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# OPTIMIZATION OF TRANSDUCER GAIN DURING FOCUSED ULTRASOUND SURGERY IN THE PRESENCE OF LARGE BLOOD VESSELS

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## INTRODUCTION

High Intensity Focused Ultrasound (HIFU) shows considerable promise as a minimally-invasive technique for tumor ablation. A typical HIFU procedure involves focusing of acoustic energy in a small region, with the absorbed acoustic energy causing localized rise in tissue temperature. Temperature rise of the order of 40-60$^o$C is achieved within few seconds, causing immediate cell necrosis in the targeted region.

Lesion volume, which quantifies the extent of cell damage due to HIFU exposure, is dependent on the amount of focusing and presence of nearby structures such as bones and large blood vessels. Blood flow can significantly influence the ablation procedure if the target volume is located close to large blood vessels. Using a more highly focused beam can reduce the blood flow effects, though increasing the amount of focusing will reduce the treated volume and increase the treatment time.

In this study, the effect of blood flow and the amount of focusing on the efficacy of the HIFU procedure is analyzed. A 3-D finite element model is developed to predict temperature rise and lesion size for clinically relevant input parameters. Optimal values for focusing gains are calculated for different vessel locations and vessel orientations, with the objective of maximizing lesion volume and minimizing treatment time.

## METHOD

An axisymmetric propagation model is used for calculating the acoustic pressure field and a 3D thermal model is used for calculating temperature rise and lesion volume. Fig. 1 contains the different geometries considered in this analysis. Fig 1a shows the pure diffusion model, which has no large blood vessels near the focal region. Figs. 1b and 1c show the flow geometries, with a large vessel oriented parallel and perpendicular to the beam axis respectively. The vessel has a diameter of 6 mm, which is typical for larger arteries and veins. The ultrasound transducer radius, *a*, is varied between 2.5 to 5cm, while the focal length, d, is maintained at 8 cm. The operating frequency, f($=\omega/2\pi$), is 1 MHz. Clinically relevant values of input power (80W) and pulse duration are used in this analysis [1]. Tissue and blood properties are taken from [2].

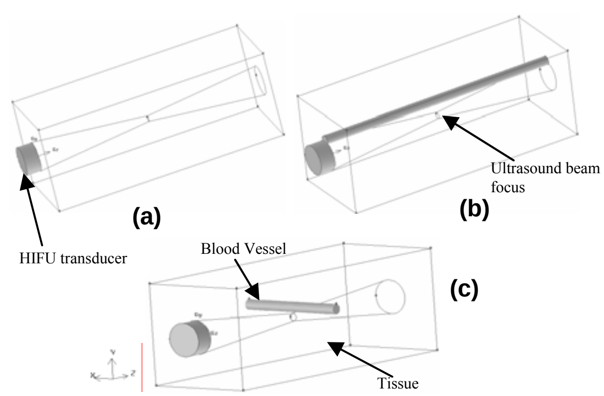



**Figure 1**

**Schematic of a) No-flow b) Parallel and c) Perpendicular flow models.**

Acoustic pressure and time averaged intensity fields are obtained by solving the KZK non-linear wave equation [3]. Heat absorption rate per unit tissue volume is calculated from the intensity profile using the relation, Q= 2*α*I, where α is the attenuation coefficient of tissue [2]. Tissue temperature rise T(x,y,z,t) inside the tissue domain is computed using the bio-heat transfer equation [4]. The velocity field inside the blood vessel is obtained by solving the mass and momentum conservation equations. Temperature rise inside the vessel domain is calculated by solving the energy equation. From the transient temperature field, the volume of necrosed tissue is calculated using a thermal dose method developed by [5]. Our model is validated with previously published numerical and experimental results [6].

## RESULTS

Fig. 2 displays the variation of lesion volume as a function of focusing gain (G) and pulse duration ($t_p$) in the absence of nearby large blood vessels. The transducer focusing gain, defined as $G = \omega a^2 / 2cd$ , where c is speed of sound in tissue, is a measure of the intensity at the focus relative to the intensity at the transducer. Focusing gain is varied by changing $a$ and keeping $\omega$ , c, and d, constant. Also identified is the optimal gain value, $G_{optimal}$, defined as the focusing gain for which the lesion volume generated is the maximum.

