MOLECULAR BASIS OF ELECTROPHYSIOLOGICAL DIVERSITY OF NEOCORTICAL INTERNEURONS

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Abstract

- A full understanding of how ion channels are expressed and function in non-pathological conditions is the first step in order to determine the identity of ion channels whose malfunction leads to pathological situations.
- Up till now studies investigating ion channel expression and function have been limited to a few channels. The complex firing patterns displayed by neurons are not due to a single ion channel but to the interaction between ion channel constellations co-expressed by the neuron.
- We recently developed single cell multiplex RT-PCR protocols that allow simultaneous detection of mRNAs encoding for more than 51 proteins from fully morphologically and electrophysiologically characterized neurons.
- This mRNA profile includes 3 calcium binding proteins, 9 neuropeptides, 5 enzymes and over 24 K^+ and 9 Ca^{2+} channel alpha and beta subunits.
- Whole-cell patch clamp recordings from interneurons in layers 2 to 6 were performed in somatosensory cortex neocortical slices of juvenile rats (P13-P16). After whole-cell the electrophysiological properties of the cells were studied in detail, the neuron was loaded with biocytin for subsequent 3 D anatomical computer reconstructions and at the end of the experiment cytoplasm was aspirated for subsequent single cell RT-PCR.

Introduction

A major challenge in the post-genomic era is to establish the functions of specific genes and combinations of genes. This becomes a high-priority issue in the case of channelopathies, pathological states suspected to be caused by ion channel malfunction. In order to determine which ion channels are causing these pathologies we must first fully understand how ion channels are express and function in non -pathological conditions. Up till now studies investigating ion channel expression and function have been limited to a few channels. Nevertheless the complex neuron's firing patterns are not result of the activity of a single ion channel but of the interaction between ion channel constellations co-expressed by the neuron. While it is believed that these electrophysiological behaviors are generated because neurons express different combinations of ion channel genes, the actual expression profile that underlies the behavior of any specific type of neuron, is not known. The aim of this study was to derive the genetic basis of the electrophysiological behaviors of normal interneurons. To achieve this goal the electrophysiological behavior of single neocortical interneurons was obtained using the whole-cell patch-clamp technique and the gene expression profile (mRNA) of a spectrum of ion channels and molecular markers was determined by harvesting the cytoplasm of the neuron and using the single cell multiplex RT-PCR technique. Neurons were also loaded with the neuronal dye, biocytin, to allow 3D anatomical computer reconstruction and identification of the recorded neurons.

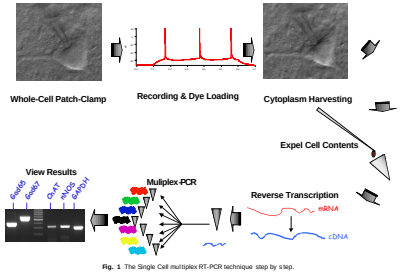


Fig. 1 The Single Cell multiplex RT-PCR technique step by step.

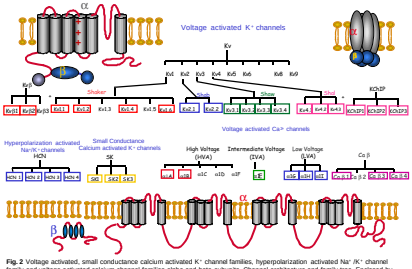
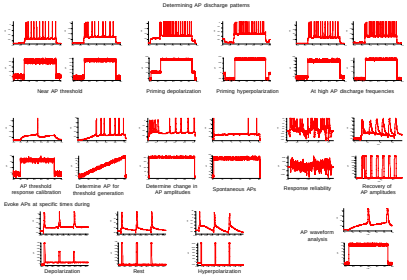


Fig. 2 Voltage activated, small conductance calcium activated K^+ channel families, hyperpolarization activated Na^+/K^+ channel family and voltage activated calcium channel families alpha and beta subunits. Channel architecture and family tree. Enclosed by a squareare the subunits whose mRNA expression was simultaneously tested in this study.



