

Towards prediction of acute and chronic drug effects using multi-parameter profiling of hiPSC-derived cardiomyocytes

De Korte T¹, Wilbers R¹, Langenberg K¹, Nacken P¹, Vlaming MLH¹, Braam SR¹

¹Ncardia, Galileiweg 8, 2333 BD Leiden, The Netherlands

Abstract

Standardization and validation of hiPSC-derived cardiomyocyte-based assays for *in vitro* cardiac safety studies are currently assessed by the Comprehensive *in vitro* Proarrhythmia Assay (CiPA) consortium. Within CiPA, the acute effects of reference compounds (30±2 minutes after addition) are evaluated. However, besides acute effects on ion channels, especially chronic cardiotoxicity is a serious issue in the clinic.

In this study, we assessed both acute and chronic effects of a set of reference compounds on the electrophysiology and impedance of hiPSC-derived cardiomyocytes (Pluricyte® Cardiomyocytes).

While ion channel inhibitors, e.g. hERG-channel blocker E4031, clearly caused acute drug effects on the electrophysiology of cardiomyocytes, other compounds affected the electrophysiology or impedance only after longer incubation times. For example, lapatinib, a tyrosine kinase inhibitor significantly increased the impedance peak width after 16h (54%, $P \leq 0.01$) to 24h (114%, $P \leq 0.0001$) incubations. In addition, the antiprotozoal drug pentamidine did not cause any acute effects, but induced a field potential duration prolongation exclusively from 12 hours after treatment caused by disruption of hERG protein trafficking in Pluricyte® Cardiomyocytes.

Taken together, our results show that studying both acute and chronic drug-effects in hiPSC-derived cardiomyocytes enables a better understanding of the wide range of drug-induced cardiotoxicities that can occur and will help to explain the cellular mechanisms behind late onset drug-induced cardiomyopathy.

Human Pluricyte® Cardiomyocytes are fully functional and show a relatively high level of maturity

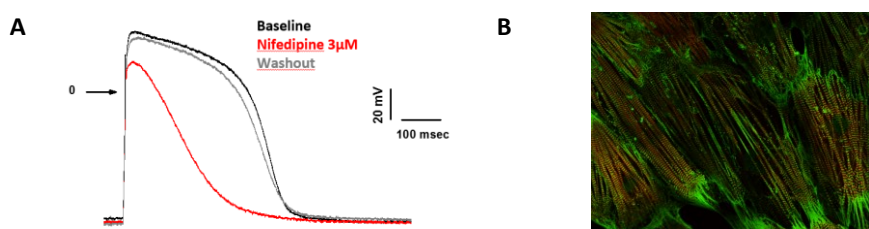


Figure 1. Characteristics of Pluricyte® Cardiomyocytes cultured in Pluricyte® Cardiomyocyte Medium.

A: A typical action potential of Pluricyte® Cardiomyocytes (measured by PhysioStim, Lautrec, France), demonstrating a low resting membrane (~-78mV) potential and fast upstroke velocity. As expected, L-type calcium channel blocker nifedipine decreased the APD20 (65%), APD90 (46%) and APA (6.2%). **B:** Pluricyte® Cardiomyocytes exhibit a high degree of ultra-structural sarcomere organization as determined by immunofluorescence (Green: alpha actinin; Red: myosin heavy chain 7).

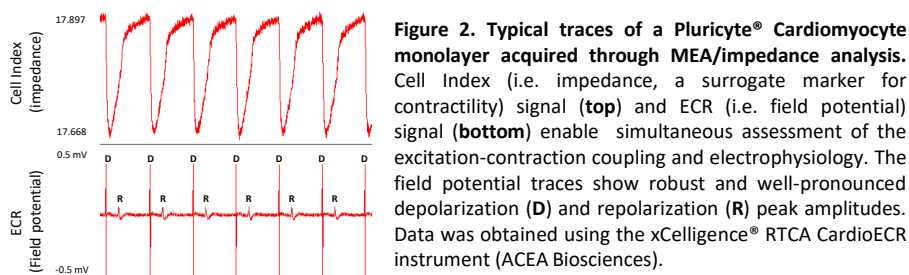


Figure 2. Typical traces of a Pluricyte® Cardiomyocyte monolayer acquired through MEA/impedance analysis. Cell Index (i.e. impedance, a surrogate marker for contractility) signal (top) and ECR (i.e. field potential) signal (bottom) enable simultaneous assessment of the excitation-contraction coupling and electrophysiology. The field potential traces show robust and well-pronounced depolarization (D) and repolarization (R) peak amplitudes. Data was obtained using the xCelligence® RTCA CardioECR instrument (ACEA Biosciences).

