Commun. Comput. Phys.
doi: 10.4208/cicp.171214.200715s

Vol. **18**, No. 4, pp. 1050-1071
October 2015

Multiphysics Modeling of Liver Tumor Ablation by High Intensity Focused Ultrasound

Maxim Solovchuk[1,2,*], Tony Wen-Hann Sheu[1,3,*] and Marc Thiriet[4]

[1] *Center of Advanced Study in Theoretical Sciences (CASTS), National Taiwan University.*
[2] *Institute of Biomedical Engineering and Nanomedicine, National Health Research Institutes, No. 35, Keyan Road, Zhunan, Taiwan 35053.*
[3] *Department of Engineering Science and Ocean Engineering, National Taiwan University, No. 1, Sec. 4, Roosevelt Road, Taipei, Taiwan 10617.*
[4] *Sorbonne Universities, UPMC Univ Paris 06, UMR 7598, Laboratoire Jacques-Louis Lions, F-75005, Paris, France.*

Received 17 December 2014; Accepted (in revised version) 20 July 2015

Abstract. High intensity focused ultrasound is a rapidly developing technology for the ablation of tumors. Liver cancer is one of the most common malignancies worldwide. Since liver has a large number of blood vessels, blood flow cooling can reduce the necrosed volume and may cause regeneration of the tumor to occur. All cancer cells should be ablated without damaging of the critical tissues. Today, treatment planning tools consider liver as a homogeneous organ. This paper is a step towards the development of surgical planning platform for a non-invasive HIFU tumor ablative therapy in a real liver geometry based on CT/MRI image. This task requires coupling of different physical fields: acoustic, thermal and hydrodynamic. These physical fields can influence each other. In this paper we illustrate how a computational model can be used to improve the treatment efficiency. In large blood vessel both convective cooling and acoustic streaming can change the temperature considerably near blood vessel. The whole tumor ablation took only 30 seconds in the considered simulation case, which is very small comparing with the current treatment time of several hours. Through this study we are convinced that high ultrasound power and nonlinear propagation effects with appropriate treatment planning can sufficiently reduce the treatment time.

AMS subject classifications: 80A20, 65Z05, 68U20, 65N06

Key words: Multiphysics and multiscale model, liver tumor, computational surgery, blood flow, focused ultrasound.

*Corresponding author. *Email addresses:* `solovchuk@gmail.com` (M. Solovchuk), `twhsheu@ntu.edu.tw` (T. W.-H. Sheu), `marc.thiriet@inria.fr` (M. Thiriet)

1 Introduction

Liver cancer is the second leading cause of cancer death in men [1,2] and the sixth leading cause among women in the world. In 2008 around 750 000 patients suffered liver disease in the world [2]. At an early stage liver cancer can be successfully treated with surgery or liver transplantation. For a patient diagnosed at an advanced stage of disease fewer surgical options exist. Unfortunately, no more than 20 percent of patients can be treated with the surgery [2, 3]. If liver tumor cannot be surgically removed, patients can choose local ablation, tumor destruction either with radiofrequency (RFA) or percutaneous ethanol injection (PEI), or embolization by blocking or reducing the blood flow to cancer cells in the liver.

High intensity focused ultrasound (HIFU) is a rapidly developing method for the tumor ablation and it can be used when other methods cannot be applied. It has been successfully applied for the treatment of benign and malignant tumors [3–5]. The principles of using focused ultrasound are very similar to the use of magnifying glass to initiate the fire [6]. Ultrasound beam distributed over the transducer surface is focused onto a very small area. Ultrasound energy is transformed into thermal energy and temperature at the focal region can be increased. If the temperature reaches 56^0C just for one second, protein denaturates and causes an irreversible tissue damage [7]. The goal of the treatment is to reach this temperature (or corresponding thermal dose) in the whole tumor [8]. If ultrasound beam is properly focused to heat the tumor, the intervening tissues between the transducer and the tumor are not damaged. It is a completely non-invasive method and it has fewer complications in comparison with other treatment modalities.

Ultrasound beam should be properly focused to heat the tumor and avoid the damage of the healthy tissues. Focused ultrasound therapy is usually performed with magnetic resonance imaging or diagnostic ultrasound guidance. Focal area of focused ultrasound transducer (about 1-2 cm in length and 1-2 mm in width) is much smaller than the tumor size. Many sonications should be performed in order to ablate the whole tumor. For the safety and efficiency sake there is a cooling between the ultrasound pulses. Usually treatment time takes several hours [9, 10]. Courivard et al. [10] investigated experimentally in vivo liver tissue ablation by focused ultrasound and the average total procedure time was 380 min. Appropriate treatment planning can sufficiently reduce the treatment time and improve the therapy [11, 12]. Computational fluid dynamics plays a key role in the modeling and analysis of biomedical and biological systems, when many physical mechanisms are involved [13–15]. Several parameters can be optimized during treatment planning including ultrasound power, heating time, and scanning path.

Usually linear acoustic model is implemented [9] and homogeneous tissue is considered [11] for the planning of tumor ablation. At high intensities nonlinear propagation effects become important. Nonlinear propagation effects can elevate the temperature and reduce the treatment time [16]. However, simulation of nonlinear acoustic field is more expensive comparing with the linear case [17].