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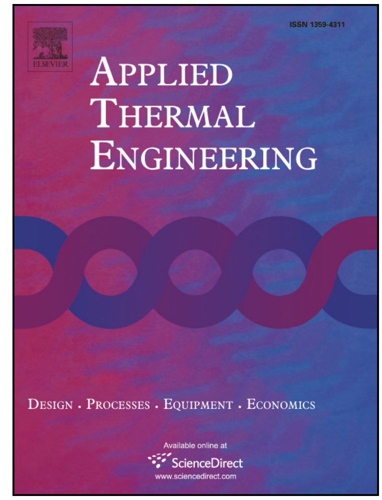

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Abstract Cryoballoon ablation has emerged as a significant therapeutic technique to isolate pulmonary veins for the treatment of atrial fibrillation (AF). The temporal and spatial variation of the thermal field in clinical ablation is uncharted and can not be measured in real time. Finite element analysis is used to study the temperature filed in the process of tissue cooling and lesion formation within the myocardium. In this paper, we established the 2D axisymmetric simplified model of pulmonary vein antrum and the temperature distribution was obtained by solving the Pennes equation coupled with the phase change model. Furthermore, the tissue damage integral analysis was adopted in our research which gives an indicator of tissue injury during the ablation. In order to verify the reliability of the model, in-vitro experiments were conducted using a porcine heart and clinical research conclusions were also quoted as a reference.

Keywords: Cryoballoon ablation, Bioheat transfer, Thermal field, Tissue damage, Atrial fibrillation

1. Introduction

Cryosurgery has been widely proven to be an excellent medical technique to treat various tumors and cardiac arrhythmias for the past few decades [1-6]. Particularly the AF, one of the most common cardiac arrhythmia, has made great progress. Pulmonary veins is crucial in the pathogenesis of AF, and complete pulmonary vein isolation (PVI) from the left atrium has been defined as the cornerstone in AF ablation[7]. PVI correlated closely with circumferential and transmural lesions at the veno-atrial junction[8]. The previous ways involve using a spot cryo catheter to place point-by-point circumferential lesions around the PVs and a circular cryoablation catheter for PVI[9]. Both technologies have been proven to be effective in achieving myocardial ablation. But all these failed to applied in large scale since the technical difficulties and long freezing time[10, 11]. Recently, the development of balloon technology has been used to simplify PVI and reduce the procedure time [12]. The cryoballoon catheter designed for inflation at the PV ostium, thereby allowing for temporary occlusion of PV blood flow and circumferential ostial contact[13]. Once occlusion is confirmed, the refrigerant (N_2O) is sprayed via 4 injection ports into the balloon where it undergoes a liquid-to-gas phase change to cooling the tissue.

Obviously，it is necessary to produce transmural lesions encircling pulmonary veins to achieve complete PVI. But, it is difficult to monitor the temperature distributions in the tissue during the operation[14]. However, the cooling rates, minimal temperature, phase transition and isotherm distribution during the freezing are essential to the successful ablation. For example，some researchers have defined specific temperatures range as the damage region or applied different cooling rate to destroy tissues as the ablating approach[2, 15]. This means that performing high quality surgery is based in a profound understanding of thermal evolution. Due to the special physiological structure and function of heart, the simulation study of cardiac thermal field and cryoinjury generated by the latest cryoballoon technique are fewer than other organs. From the heat transfer point of view, only Fasano's[16] investigation involves temperature analysis by simulation method in cryoballoon ablation. But, his study focused mainly on the temperature variation in the esophageal. The thermal filed in atrial