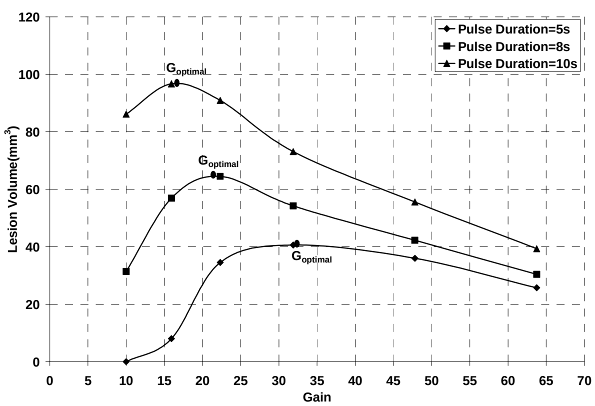
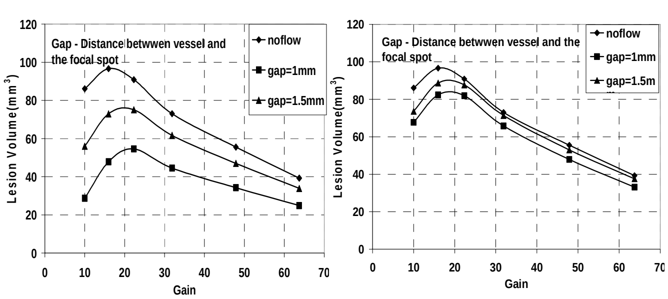



**Figure 2**

**Lesion volume as a function of transducer focusing gain for different pulse durations (no-flow model).**

Highly focused beams are seen to produce relatively small lesions relative to lower gains, especially for longer exposure times. For the 8-second exposure time, the lesion volume for G = 63.75 is half the lesion size at the optimal gain (G ≈ 22). The optimal gain value decreases with increasing exposure time.




**(a)** **(b)**

**Figure 3**

**Lesion volume as a function of transducer focusing gain for a) Parallel model and b) Perpendicular model.**

In Fig. 3A, the lesion volume is analyzed for different distances between the ultrasound beam and the blood vessel, for the parallel configuration. The lesion volumes for the no-flow case, which also represent the lesion size for a very large gap (distance between the vessel and the beam focus) is between 37% and 67% larger than the gap of 1.0 mm, with the lower gains exhibiting the largest relative increase. When the gap is 1.5 mm, the reduction in lesion size, relative to no-flow, is between 20% and 40%. The optimal gain decreases slightly with increasing gap between the beam and the vessel.

Similar trends are observed for the perpendicular orientation (Fig. 3B), but the magnitudes of the differences due to gap are considerably less. Moving from a 1.0 mm gap to a 1.5 mm gap, the increase in lesion volume varies between ~10% and 21%. Increasing the gap beyond 1.5 mm results in little additional increase in lesion volume.

## DISCUSSION

Fig. 2 shows that by reducing the focal gain of the HIFU beam and distributing the energy to a larger volume, lesion size can be increased significantly. Consequently, using an optimally focused HIFU beam instead of a highly focused one will help clinicians maximize lesion volume obtained per pulse which, in turn, would reduce the treatment time. While using a moderately focused transducer, which distributes ultrasound energy more widely, temperature rise obtained outside the focal region should be monitored to prevent excessive collateral damage.

Due to conduction of heat to the vessel at many axial locations, the reduction in lesion volume is considerably larger for the parallel orientation than the perpendicular (Fig. 3). Lesion volumes for other angles are expected to fall between the values obtained for these two orientations. The results also suggest that, for the flow to have any impact on the ablation procedure, the distance between the vessel wall and the focal point should be of the order of 6 dB width of the HIFU beam (a few mm).

Blood flow shifts the optimal gain towards the high gain side, for both the orientations. This is expected since low gain transducer produces larger focal region and hence could be more readily influenced by the blood.

## CONCLUSION

This study suggests that by optimizing the amount of focusing, pulse characteristics, and HIFU beam orientation, lesion volume can be increased and treatment time can be reduced significantly.

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