# Deep hyperthermia: How much focusing is good enough?

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## INTRODUCTION

The application of the time-dependent Green's function for solving the bioheat transfer equation (BHTE) was demonstrated by Gao et al [1]. The authors used this technique to describe both steady-state and time-dependent examples of a thermal conduction hyperthermia system and an RF interstitial system and to explore the effects of inhomogeneous blood perfusion. The same method has been employed by Giordano et al [2] to demonstrate the effectiveness of a shell source for magnetic fluid hyperthermia. The approach of the Green's function to study the BHTE has also been used for assessing the RF safety of implants inside an MRI scanner [3] and of mobile phones [4]. Here, we will use the same technique to show the effect of decreasing focus size on the heating of the target volume.

## MATERIALS AND METHODS

Current deep hyperthermia systems are based on annular antenna arrays to achieve focusing. Therefore, it is reasonable to assume the steady-state cylindrical Green's function, since treatment time in hyperthermia is longer than the time required for the steady-state to establish:

$$G(r) = \frac{\rho_t}{2\pi k} K_o(\upsilon r) \tag{1}$$

where $r$ is the distance from the (line) source, $\rho_t$ is the mass density of the tissue, $k$ is the thermal conductivity of the tissue and $K_o$ is the modified Bessel function of the second kind and zero order. The parameter $\upsilon$ is related to tissue perfusion:

$$\upsilon^2 = \rho_t \rho_b c_b m / k \tag{2}$$

where $\rho_b$ is the mass density of blood, $c_b$ is the specific heat of blood and $m$ is the volumetric flow rate of blood per unit mass of tissue.

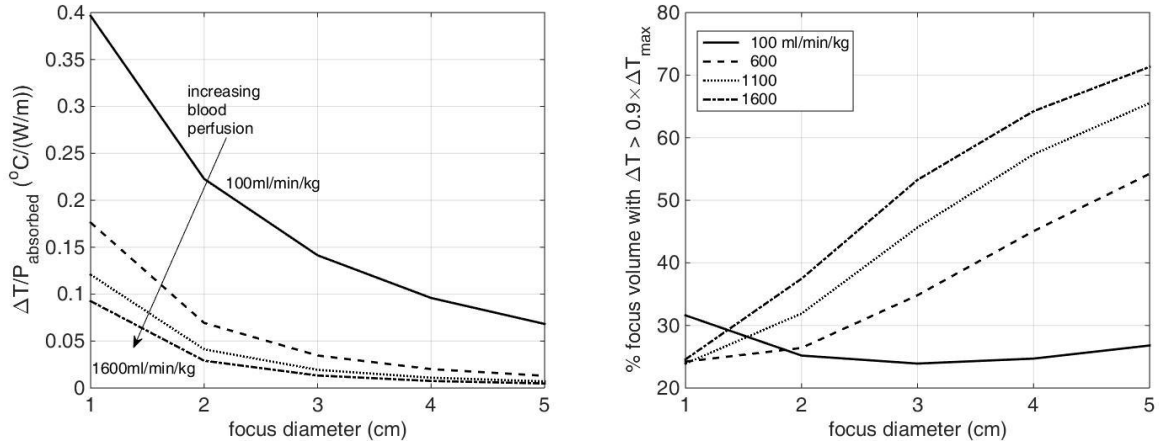
The temperature distribution resulting from a given power source can be found by convolving the SAR distribution with the Green's function. This convolution is performed numerically. Two implicit assumptions are made for this approach [3]: (a) thermal parameters of tissue are the same everywhere in the calculation domain and constant with time; (b) the region of interest is small compared to the whole body and is not near the surface so the infinite boundary condition can be used. Therefore this approach is valid for examining local heating only.

To obtain the numerical results a cylindrical focus of varying diameter was assumed with a pulse shape in space, i.e., the value of SAR was constant inside the focus and zero everywhere else. The problem was solved in an axisymmetric fashion, so a cross-sectional area could be determined, where the temperature rise stayed larger than 50% or 90% of the maximum temperature rise in the focus.

## RESULTS

The results confirm that the effect of blood perfusion is significant for the maximum temperature rise in the target volume. It is clear from Fig. 1a that the deposited energy required to achieve the same temperature rise is smaller for smaller target volumes. However, in terms

of treatment parameters, it is also clear that it is difficult to treat a large part of the target when the latter is small, i.e., the volume where the temperature rise is above 90% of the maximum temperature rise decreases rapidly with focus diameter (Fig. 1b) in the presence of a normal to high blood perfusion.




(a) (b)

Figure 1: (a) Normalized maximum temperature rise inside a target volume (focus size) with respect to focus diameter. (b) Percentage of target volume with a temperature rise higher than 90% of the maximum temperature rise as a function of the focus size. In all cases a thermal conductivity of 0.5 W/(K m) was assumed.

## CONCLUSIONS

The study shows that, although focusing can increase the maximum temperature rise inside the treated tissue, it compromises the volume where sufficient temperature rise occurs. Therefore, finer focusing may require far more applications of the treatment (focus scanning).

## REFERENCES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