Modeling heat transfer in ablation procedures for the treatment of atrial fibrillation: saving lives with mathematics

Antonio Fasano
Prof. Emeritus, Univ. of Florence, Italy; Scientific Manager and R&D Director, FIAB, Florence, Italy
fasano@math.unifi.it

Abstract

Atrial Fibrillation a frequent form of heart arrhythmia, due to unwanted electric stimuli altering the normal heart rhythm. When resistant to drugs it is treated by "burning" the sites where electrical disturbances originate. Most of the times these are located where the four pulmonary veins empty into the left atrium. Such an ablation procedure can be done either by delivering radiofrequency power (RF ablation), or by means of a balloon inflated with a very cold gas (cryoablation). Both procedures, which are equally effective, present the risk of damaging organs facing the left atrium, in particular the phrenic nerves (regulating diaphragm motion, i.e. respiration) and the esophagus, owing to the large amount of heat delivered (RF) or absorbed (cryo). Among the esophagus lesions, a rare but lethal form is the atrio-esophageal fistula, which manifests itself weeks after the intervention in a dramatically irreversible form. Hence the great importance of having the best possible information about the generated thermal field.

By means of a mathematical model based on some idealized geometry, we have reasonably computed the evolution of temperature in the region between the ablator and the esophagus for different anatomical configurations. Moreover, for the RF ablation, we have calculated the electric field, which exhibits a sharp asymmetry, being deviated by the blood flow in the heart.

The model helps to understand the crucial influence of anatomical features such as, the atrium-esophagus distance, the esophagus thickness, and above all the epicardial fat layer thickness, acting as a shield for the thermal shock.

Simulating the thermal field evolution has led to important conclusions, which are very important for the patient safety. First of all, we compared the outcome of numerical computation with the clinical data, obtained by measuring the luminal esophageal temperature (LET) with a probe equipped with thermal sensors. The agreement was very

good and allowed to have a better interpretation of the experimental data. Moreover, simulations can suggest a good strategy to select the (upper or lower) threshold temperature at which an alarm tells the physician to stop the procedure. A key point to be considered is that mathematics is the only access we have to the outer esophageal surface, which in critical cases turns out to be very different from LET, due to the large thermal gradients involved.
Finally, for cryoablation, we found that by measuring the LET decreasing rate at the beginning of the procedure one can reasonably predict what the LET final value will be, well before any damage may be caused to the patient. A patented system has been developed at FIAB exploiting this correlation, which is likely to save lives in the future.

References

[1] S. Deiss, A. Metzner, F. Ouyang, R.R. Tilz, S. Mathew, C. Lemes, C.H. Heeger, T. Maurer, K.H. Kuck, E. Wissner. Incidence of significant delayed esophageal temperature drop after cryoballoon-based pulmonary vein isolation. J. Cardiovasc. Electrophysiol. doi:10.1111/jce.13008 (2016).

[2] A. Fasano, L. Anfuso, S. Bozzi, C. Pandozi. Safety and necessity of thermal esophageal probes during radiofrequency ablation for the treatment of atrial fibrillation. To appear in J. Atrial Fibrillation.

[3] A. Fasano, L. Anfuso, G. Arena, C. Pandozi. Cryo-ablation for pulmonary veins isolation: importance of esophageal temperature monitoring. Submitted.

[4] A. Fasano. Importance of time response in monitoring esophageal temperature. Letter to the Editor of Heart Rhythm, to appear in Heart Rhythm.

[5] K. Kiuchi, K. Okajima, A. Shimane, G. Kanda, K. Yokoi, J. Teranishi, K. Aoki, M. Chimura, T. Toba, S. Oishi, T. Sawada, Y. Onishi, T. Onishi, S. Kobayashi, Y. Taniguchi, S. Yamada, Y. Yasaka, H. Kawai, A. Yoshida, K. Fukuzawa, M. Itoh, K. Imamura, R. Fujiwara, A. Suzuki, T. Nakanishi, S. Yamashita, K. Hirata, H. Tada, H. Yamasaki, Y. Naruse, M. Igarashi, K. Aonuma. Impact of esophageal temperature monitoring guided atrial fibrillation ablation on preventing asymptomatic excessive transmural injury. Journal of Arrhythmia 2015, DOI: 10.1016/j.joa.2015.07.003.