Available online at www.sciencedirect.com
ScienceDirect
Mathematical Biosciences 207 (2007) 352–364
Mathematical Biosciences
www.elsevier.com/locate/mbs

Scaling properties of pyramidal neurons in mice neocortex

Andreas Schierwagen [a,*], Alán Alpár [b], Ulrich Gärtner [b]

[a] *Institute for Computer Science, University of Leipzig, 04109 Leipzig, Germany*
[b] *Department of Neuroanatomy, Paul Flechsig Institut for Brain Research, University of Leipzig, 04109 Leipzig, Germany*

Received 2 June 2006; received in revised form 21 August 2006; accepted 24 August 2006
Available online 5 September 2006

Abstract

Dendritic morphology is the structural correlate for receiving and processing inputs to a neuron. An interesting question then is what the design principles and the functional consequences of enlarged or shrinked dendritic trees might be. As yet, only a few studies have examined the effects of neuron size changes. Two theoretical scaling modes have been analyzed, conservative (isoelectrotonic) scaling (preserves the passive and active response properties) and isometric scaling (steps up low pass-filtering of inputs). It has been suggested that both scaling modes were verified in neuroanatomical studies. To overcome obvious limitations of these studies like small size of analyzed samples and restricted validity of utilized scaling measures, we considered the scaling problem of neurons on the basis of large sample data and by employing a more general method of scaling analysis. This method consists in computing the morphoelectrotonic transform (MET) of neurons. The MET maps the neuron from anatomical space into electrotonic space using the logarithm of voltage attenuation as the distance metric. The theory underlying this approach is described and then applied to two samples of morphologically reconstructed pyramidal neurons (cells from neocortex of wildtype and synRas transgenic mice) using the NEURON simulator. In a previous study, we could verify a striking increase of dendritic tree size in synRas pyramidal neurons. Surprisingly, in this study the statistical analysis of the sample MET dendrograms revealed that the electrotonic architecture of these neurons scaled roughly in a MET-conserving mode. In conclusion, our results suggest only a minor impact of the Ras protein

* Corresponding author. Tel.: +49 341 9732234; fax: +49 341 9732299.
E-mail address: schierwa@informatik.uni-leipzig.de (A. Schierwagen).

0025-5564/$ - see front matter
doi:10.1016/j.mbs.2006.08.019

on dendritic electroanatomy, with non-significant changes of most regions of the corresponding METs.

Keywords: Pyramidal neurons; Dendritic morphology; Dendrogram; Scaling; Morphoelectrotonic transform

1. Introduction

Most neurons of the mammalian central nervous system exhibit a wide variety of branched dendritic trees. The recent advances in recording and staining techniques as well as in computer-assisted methods of acquiring digitized neuronal morphology in 3D have boosted attempts to reveal dendritic structure–function relationships [1].

According to the current view, dendritic morphology is seen as the structural correlate for receiving and processing inputs to a neuron. In evolution and development, the size of neurons with their dendrites has changed. An interesting question then is what the design principles and the functional consequences of enlarged or shrinked dendritic trees might be [2].

The adoption of transgenic mice mutants has provided a new means to investigate this problem, among others. Transgenic mice mutations serve for understanding gene function, as well as for developing therapies for genetic diseases. In these mutants, the gene overexpression may affect several organs and tissues, including the brain.

In a specific mouse mutant (introduced by [3] and referred to as synRas mice), a permanently active Ras protein (Val12-Ha-Ras) in post-mitotic neurons is expressed. In this mutant the expression of Ras starts post-natally around day 15, when neurons are post-mitotic and the majority of synaptic contacts has been established. The volume of the neocortex of synRas mice is expanded up to 25% as compared to wildtype mice. In particular cortical pyramidal neurons express the synRas construct at high levels resulting in a dramatically enlarged volume of the cortical pyramidal cells which is mainly caused by increased dendritic diameter and tree degree [4,5]. The number of neurons, however, remains unchanged [3].

Changes are generally more prominent in layer V than in layers II/III. Topological analyses [6] revealed significant differences between synRas and wildtype mice regarding any parameters considered, i.e., number of intersections, branching points (nodes) and tips (leaves), in both basal dendrites and the apical arbor of layer V neurons but not of layers II/III neurons. In subsequent studies these findings have been substantiated [7,8].

The significance of such changes in dendritic morphology to a neuron's capabilities for receiving and processing inputs could be examined in various ways. Using compartmental models of reconstructed cortical neurons and model neurons, recent simulation studies have investigated the role of branching complexity and spatial distribution of dendritic volume in determining neural integration, synaptic plasticity, and the firing patterns that define neuronal function [9–11].

In this study, we employed compartmental modeling to simulate the electrotonic properties of both wildtype and synRas pyramidal neurons. In particular, we used the morphoelectrotonic transform (MET, cf. [12,23]) to explore the scaling mode realized by the larger dendritic trees of synRas pyramidal cells.