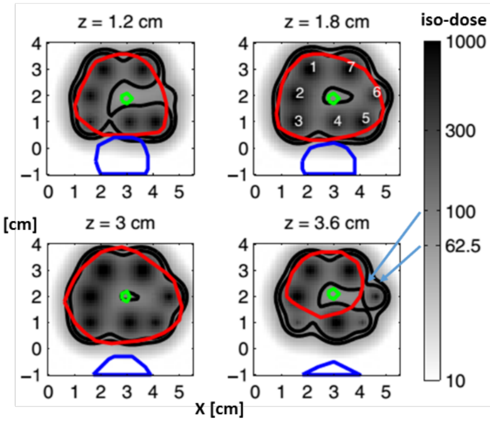
Methodology

Prostrate treatment was used as the test case for optimising the planning of PDT. MRI slices through the prostate of a patient suited for PDT were used to construct a model of the target tissue in which positions along the z-axis were identified for the placement of cylindrical light diffusers. Light dose arriving from the diffusers at specific points were calculated using standard diffusion theory. The optimal length for diffusers and the optimal emission profile along their length were solved for four optical properties covering the range of effective attenuation by the prostrate tissue and for different numbers and positions of diffusers ranging from 5 to 21. The solutions providing these customised emission profiles (tailored diffusers) were compared to those in which the diffusers provided fixed emission profile along their length (flat diffusers).



Geometry of the modeled prostate (red) with the urethra (green) and rectum (blue)

Results and Impact



Light exposure maps on the xy plane from 7 diffusers (red = prostrate; green = urethra; blue = rectum)

The main impact of increasing the number of diffusers up to optimal is to improve prostate coverage without over-dosing more rectum. More diffusers result in more homogeneous prostate coverage. Variations in diffuser placement have little effect on light dose distribution, particularly in terms of prostate coverage.

For all scenarios rectal over-dosing decreases by about 30% for every five additional diffusers added until the optimum is reached. In contrast, increasing the number of diffusers only has a positive effect for the urethra when tissue has high light attenuation. For all numbers of diffusers examined, prostate coverage and sparing of the rectum and urethra appear similar between tailored and flat diffusers. Regardless of the diffuser type, improving dose distribution by increasing the number of diffusers reaches a plateau dependent on tissue attenuation. Tailored diffusers with lengths set to the length of the prostate performed as well as or better than tailored or standard diffusers which had their length also optimized.

Our results for prostrate treatment indicate that improvement offered by tailored diffusers will likely be masked by the effects of the variations of optical properties found in clinical practice. Although prostate PDT does not profit significantly from using tailored diffusers, other applications warrant testing to assess whether tailored diffusers can deliver more conformal light doses and thus better treatment. In particular, optimisation of interstitial light delivery should be considered for locations with more complicated geometries, such as tumours of the brain or head and neck.

Rendon, A.; Beck, J.C.; Lilge, L. (2008) Treatment planning using tailored and standard cylindrical light diffusers for photodynamic therapy of the prostate. Physics in Medicine and Biology **53**: 1131–1149.

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