Chapter 13
Review of Machine Learning for Bioimpedance Tomography in Regenerative Medicine

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ABSTRACT

Monitoring cell growth and activities is crucial for regenerative medicine. Although optical imaging can provide high resolution, such methods are limited by the penetration depth. Bioimpedance tomography is an alternative way as it can overcome the penetration problem and possess the advantages of non-radiative, non-destructive, and high temporal resolution. In addition, with the rapid development of machine leaning, learning-based bioimpedance tomography is gradually introduced into regenerative medicine and demonstrates powerful potential. This chapter aims to provide an overview of the state-of-the-art machine learning methods of bioimpedance tomography in regenerative medicine while offering perspectives for future research directions. This chapter first summarizes the electrical properties of tissues and the principle of electrical impedance tomography (EIT) then extensively reviews the recent progress on learning-based single-modal and multi-modal imaging methods of EIT for regenerative medicine. Finally, promising future research directions are discussed.

DOI: 10.4018/978-1-6684-5092-5.ch013

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INTRODUCTION

In regenerative medicine, three-dimensional (3D) cell culture is of profound importance as it can better mimic the function of living tissues compared to cell monolayers, which has significant implications for drug screening. Providing better models of cell behavior may benefit the study and treatment of human diseases, reduce animal testing, and facilitate the development of decisional tools in the regenerative medicine domain. A key challenge in 3D cell culture is determining the cellular state in-depth and over time. Therefore, suitable imaging techniques are desired to monitor 3D cell culture continuously and non-destructively.

The emergence of agile, non-intrusive, and non-radiative tomography modalities, such as bioimpedance tomography (BT, or Electrical Impedance Tomography, EIT), can enable rapid, non-destructive, and label-free imaging in regenerative medicine. Bioimpedance tomography is an emerging imaging technique that measures bioimpedance to image cells and accordingly infers the physical properties of cells, such as the physiological status, shape, location, and dynamic response to drugs. The BT system places an array of electrodes around the region of interest (ROI) and measures the boundary voltages induced by currents successively injected into selected pair of electrodes. The resulting voltage measurements are processed to reconstruct the spatial conductivity distribution within the ROI. Image reconstruction of BT is a typical inverse problem that is nonlinear, ill-posed, and ill-conditioned. The spatial resolution that BT can typically achieve is around 10% of the diameter of the sensing region (Metherall et al., 1996).

Recent years have witnessed the explosive applications and research of BT in regenerative medicine, especially in 3D cell culture imaging. However, the long-standing challenges in sensor design and image reconstruction have hindered the massive adoption of BT as a standard tool in regenerative medicine. The issues to be addressed urgently include, for instance, sensor miniaturization and calibration, high-resolution/adaptive-resolution image reconstruction with preferable real-time performance, and quantitative tomographic image analysis.

This book chapter focuses on the latest developments in advanced machine learning-based image reconstruction methods for miniature BT systems in regenerative medicine and summarizes the recent progress and results of the relevant research, including model-based deep learning for BT and learning-based information fusion in regenerative medicine. The book chapter, together with the other chapters in the book, could interest the readers in the broad area of data-driven medical engineering and provide an overview of the state of the art in BT within regenerative medicine. The advancement of machine learning for BT in regenerative medicine can contribute to developing data-driven decisional tools in the field and thus ultimately generate significant clinical benefits for patients.

BACKGROUND

Electrical Properties of Tissues

The frequency-dependent electrical properties of biological cells and tissues have been widely reported, and they depend on the morphological, pathological, and physiological status of cells and tissues (Miklavčič et al., 2006; Pethig & Kell, 1987; Schwan, 1994). A simple model only considers the interfacial polarization, and the electrical properties of tissues depend on stimulation frequencies, cells, and extracellular matrices (Hanai, 1960; Heileman et al., 2013; Schwan, 1994). The current cannot flow through the cell

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