

## THE IMPACT OF INPUT PARAMETERS IN NUMERICAL PHASE/AMPLITUDE OPTIMISATION FOR HYPERTHERMIA TREATMENT PLANNING

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### Introduction

In regional hyperthermia, finding optimal phase/amplitude settings for the antennas is by no means a trivial task, since the number of degrees of freedom increases with the number of antennas. At our institute hyperthermia treatments are performed using the 70 MHz AMC-4 waveguide system, with 4 separately adjustable amplitudes and phases. Numerical optimisation techniques are useful to obtain optimal phase/amplitude settings for the applicators to achieve maximal tumour heating without toxicity to normal tissue.

### Purpose

This study investigates the impact of user-defined constraints and objective functions on the results of temperature based phase/amplitude optimisation.

### Methods

Treatment planning was based on a CT scan of a patient with oesophageal cancer in treatment position. The data set was segmented semi-automatically in the tissue types fat, muscle, bone, lungs and inner air. The tumour, heart, aorta and spinal cord were outlined manually by the radiation oncologist. The data set was downsampled to a resolution of  $1 \times 1 \times 1 \text{ cm}^3$  and the E-Fields were calculated using the finite difference time domain (FDTD) method. Steady state temperatures were calculated by solving the Pennes Bio Heat Transfer Equation. The spinal cord is an organ at risk. The heart and aorta were kept at a constant temperature of  $37.5 \text{ }^\circ\text{C}$ , because of their very high blood flow.

Optimal phase/amplitude settings were determined using temperature based optimisation, aiming to maximise the tumour temperature ( $T_{\text{tumour}}$ ), respecting constraints to normal tissue ( $T_{\text{tissue}}$ ). Several user-defined constraints and objective functions were applied and the resulting phase/amplitude settings and temperature distributions were compared. For all optimisation strategies, no antenna was allowed to supply less than 10% or more than 40% of the total power. The following optimisation strategies were examined:

Strategy	Objective	Normal tissue	Spinal cord
<b>I</b>	Aim for $T_{\text{tumour}} \geq 43 \text{ }^\circ\text{C}$	$\leq 42 \text{ }^\circ\text{C}$	$\leq 40 \text{ }^\circ\text{C}$
<b>II</b>	Aim for $T_{\text{tumour}} \geq 43 \text{ }^\circ\text{C}$	$\leq 45 \text{ }^\circ\text{C}$	$\leq 40 \text{ }^\circ\text{C}$
<b>III</b>	Aim for $T_{\text{tumour}} \geq 43 \text{ }^\circ\text{C}$	$\leq 45 \text{ }^\circ\text{C}$	$\leq 45 \text{ }^\circ\text{C}$
<b>IV</b>	Maximise $\Sigma T_{\text{tumour}} / \Sigma T_{\text{tissue}}$	$\leq 45 \text{ }^\circ\text{C}$	$\leq 40 \text{ }^\circ\text{C}$
<b>V</b>	Maximise $\Sigma T_{\text{tumour}} / \Sigma T_{\text{tissue}}$	$\leq 45 \text{ }^\circ\text{C}$	$\leq 45 \text{ }^\circ\text{C}$

Strategy I-III aimed at maximising the tumour temperature, whereas strategy IV and V aimed at maximising the ratio between the temperatures in tumour and normal tissue. In the clinic, patients with oesophageal cancer are treated in prone position, so the top antenna is closest to the spinal cord.

## Results

The resulting power ( $P$  [W]) and phase ( $\Phi$ ) settings of the different optimisation strategies, together with the total power deposited in the patient are shown in Table I. The top antenna is the reference, i.e. phase  $0^\circ$ . Strategies II and III have more lenient constraints than I, so the total power as well as the power supplied by the top antenna is higher. This also holds for strategy V compared to IV.

Strategy	$P_{\text{top}}$	$P_{\text{bot}}$	$P_{\text{left}}$	$P_{\text{right}}$	$\Phi_{\text{top}}$	$\Phi_{\text{bot}}$	$\Phi_{\text{left}}$	$\Phi_{\text{right}}$	Total power
<b>I</b>	61	129	83	112	$0^\circ$	$22^\circ$	$19^\circ$	$20^\circ$	384
<b>II</b>	65	176	119	158	$0^\circ$	$0^\circ$	$-22^\circ$	$-10^\circ$	519
<b>III</b>	136	233	114	133	$0^\circ$	$31^\circ$	$21^\circ$	$4^\circ$	616
<b>IV</b>	72	187	120	88	$0^\circ$	$-3^\circ$	$-10^\circ$	$20^\circ$	467
<b>V</b>	150	216	99	99	$0^\circ$	$22^\circ$	$14^\circ$	$19^\circ$	565

**Table I**

Table II shows the tumour temperatures  $T_{10}$ ,  $T_{50}$  and  $T_{90}$  obtained with the settings in Table I, as well as the maximum temperature in the spinal cord ( $T_{\text{max-cord}}$ ) and in normal tissue ( $T_{\text{max-tissue}}$ ) and the ratio  $\Delta T_{50}/\Delta N_{50}$  of the  $T_{50}$  in tumour and normal tissue ( $N_{50}$ ), with respect to  $37^\circ\text{C}$ . Stricter constraints resulted in lower tumour temperatures. The objective function had a minor impact on the achieved tumour temperatures (compare II and IV or III and V). However, strategy IV and V showed a lower  $N_{50}$  compared to II and III, which may lead to a reduction of systemic stress. Particularly the constraints to normal tissue are of vital importance for the achieved tumour temperatures.

Strategy	$T_{10}$ ( $^\circ\text{C}$ )	$T_{50}$ ( $^\circ\text{C}$ )	$T_{90}$ ( $^\circ\text{C}$ )	$T_{\text{max-cord}}$ ( $^\circ\text{C}$ )	$T_{\text{max-tissue}}$ ( $^\circ\text{C}$ )	$\Delta T_{50}/\Delta N_{50}$
<b>I</b>	42.4	41.3	39.5	40.0	42.0	15.7
<b>II</b>	43.8	42.5	40.0	40.0	45.0	12.4
<b>III</b>	45.8	43.9	41.2	42.6	45.0	12.5
<b>IV</b>	43.7	42.4	39.7	40.0	45.0	16.2
<b>V</b>	45.5	43.8	40.9	42.5	45.0	15.6

**Table II**

## Conclusion

The choice of the objective function and especially constraints to normal tissue temperatures is crucial for the obtained settings and temperatures. A thorough discussion on clinically relevant optimisation strategies is essential.

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