Ion channel blockers E4031 and nifedipine induce acute effects on the electrophysiology of Pluricyte® Cardiomyocytes

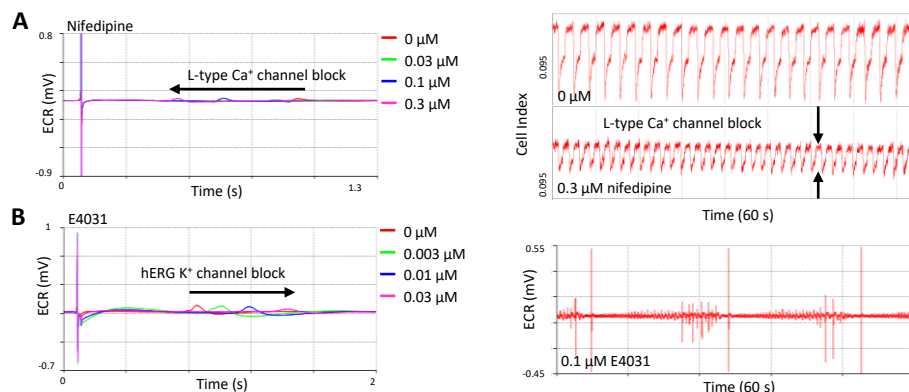


Figure 3. Acute effects of E4031 and nifedipine on the electrophysiology and impedance of Pluricyte® Cardiomyocytes. **A:** L-type calcium channel blocker, nifedipine, induced a clear decrease in field potential duration and Cell Index amplitude, which is line with the decrease in APD seen in Figure 1A. **B:** E4031, a hERG channel blocker, induced a concentration-dependent increase of the field potential duration and flattening of the repolarization peak. Arrhythmic-like events were observed at $\geq 0.1 \mu\text{M}$. Measurements were obtained using the xCelligence® RTCA CardioECR instrument (ACEA Biosciences).

The tyrosine kinase inhibitor, lapatinib, alters the excitation-contraction coupling in Pluricyte® Cardiomyocytes after long term incubation

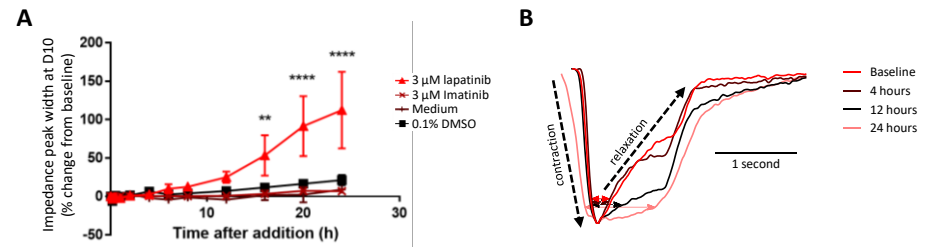


Figure 5. Long-term effect of lapatinib on the impedance peak width of Pluricyte® Cardiomyocytes. **A:** Unlike imatinib, lapatinib induced an increase in impedance peak width (D10) after 16h (54%, $P \leq 0.01$) to 24h (114%, $P \leq 0.0001$) post-addition, suggesting a long-term effect on the relaxation time of the cardiomyocytes. **B:** Overlay of impedance waveforms showing an increase in peak width in Pluricyte® Cardiomyocytes after long-term incubation with 3 μM lapatinib. 1 waveform represents the average of all wave forms recorded during one measurement of 60 seconds. Data was obtained using the xCelligence® RTCA CardioECR instrument (ACEA Biosciences). All error bars represent SDs. Significance values indicated are the result from Dunnett's multiple comparisons test, after performing two way ANOVA. ** $P \leq 0.01$, **** $P \leq 0.0001$.

