Simulating Cardiac Cryoablation considering the Osmotic Virial Equation for Freezing and Thawing

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Aims: Cardiac cryoablation is a procedure for treating cardiac arrhythmias, in which arrhythmogenic tissue is ablated by freezing. Computer models allow for simulating temperature distributions present during the procedure, by which factors related to cell death can be derived, making this a valuable method for optimization. A crucial point in simulating temperature distributions during cryoablation is the accurate consideration of the latent heat of fusion released during freezing and absorbed during thawing of tissue. Most computer models used for simulating cryoablation consider the latent heat of fusion by distributing it uniformly or bell shaped over a narrow temperature range close to the freezing point of water. In this work we developed an adapted model considering tissue as an electrolytic solvent taking into account the temperature dependent frozen ratio derived from the osmotic virial equation together with the latent heat during eutectic phase change.

Methods: To analyze the differences when considering this alternative approach, a model of a tube shaped cryoapplicator in contact with myocardial tissue and surrounded by blood was simulated using an adaptation of Pennes' bioheat equation and the effective heat capacity model. In a reference simulation the latent heat of fusion was distributed uniformly on the effective heat capacity over a small temperature range, while in another simulation the adapted model considering the frozen ratio and eutectic phase change was applied.

Results: Simulations of a freeze-thaw cycle showed slightly warmer tissue temperatures and lower cooling rates during freezing considering the new approach, while a considerably smoother rewarming behavior was obtained during the simulated thawing phase, indicating also changes in factors responsible for myocardial cell death.

Conclusion: The adapted modeling approach allows for analyzing cryoablation scenarios considering a more realistic physical behavior during freezing/thawing, enabling also the more accurate simulation of temperature dependent quantities such as cryoimpedance.