Abstract

The behavior of the heart is governed by electrical currents generated in the myocardium, and therefore, the study of the cardiac electrical activity is essential for the diagnosis of cardiac diseases. Electrical currents in the myocardium generate an electric field that propagates through the conductive tissues of the body to reach the torso surface and, consequently, recording the surface potential distribution provides indirect information of the myocardial behavior. The "Body Surface Potential Mapping" (BSPM) technique allows the noninvasive multichannel recording on the surface of the torso, providing a complete knowledge of the electrical activity by observing events undetectable by conventional techniques.

The mathematical relationship between the myocardial electrical activity and fields recorded on the torso surface can be found by solving either the forward or the inverse problem of the electrocardiography. The forward problem of the electrocardiography entails the calculation of the torso potentials from the electrical activity of the heart and the 3D body model, while the inverse problem resolution allows the noninvasive reconstruction of the electrical activity of the heart from surface potentials. The inverse problem is of great importance in clinical applications since it allows estimating the electrical activity of the myocardium with only noninvasive recordings. However, inverse problem resolution is still a big challenge in electrocardiography since it is ill-posed, very unstable and has multiple solutions.

In this thesis different algorithms and strategies based on the inverse problem resolution were developed and applied in the noninvasive diagnosis of ventricular and atrial arrhythmias and evaluated with mathematical cellular models and clinical data bases. The thesis focuses on the inverse problem resolution for the noninvasive reconstruction of the myocardial electrical activity for different diseases and propagation patterns, implementing a novel system for complex propagation patterns. The obtained results and propagation patterns were evaluated and classified with the corresponding optimal resolution strategy that minimizes the error and increases the stability of the system, proving its advantages and disadvantages depending on the different diseases and their activation pattern.

A novel iterative method was implemented for the inverse problem dipolar resolution optimized for representing simple propagation patterns, achieving a high stability and robustness against noise by constraining the solution to a limited number of dipoles. However, propagation patterns not representable by few dipoles need to be computed with the inverse problem in terms of epicardial solutions which provide a more detailed estimation of the myocardial activity. Inverse problem resolution in the voltage and phase domains showed a good accuracy for simple and organized propagation patterns. This method allowed the noninvasive diagnosis of the Brugada syndrome or the location of ectopic focus in atrial arrhythmias by performing a parametric analysis of the electrograms morphology or the activation map reconstruction. However, mathematical and patient results presented in this thesis proved that, for complex propagation patterns like atrial fibrillation (AF), inverse solutions in the voltage and phase domains are over-smoothed and over-optimistic, simplifying the complex AF activity, leading to non-physiological results that do not match with the complex intracardiac electrograms recorded in AF patients. In this thesis, we proposed a novel technique for the noninvasive identification and location of high dominant frequency AF sources, based on the assumption that in many cases atrial drivers present the highest activation rate with an intermittent propagation to the rest of the tissue that activates at a slower rate. Although, voltage and phase inverse solutions for AF complex propagation patterns were over smoothed and inaccurate, the noninvasive estimation of frequency maps was significantly more accurate, allowing the identification of the AF frequency gradient and location of high frequency sources. This technique may help in planning ablation procedures, avoiding unnecessary interseptal punctures for right-to-left frequency gradients cases and facilitating the targeting of the AF drivers, reducing risk and time of the clinical procedure.