The hERG trafficking inhibitor, pentamidine, induces an increase in field potential duration of Pluricyte® Cardiomyocytes after long term incubation

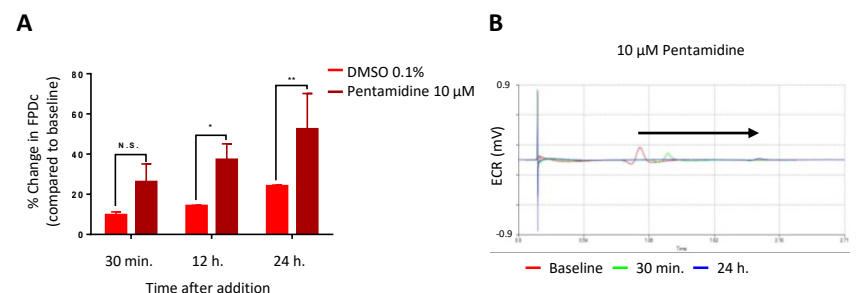


Figure 6. Long-term effect of pentamidine on the field potential duration of Pluricyte® Cardiomyocytes. **A:** Pentamidine showed no acute effects on the hERG channel, but after 24 hours of incubation, it significantly increased the field potential duration by disrupting hERG protein trafficking. **B:** An overlay of field potential traces show an increase in field potential duration and flattening of the repolarization peak of Pluricyte® Cardiomyocytes after 24 hours incubation with 10 μM pentamidine. Data was obtained using the xCelligence® RTCA CardioECR instrument (ACEA Biosciences). All error bars represent SDs. Significance values indicated are the result from Dunnett's multiple comparisons test, after performing two way ANOVA. * $P \leq 0.05$, ** $P \leq 0.01$.

Doxorubicin and Geldanamycin affect Pluricyte® Cardiomyocyte cell viability after long-term incubation

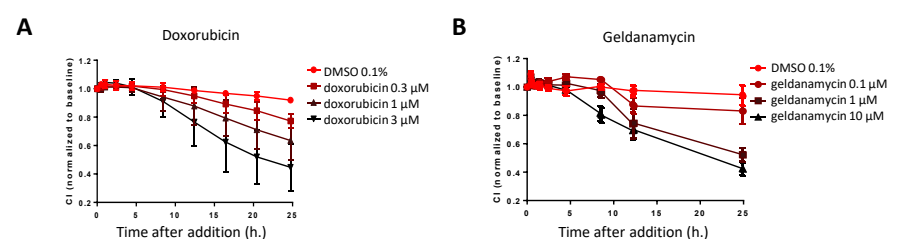


Figure 7. Long-term effect of doxorubicin and geldanamycin on the cell viability of Pluricyte® Cardiomyocytes. Since changes in cell morphology and adhesion are reflected by changes in impedance, impedance can be used as a label-free readout for long-term cell viability. **A:** The anticycline, doxorubicin, induced a concentration- and time-dependent decrease in cell viability from 12 hours after addition. **B:** Geldanamycin, an ER-to-Golgi traffic inhibitor, induced a time-dependent decrease in cell viability at 1 μM and 10 μM from 12 hours after addition. Data was obtained using the xCelligence® RTCA CardioECR instrument (ACEA Biosciences). All error bars represent SDs.

Concluding Remarks

- Pluricyte® Cardiomyocytes cultured in Pluricyte® Cardiomyocyte Medium show a ventricular, relatively mature phenotype.
- The typical long-term effects of anti-cancer drugs and (hERG) trafficking inhibitors are observed in Pluricyte® Cardiomyocytes by measuring the impedance, field potential or cell viability in a long-term, label-free and real-time manner.
- Studying both acute and long-term cardioactive effects in hiPSC-derived cardiomyocytes using a multi-parameter approach could provide a more detailed cardiotoxicity profile of (novel) compounds. This approach will further improve safety pharmacology decision-making at an early stage of drug development.

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