Impedance Spectroscopy of Adherent Mammalian Cell Culture for Biochemical Applications: A Review

By: Voiculescu, I (Voiculescu, Ioana)[1]; Li, F (Li, Fang)[2]; Nordin, AN (Nordin, Anis Nurashikin)[3]

View Web of Science ResearcherID and ORCID

IEEE SENSORS JOURNAL
Volume: 21 **Issue:** 5 **Pages:** 5612-5627
DOI: 10.1109/JSEN.2020.3041708
Published: MAR 1 2021
Document Type: Review
View Journal Impact

Abstract

This review paper is focused on various applications of electric cell-substrate impedance sensing (ECIS) using adherent, two-dimensional (2D) mammalian cell culture. The ECIS technique is a non-destructive electrical approach to in vitro monitor in continuous fashion and real time the cell behavior related to attachment, growth, morphology, motility, proliferation and viability. The use of living cells as sensorial elements provides the opportunity for analysis of a large variety of pharmaceutical compounds and toxicants that affect cellular responses. In this review, we will cover some of the most important applications of the ECIS technique such as: impedance of cancer cell, toxicity studies, and investigation of stem cell using impedance spectroscopy sensing. Contractile activity of beating cardiomyocytes recorded with ECIS will also be presented. Combination of impedance sensing and resonant frequency measurements of cell monolayer will be discussed. An innovative stretchable device with integrated ECIS electrodes will be discussed. Recently, the ECIS technique was combined with machine learning algorithms to distinguish stem cell proliferation from the differentiation processes. This review demonstrates that ECIS is a powerful tool, effective to investigate mammalian cell properties and physiological functions and provides advantages over conventional assays, including simple, rapid and noninvasive cell screening.

Keywords

Author Keywords: Impedance; Electrodes; Sensors; Impedance measurement; Substrates; Immune system; Monitoring; ECIS stem cell; ECIS cardiac cell; ECIS toxicity studies; ECIS cancer cell; impedance spectroscopy

Author Information

Reprint Address:
City University of New York (CUNY) System City College of New York (CUNY) CUNY City Coll, Dept Mech Engn, New York, NY 10031 USA.
Corresponding Address: Voiculescu, I (corresponding author)
+ CUNY City Coll, Dept Mech Engn, New York, NY 10031 USA.

Addresses:
+ [1] CUNY City Coll, Dept Mech Engn, New York, NY 10031 USA
[2] New York Inst Technol, Dept Mech Engn, Old Westbury, NY 11568 USA
+ [3] Int Islamic Univ Malaysia, Elect Engn Dept, Gombak 53100, Selangor, Malaysia

E-mail Addresses: voicules@ccny.cuny.edu; fli08@nyit.edu; anisnn@iium.edu.my

Funding

Funding Agency (Show details)	Grant Number
U.S. Army Research Office	W911NF-13-D-0001 5710004049-003
Consiliul National al Cercetarii Stiintifice (CNCS) Unitatea Executiva pentru Finantarea Invatamantului Superior, a Cercetarii, Dezvoltarii si Inovarii (UEFISCDI)	PN-III-P2-2.1-PED-2019-4423
Professional Staff Congress/CUNY (PSC-CUNY)	

View funding text

Publisher

IEEE-INST ELECTRICAL ELECTRONICS ENGINEERS INC, 445 HOES LANE, PISCATAWAY, NJ 08855-4141 USA

Journal Information

Impact Factor: Journal Citation Reports

Categories / Classification

Research Areas: Engineering; Instruments & Instrumentation; Physics

Web of Science Categories: Engineering, Electrical & Electronic; Instruments & Instrumentation; Physics, Applied

See more data fields

Cited References: 73

Showing 30 of 73 **View All in Cited References page** *(from Web of Science Core Collection)*

1. **Dynamic monitoring of beating periodicity of stem cell-derived cardiomyocytes as a predictive tool for preclinical safety assessment** — **Times Cited: 88**
By: Abassi, Yama A.; Xi, Biao; Li, Nan; et al.
BRITISH JOURNAL OF PHARMACOLOGY Volume: 165 Issue: 5 Pages: 1424-1441 Published: MAR 2012

2. **Real-Time Measurement of Melanoma Cell-Mediated Human Brain Endothelial Barrier Disruption Using Electric Cell-Substrate Impedance Sensing Technology** — **Times Cited: 5**
By: Anchan, Akshata; Kalogirou-Baldwin, Panagiota; Johnson, Rebecca; et al.
BIOSENSORS-BASEL Volume: 9 Issue: 2 Article Number: 56 Published: JUN 2019

3. **Bioelectrical impedance assay to monitor changes in cell shape during apoptosis** — **Times Cited: 215**
By: Arndt, S; Seebach, J; Psathaki, K; et al.
BIOSENSORS & BIOELECTRONICS Volume: 19 Issue: 6 Pages: 583-594 Published: JAN 15 2004

