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THE SIMULATIONS OF ULTRASOUND POWER PATTERNS OF LOW-FREQUENCY CYLINDRICAL TRANSDUCERS FOR TUMORS INSIDE BONES

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Abstract

This study presents the therapeutic ultrasound power pattern simulations for tumors inside bone, i.e. intraosseous tumors without cortical breakthrough, using the low-frequency cylindrical transducers. We have shown that the 3-D wave equation for damped wave is a kind of Helmholtz's equation that can be solved by the commercially available software. Therefore, such a wave equation method can be utilized to solve the reflection and refraction issues in the tissue interfaces. This work sets the cylindrical transducer with 10 cm radius and 10 cm height. Considering the different parameters of bone thickness, driving frequency, muscle depth, radius, and length of tumor through scanning the low-frequency cylindrical transducer, the select 50 KHz driving frequency transducer seemed most optimal to treat most cases of intraosseous tumors.

Key words: hyperthermia, bone tumor, intraosseous tumor, ultrasound therapy, ultrasonic power depositions, tissue interfaces

Introduction

The purpose of this paper is to evaluate the feasibility to treat intraosseous tumors without cortical breakthrough using the cylindrical therapeutic transducer. Because of the heterogeneity of the tissues, we propose the numerical wave equation method to solve the reflection and refraction in the tissue interfaces.

Method

The hypothetical geometric relationship among the tumor, bone, muscle, and cylindrical transducer is presented in Fig. 1. We can regard this diagram as the characteristics of the hyperthermic therapy for the tumor inside bone of extremities using the cylindrical transducer. R and H are the radius and height of the cylindrical transducer and L_s stands for the length of the transducer scanning parallel with the z-axis.

If the velocity normal to the surface (U_a) is uniform and proportional to $e^{j\omega t}$, where t is time and $j=(-1)^{1/2}$, then the resulting velocity potential (Ψ_p) at a field point p can be approximated by the Rayleigh-Sommerfield diffraction integral[1]:

$$\Psi_p = \iint_A \frac{U_a}{2\pi s} e^{-jks} dA \qquad (1)$$

where s is the distance from the source point dA to the field point p.

The ultrasound is an acoustic wave. It is reasonable to calculate ultrasound intensity field by wave equation. We can get the 3-D acoustic wave equation for damped wave as

$$c^2 \nabla^2 \Psi = \frac{\partial^2 \Psi}{\partial t^2} + \frac{R'}{\rho} \frac{\partial \Psi}{\partial t} \qquad (2)$$

This equation can be proved to be the typical form of the Helmholtz's equation. We utilize the PDE toolbox of Matlab to solve the 2-D Helmholtz's equation and calculate the intensity field.

Results

The results show that, compared with the traditional Rayleigh-Sommerfield diffraction integral method, the wave equation method is feasible to calculate the ultrasound intensity distributions. Moreover, the cylindrical transducer is useful to treat most cases of intraosseous tumors.

Conclusion

Considering the different values of bone thickness, driving frequency, muscle depth, tumor radius, and tumor length, through scanning the low-frequency cylindrical transducer, we can treat most cases of intraosseous tumors and improve their clinical outcomes.

Reference

[1] S. J. Tu, K. Hynynen, R. B. Roemer, "Simulation of bidirectional ultrasound hyperthermia treatments of neck tumours", Int. J. Hyperthermia, vol. 10, no. 5, pp.707-722, 1994.

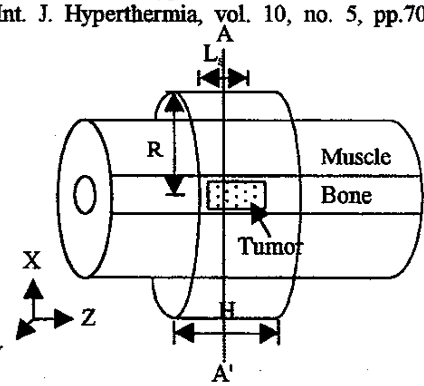

Fig. 1 The hypothetical geometric relationship among the tumor, bone, muscle, and cylindrical transducer.