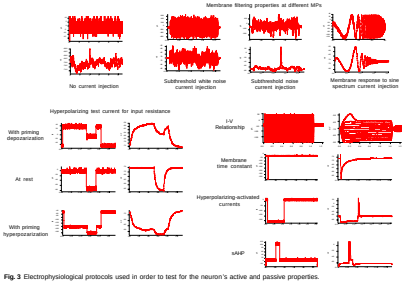


Fig. 3 Electrophysiological protocols used in order to test for the neuron's active and passive properties.

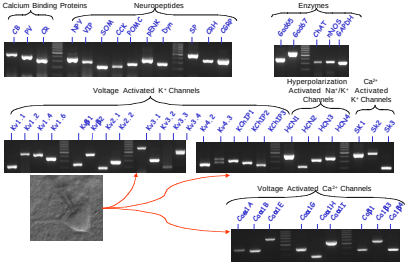


Fig. 4 Agarose Gels showing the PCR products for the 51 mRNAs simultaneously tested (in this case from 250pg of total brain cDNA).

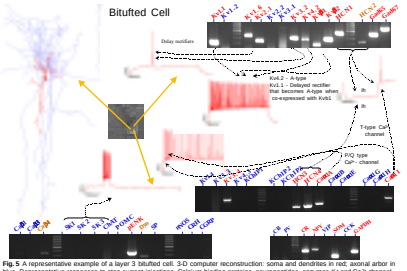


Fig. 5 A representative example of a layer 3 bitufted cell. 3-D computer reconstruction: soma and dendrites in red, axonal arbor in blue. Representative responses to step current injections. Calcium binding proteins, neuropeptides, enzymes K^+ and Ca^{2+} channel mRNA expression profile.

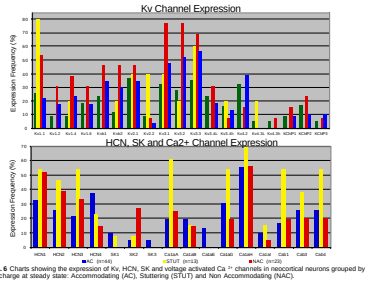


Fig. 6 Charts showing the expression of Kv, HCN, SK and voltage activated Ca $^{2+}$ channels in neocortical neurons grouped by discharge at steady state: Accommodating (AC), Stuttering (STUT) and Non Accommodating (NAC).

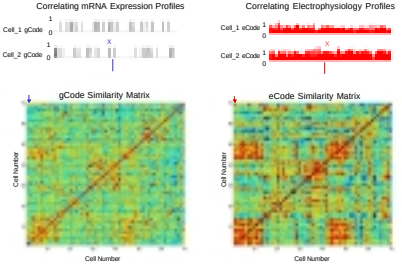


Fig. 7 How the gCode Correlation Matrix and the eCode Correlation Matrix are obtained.

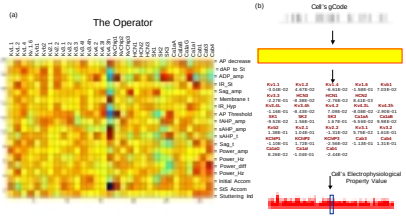


Fig. 8 (a) Matrix of the coefficient values for obtaining 20 electrophysiological parameters. Red colors indicate high values for the coefficients and blue means low values. **(b)** How the "Operator" works.

Conclusions

- This study revealed interesting insights in how gene expression can influence the electrophysiological behavior of a neuron.
- It has given a detailed description of rat neocortical interneurons, which up to now had not been systematically studied on the molecular level combined with electrophysiological behavior.
- This study showed that the molecular diversity of interneurons is far greater than assumed from their seemingly homogeneous electrophysiological behavior. The core of the study is that mathematical means could be applied to find correlations between electrophysiological features and gene expression profiles.
- Using the applied techniques it will also be possible to get precise information about developmental changes in ion channel expression and firing patterns in healthy and non-healthy animals.