4. **The Use of Real-Time Cell Analyzer Technology in Drug Discovery: Defining Optimal Cell Culture Conditions and Assay Reproducibility with Different Adherent Cellular Models** — **Times Cited: 73**
By: Atienzar, Franck A.; Tilmant, Karen; Gerets, Helga H.; et al.
JOURNAL OF BIOMOLECULAR SCREENING Volume: 16 Issue: 6 Pages: 575-587 Published: JUL 2011

5. **Evaluation of Impedance-Based Label-Free Technology as a Tool for Pharmacology and Toxicology Investigations** — **Times Cited: 35**
By: Atienzar, Franck Andre; Gerets, Helga; Tilmant, Karen; et al.
BIOSENSORS-BASEL Volume: 3 Issue: 1 Special Issue: SI Pages: 132-156 Published: MAR 2013

6. **Real-time label-free monitoring of adipose-derived stem cell differentiation with electric cell-substrate impedance sensing** — **Times Cited: 142**
By: Bagnaninchi, Pierre O.; Drummond, Nicola
PROCEEDINGS OF THE NATIONAL ACADEMY OF SCIENCES OF THE UNITED STATES OF AMERICA Volume: 108 Issue: 16 Pages: 6462-6467 Published: APR 19 2011

7. **ECIS based wounding and reorganization of cardiomyocytes and fibroblasts in co-cultures** — **Times Cited: 10**
By: Cavallini, F.; Tarantola, M.
PROGRESS IN BIOPHYSICS & MOLECULAR BIOLOGY Volume: 144 Pages: 116-127 Published: JUL 2019

8. **Application of ECIS to Assess FCCP-Induced Changes of MSC Micromotion and Wound Healing Migration** — **Times Cited: 2**
By: Chiu, Sheng-Po; Lee, Yu-Wei; Wu, Ling-Yi; et al.
SENSORS Volume: 19 Issue: 14 Article Number: 3210 Published: JUL 12 2019

9. **Application of Electric Cell-Substrate Impedance Sensing to Investigate the Cytotoxic Effects of Andrographolide on U-87 MG Glioblastoma Cell Migration and Apoptosis** — **Times Cited: 4**
By: Chiu, Sheng-Po; Batsaikhan, Buyandelger; Huang, Huei-Mei; et al.
SENSORS Volume: 19 Issue: 10 Article Number: 2275 Published: MAY 2 2019

10. **Machine Learning for Stem Cell Differentiation and Proliferation Classification on Electrical Impedance Spectroscopy.** — **Times Cited: 1**
By: Cunha, Andre B; Hou, Jie; Schuelke, Christin
Journal of electrical bioimpedance Volume: 10 Issue: 1 Pages: 124-132 Published: 2019 -Jan

11. **Improved cell sensitivity and longevity in a rapid impedance-based toxicity sensor** — **Times Cited: 37**
By: Curtis, Theresa M.; Tabb, Joel; Romeo, Lori; et al.
JOURNAL OF APPLIED TOXICOLOGY Volume: 29 Issue: 5 Pages: 374-380 Published: JUL 2009

12. **A portable cell-based impedance sensor for toxicity testing of drinking water** — **Times Cited: 80**
By: Curtis, Theresa M.; Widder, Mark W.; Brennan, Linda M.; et al.
LAB ON A CHIP Volume: 9 Issue: 15 Pages: 2176-2183 Published: 2009

13. Title: [not available] Times Cited: 33
By: Freshney, RI.
Culture of Animal Cells: A Manual of Basic Technique and Specialized Applications Volume: 7 Published: 2016
Publisher: Wiley-Blackwell, New York

14. Data-Analytics Modeling of Electrical Impedance Measurements for Cell Culture Monitoring Times Cited: 4
By: Garcia, Elvira; Perez, Pablo; Olmo, Alberto; et al.
SENSORS Volume: 19 Issue: 21 Article Number: 4639 Published: NOV 2019

15. Cell line classification using electric cell-substrate impedance sensing (ECIS) Times Cited: 1
By: Gelsinger, M. L.; Tupper, L. L.; Matteson, D. S.
Int. J. Biostatistics Volume: 16 Issue: 1 Pages: 1-12 Published: Dec. 2019

16. A MORPHOLOGICAL BIOSENSOR FOR MAMMALIAN-CELLS Times Cited: 568
By: GIAEVER, I; KEESE, CR
NATURE Volume: 366 Issue: 6455 Pages: 591-592 Published: DEC 9 1993

17. MICROMOTION OF MAMMALIAN-CELLS MEASURED ELECTRICALLY Times Cited: 614
By: GIAEVER, I; KEESE, CR
PROCEEDINGS OF THE NATIONAL ACADEMY OF SCIENCES OF THE UNITED STATES OF AMERICA Volume: 88 Issue: 17 Pages: 7896-7900 Published: SEP 1991

