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Editorial:

Current Trends in Mathematical Modeling of High-Temperature Thermal Therapies

We are delighted to present this special issue of *The Open Biomedical Engineering (TOBEJ)* focused on the current trends in mathematical modeling of high-temperature thermal therapies (ablation therapies). Clinical application and research of these therapies has seen rapid growth in the last decade, particularly for applications of cardiac arrhythmia (cardiac catheter ablation) and cancer treatment (tumor ablation). The general goal of these therapies is destruction of unwanted tissue (e.g. cancer tissue) *via* image-guided application of heat – typically *via* an applicator steered to the target location. Mathematical modeling of these therapies has become an important research tool, allowing investigation of underlying biophysics, as well as development of new medical devices.

This special issue presents papers on current research directions from several of the major contributors to this field. While not all heating modalities are covered, many concepts presented are applicable to other modalities (e.g. laser, focused ultrasound). Most of the presented papers are related to tumor ablation, and one of the papers is discussing cardiac ablation.

One of the essential features is the assessment of ablation zone (or thermal lesion) size. In this regard, Dr. Chang presents a study where the current methods used for predicting tissue injury (iso-temperature contours, cumulative equivalent minutes, and Arrhenius formulation) are exhaustively compared. Despite the fact that the study is focused on radiofrequency (RF) ablation, many of the presented concepts and conclusions can be applied to modeling studies of therapies based on other energy types.

Drs. Saito and Ito present initial results on the possibility of monitoring the thermal lesion progress during microwave ablation by assessing the reflection coefficient change of the microwave antenna. Results are presented using mathematical models with experimental validation. Their results suggest that the proposed method could be used to improve monitoring during the procedure. Inadequate monitoring capabilities during tumor ablation procedures are currently one of the primary limitations.

In addition to monitoring, prediction of the thermal lesion dimensions before treatment would be of great benefit to aid the physician in treatment planning. Dr. Preusser’s group is working on this topic, where they work towards computer-assisted optimization of the procedure (i.e. finding the optimal applicator location for a given patient, and locating regions that are not heated sufficiently). The paper by this group published in this special issue by Kröger *et al*. presents a method that predicts the effect of large vessels *via* a rapid algorithm that can potentially be used in real-time. This is of clinical importance since tumor recurrence due to insufficient heating very often occurs close to large vessels. The proposed method combines a mathematical model that takes into account the RF applicator type and generator setting (similar to that presented in other papers of this issue, and hence patient independent), with a patient-specific model geometry based on medical imaging data (consequently patient dependent) providing patient specific estimates of vessel effects. This is a research area of great current interest, where mathematical modeling of applicators for thermal therapy is closely combined with medical imaging techniques in order to implement systems that provide predictions of treatment outcome.

Dr. Prakash presents a detailed review of techniques currently in use for mathematical modeling of microwave ablation. He starts with a description of the electromagnetic field problem and modeling of frequency-dependent dielectric tissue properties. Then effects of temperature-dependent changes of dielectric properties as well as temperature-dependent perfusion are covered. The necessary steps of spatial and temporal discretization are covered, and models from current literature are presented, including some recent efforts of using models for treatment planning – related to the paper by Kröger *et al*. discussed above.

Finally, studies by Strigel *et al.* and González Suárez *et al.* offer examples of mathematical modeling centered on specific devices. Both examples are clearly oriented towards the R&D of new devices for high-temperature thermal therapy. The study by Strigel *et al*. employs mathematical models to evaluate different designs of an RF electrode array for use during liver resection in patients with liver cancer. The aim is to assess different electrode designs (needle vs. blade shaped, distance between electrodes) and different modes of applying RF power (monopolar vs. bipolar) to determine the design with the best performance.

Another example employing mathematical models for device design is the study by González Suárez *et al.* in which theoretical models are employed to improve epicardial RF ablation techniques for treating atrial fibrillation. Since the presence of epicardial adipose tissue interposed between the ablation electrode and target site (atrial wall) impedes the passage of RF current, and thus reduces the effectiveness of ablation, the aim of this study was to assess different electrode designs (dry vs. cooled) and different modes of controlling RF power (constant current, temperature and voltage).

Both studies (Strigel *et al.* and González Suárez *et al.*) aim to assist the development of new RF applicators *via* computer simulations. The models allow rapid evaluation of different parameters and can suggest improvements in electrode design, thereby reducing the amount of experimental work that is required. In this respect, the research of groups focused on the accurate characterization of physical properties of biological tissues is a key piece.

In addition to the above applications, the mathematical models can also serve as teaching aid. Some results, such as temperature isotherms and their change during the procedure allows students as well as end-users (physicians) to better understand the biophysics of the procedure, thereby aiding the teaching and more effective use of the devices.

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