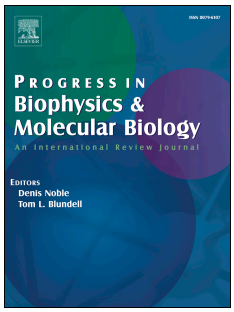
Accepted Manuscript



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J. Christoph, J. Schröder-Schetelig, S. Luther

PII: S0079-6107(17)30212-2

DOI: 10.1016/j.pbiomolbio.2017.09.015

Reference: JPBM 1277

To appear in: *Progress in Biophysics and Molecular Biology*

Received Date: 8 September 2017

Accepted Date: 10 September 2017

Please cite this article as: Christoph, J., Schröder-Schetelig, J., Luther, S., Electromechanical optical mapping, *Progress in Biophysics and Molecular Biology* (2017), doi: 10.1016/j.pbiomolbio.2017.09.015.

Electromechanical Optical Mapping

J. Christoph[a,b,1,*], J. Schröder-Schetelig[a,c,1], S. Luther[a,b,c,d,1,**]

[a]*Max Planck Institute for Dynamics and Self-Organization, Am Fassberg 17, 37077 Göttingen, Germany*
[b]*German Center for Cardiovascular Research, Partner Site Göttingen, Germany*
[c]*University of Goettingen, Institute for Nonlinear Dynamics, Göttingen, Germany*
[d]*University Medical Center Goettingen, Institute of Pharmacology, Göttingen, Germany*

Abstract

Optical mapping is a widely used imaging technique for investigating cardiac electrophysiology in intact, Langendorff-perfused hearts. Mechanical contraction of cardiac tissue, however, may result in severe motion artifacts and significant distortion of the fluorescence signals. Therefore, pharmacological uncoupling is widely used to reduce tissue motion. Recently, various image processing algorithms have been proposed to reduce motion artifacts. We will review these technological developments. Furthermore, we will present a novel approach for the three-dimensional, marker-free reconstruction of contracting Langendorff-perfused intact hearts under physiological conditions. The algorithm allows disentangling the fluorescence signals (e.g. membrane voltage or intracellular calcium) from the mechanical motion (e.g. tissue strain). We will discuss the algorithms reconstruction accuracy, resolution, and robustness using experimental data from Langendorff-perfused rabbit hearts.

Keywords: Optical Mapping, Cardiac Fibrillation, Excitation-Contraction Coupling, Image Registration, Motion Artifact, Motion Tracking

1. Introduction

Fluorescence imaging techniques are widely used in the biophysical sciences to visualize electrophysiological processes in cells and tissues. In basic cardiological research, fluorescence imaging is referred to as *optical mapping* when used to study the propagation of electrical excitation in the heart (Salama and Morad, 1976; Morad and Salama, 1979; Salama et al., 1987). Optical mapping provides high-resolution visualizations of electro-chemical wave phenomena such as membrane potential or calcium waves evolving rapidly across the heart surface (Efimov et al., 1994; Choi and Salama, 2000). Providing maps of vortex wave dynamics during heart rhythm disorders such as ventricular fibrillation, the imaging technique has had a tremendous impact on the understanding of cardiac arrhythmias (Davidenko et al., 1992; Pertsov et al., 1993; Jalife and Gray, 1996; Gray et al., 1998; Witkowski et al., 1998). Today, optical mapping is recognized as the gold-standard imaging technique in the field. Optical mapping has been used to image normal and abnormal activity in intact hearts, wedge preparations of ventricles and atria, papillary muscle and cell culture preparations. Optical mapping has been performed in various species including excised human hearts (Nanthakumar et al., 2007). With modern multi-camera imaging setups, it is possible to image the entire surface of a heart using two or more cameras and to create panoramic maps representing the activity on the shape of the outer epicardial surface using calibrated cameras and techniques for the reconstruction of the three-dimensional heart geometry (Kay et al., 2004; Rogers et al., 2007; Qu et al., 2007).

One of the major shortcomings of optical mapping, as it is presently most commonly conducted, however, is its sensitivity to motion. Even the slightest motion can cause severe motion artifacts. These artifacts superimpose the wave patterns appearing in the optical maps and can prohibit further analysis of the imaging data. As a result, isolated hearts and other heart tissue preparations are typically imaged under ostensibly unphysiological conditions: any contractile motion or beating of the tissue is being suppressed using pharmacological excitation-contraction uncoupling agents. Nevertheless, it has been shown that motion does not constitute a fundamental limitation of optical mapping. Recent advancements of optical mapping indicated that undesired effects caused by motion can be efficiently reduced by applying appropriate optical and numerical signal post-processing techniques, see section 1.3. In principle, motion artifacts can be significantly reduced or even entirely removed by using numerical computer vision techniques, tracking the motion and stabilizing the image data. In this regard, several algorithms for post-acquisition motion artifact removal have been introduced, see section 1.3. Despite significant progress in the field, however, optical mapping of contracting hearts using numerical motion-compensation algorithms is not yet commonly used. Being able to perform optical mapping studies with beating hearts or other contracting cardiac tissue preparations is a highly desired objective in basic

*Corresponding author
**Principal corresponding author
Email addresses: jan.christoph@ds.mpg.de (J. Christoph), j.schroeder-schetelig@ds.mpg.de (J. Schröder-Schetelig), stefan.luther@ds.mpg.de (S. Luther)
URL: http://www.bmp.ds.mpg.de (S. Luther)
[1]Both authors contributed equally.