18. Estimating the Risk of Drug-Induced Proarrhythmia Using Human Induced Pluripotent Stem Cell-Derived Cardiomyocytes Times Cited: 188
By: Guo, Liang; Abrams, Rory M. C.; Babiarz, Joshua E.; et al.
TOXICOLOGICAL SCIENCES Volume: 123 Issue: 1 Pages: 281-289 Published: SEP 2011

19. Zyxin is involved in thrombin signaling via interaction with PAR-1 receptor Times Cited: 15
By: Han, Jingyan; Liu, Guoquan; Profirovic, Jasmina; et al.
FASEB JOURNAL Volume: 23 Issue: 12 Pages: 4193-4206 Published: DEC 2009

20. Detection of the osteogenic differentiation of mesenchymal stem cells in 2D and 3D cultures by electrochemical impedance spectroscopy Times Cited: 63
By: Hildebrandt, Cornelia; Bueth, Heiko; Cho, Sungbo; et al.
JOURNAL OF BIOTECHNOLOGY Volume: 148 Issue: 1 Special Issue: SI Pages: 83-90 Published: JUL 1 2010

21. Simulation of microelectrode impedance changes due to cell growth Times Cited: 84
By: Huang, XQ; Nguyen, D; Greve, DW; et al.
IEEE SENSORS JOURNAL Volume: 4 Issue: 5 Pages: 576-583 Published: OCT 2004

22. Study of small-cell lung cancer cell-based sensor and its applications in chemotherapy effects rapid evaluation for anticancer drugs Times Cited: 26
By: Hui Guohua; Lu Hongyang; Jiang Zhiming; et al.
BIOSENSORS & BIOELECTRONICS Volume: 97 Pages: 184-195 Published: NOV 15 2017

23. Expression of WAVEs, the WASP (Wiskott-Aldrich syndrome protein) family of verprolin homologous proteins in human wound tissues and the biological influence on human keratinocytes Times Cited: 11
By: Jiang, Wen G.; Ye, Lin; Patel, Girish; et al.
WOUND REPAIR AND REGENERATION Volume: 18 Issue: 6 Pages: 594-604 Published: NOV-DEC 2010

24. Impedance-Based Detection of Beating Rhythm and Proarrhythmic Effects of Compounds on Stem Cell-Derived Cardiomyocytes Times Cited: 65
By: Jonsson, Malin K. B.; Wang, Qing-Dong; Becker, Bruno
ASSAY AND DRUG DEVELOPMENT TECHNOLOGIES Volume: 9 Issue: 6 Pages: 589-599 Published: DEC 2011

25. Real-time impedance assay to follow the invasive activities of metastatic cells in culture Times Cited: 122
By: Keese, CR; Bhawe, K; Wegener, J; et al.
BIOTECHNIQUES Volume: 33 Issue: 4 Pages: 842 -+ Published: OCT 2002

26. A BIOSENSOR THAT MONITORS CELL MORPHOLOGY WITH ELECTRICAL FIELDS Times Cited: 100
By: KEESE, CR; GIAEVER, I
IEEE ENGINEERING IN MEDICINE AND BIOLOGY MAGAZINE Volume: 13 Issue: 3 Pages: 402-408 Published: JUN-JUL 1994

27. Cell-substratum interactions as a predictor of cytotoxicity Times Cited: 45
By: Keese, CR; Karra, N; Dillon, B; et al.
IN VITRO & MOLECULAR TOXICOLOGY-A JOURNAL OF BASIC AND APPLIED RESEARCH Volume: 11 Issue: 2 Pages: 183-192 Published: SUM 1998

28. Electrical wound-healing assay for cells in vitro Times Cited: 293
By: Keese, CR; Wegener, J; Walker, SR; et al.

PROCEEDINGS OF THE NATIONAL ACADEMY OF SCIENCES OF THE UNITED STATES OF AMERICA Volume: 101 Issue: 6 Pages: 1554-1559 Published: FEB 10 2004

29. A microelectrode-based sensor for label-free in vitro detection of ischemic effects on cardiomyocytes Times Cited: 35
By: Krinke, Dana; Jahnke, Heinz-Georg; Paenke, Oliver; et al.
BIOSENSORS & BIOELECTRONICS Volume: 24 Issue: 9 Pages: 2798-2803 Published: MAY 15 2009

30. Label-free analysis of GPCR-stimulation: The critical impact of cell adhesion Times Cited: 12
By: Lieb, S.; Michaelis, S.; Plank, N.; et al.
PHARMACOLOGICAL RESEARCH Volume: 108 Pages: 65-74 Published: JUN 2016

Showing 30 of 73 **View All in Cited References page**