COMPARATIVE STUDY OF THE CRYOSURGICAL PROCESSES WITH TWO DIFFERENT CRYOSURGICAL SYSTEMS: THE ENDOCARE CRYOPROBE SYSTEM VERSUS THE NOVEL COMBINED CRYOSURGERY AND HYPERThERMIA SYSTEM

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Abstract — A numerical model was developed to study heat transfer process during freezing of biological tumors. Two different cryosurgical systems, Endocare cryoprobe and novel combined cryosurgery and hyperthermia system, were investigated using the multidimensional, finite element method (FED) developed in Ansys (V7.0) by us recently. The tissues were modeled as nonideal materials, the thermophysical properties of which were temperature dependent. The enthalpy method was applied to solve the highly nonlinear problem. It was found that for the same initial/boundary conditions and the same target tissues, the novel combined cryosurgery and hyperthermia system could supply the target tissue an approximate cooling rate, a much lower minimal temperature, a much greater warming rate, and a much greater thermal gradient as compared with the Endocare cryoprobe system. The numerical simulation results indicated that the novel combined cryosurgery and hyperthermia system could provide an excellent curative effect in the corresponding cryotherapy.

Keywords — FED, heat transfer, cryosurgery, cryoprobe, Ansys

1. INTRODUCTION

Cryosurgery has been recently accepted as a treatment option for eradicating undesirable tissues, especially tumor tissues, due to its minimal invasiveness and little hospitalization needs. Since 1845, a partly frozen saline solution (at about -22°C) was used to treat skin cancer tumors by James Arnott, it has been a known surgery treatment (Gage, 1992; Rabin and Stahovich, 2003). And it has become a well-established method for the ablation of benign and malignant lesions since the mid-1960s (Gage, 2004; Deng and Liu, 2005). Cryosurgery is an effective treatment for both surface tissues and internal organs, and the minimally invasive cryoprobe known widely today is suitable for the latter. The first cryoprobe was designed to treat brain tumors and the part of the brain associated with Parkinson’s disease (Lee, 1967; Rabin and Stahovich, 2003). Although the application of cryosurgery for treatment of renal, cerebral, adrenal and breast cancers is under way, the treatment modality is most commonly used for the eradication of prostate and liver tumors (Rewcastle et al., 1998). And recent improvements in imaging techniques, such as magnetic resonance imaging (MRI), computerized tomography (CT), and electrical impedance tomography (EIT), have stimulated the spread and popularity of cryosurgery (Bast and Gage, 2004).

In a typical cryosurgery process, the undesired tissues will undergo liquid-solid and reverse phase transformation in the freezing/thawing region, where the tissue will be injured or destroyed by several mechanisms, such as “solution injury”, injury caused by “intracellular ice formation (IFF)”, the re-crystallization of intracellular ice, thermal stress, (Zhang et al., 2000; Mazur et al., 1972; Zhao et al., 2006b; Zhao et al., 2007). Successful cryosurgery means maximal destruction of undesired tissues by freeze-thaw cycle, but the effect of cryosurgery is often influenced by the thermal history experienced by the tissues, which includes the cooling rate, the thawing rate, the minimal temperature, the freeze-thaw cycles, (Smith and Fraser, 1974; Gage et al., 1985; Hua and Ren, 1994; Miller and Mazur, 1976; Gage et al., 1982; Tackenberg, 1990; Rand et al., 1985). A ’critical isothermal protocol’, which assumes that complete necrosis occurs only in regions where have been embraced by a certain isothermal surface, is often regarded as a standard clinical procedure (Rewcastle et al., 1998). However, there is some variance in literatures regarding the absolute value of this critical temperature. For example, the critical temperatures listed by Gage and Baust in two recent reviews range from -2 (osteocytes, bone, dog) to -70°C (adenocarcinoma, rat) (Gage and Baust, 1998; Gage, 2004). So the critical temperature is likely to be tissue dependent, and this assumption has some biological basis.

The in vivo growth of the iceballs could be commonly monitored with real-time two-dimensional ultrasound. Since ultrasound is almost 100% reflected at the ice interface, the imaging modality enables the iceball edge to be observed clearly while the three-dimensional