Chapter 3.21
Astrocytes and Biological Neural Networks

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ABSTRACT

Artificial neural networks are a neurobiologically inspired paradigm that emulates the functioning of the brain. They are based on neuronal function, because neurons are recognized as the cellular elements responsible for the brain information processing. However, recent studies have demonstrated that astrocytes can signal to other astrocytes and can communicate reciprocally with neurons, which suggests a more active role of astrocytes in the nervous system physiology and fundamental brain functions. This novel vision of the glial role on brain function calls for a reexamination of our current vision of artificial neural networks, which should be expanded to consider artificial neuroglial networks. The neuroglial network concept has not been yet applied to the computational and artificial intelligent sciences. However, the implementation of artificial neuroglial networks by incorporating glial cells as part of artificial neural networks may be as fruitful and successful for artificial networks as they have been for biological networks.

INTRODUCTION

Artificial neural networks—a neurobiologically inspired paradigm that emulates the functioning of the brain—are based on the way we believe that neurons work, because they are recognized as the cellular elements responsible for the brain information processing. Two main cell types exist in the brain: neurons and glia. Among the four main subtypes of glia, astrocytes are the most common cells in the central nervous system (CNS). Astrocyte function has long been thought to be merely supportive of neural function. However, recent studies have demonstrated that astrocytes can signal to other astrocytes—forming a new type of cellular network in the brain—and can communicate bidirectionally with neurons, which

suggests a more active role of astrocytes in fundamental brain functions, regulating neuronal excitability and synaptic transmission (for a review see Araque, Carmignoto, & Haydon, 2001). Based on these new findings, glia is now considered as an active partner of the synapse, dynamically regulating synaptic information transfer as well as neuronal information processing. This novel vision of the glial role on brain function calls for a reexamination of our current vision of artificial neural networks, which should be expanded to consider glial cells to create artificial neuroglial networks.

In some areas of the nervous system, glial cells outnumber nerve cells 10 to 1. Glia (from the Greek, meaning glue) is important in providing a homeostatic environment to the nerve cells as well as being involved in other functions. There are three main types of glial cells in the central nervous system: astrocytes, oligodendrocytes, and microglia. Astrocytes have many processes that branch out in a starlike formation. Functions of astrocytes include: structural support for nerve cells; proliferation and repair following injury to nerves; participation in metabolic pathways that modulate extracellular concentration of ions, transmitters, and metabolites involved in functions of nerve cells and synapses. Oligodendrocytes are mainly responsible for the formation of myelin around axons in the central nervous system. These myelin sheaths play an important role in the improvement of the nerve conduction properties. While oligodendrocytes are specifically present in the central nervous system, the myelin is formed by Schwann cells in the peripheral nervous system. The third type of glial cells, microglia, are smaller cells present throughout the central nervous system that function as immune system cells in the CNS.

The astroglial cells, or astrocytes, are connected through gap junctions forming a relatively large electrically coupled syncytium. The single cells have long processes, and some of them establish contacts with blood vessels, forming part of the blood-brain barrier. Other processes extend toward and encapsulate synapses, especially glutamatergic synapses (i.e., excitatory synapses that release the neurotransmitter glutamate) and also the varicosities, from which other neurotransmitters such as monoamines are released. Neuronal cell bodies, neuronal processes, and the brain surface are also encapsulated by astroglial processes.

The astroglial cell mass constitutes a prominent part of the total brain cell number and volume (Peters, Palay, & Webster, 1991). More than 100 years ago, Virchow proposed that these cells have a metabolic and structural supportive role for neurons. Since then and until the last 15 to 20 years, this idea of astrocytes as simple supportive and passive cells has been maintained. Very little attention was paid to the astroglial cells for decades, mostly because the absence of conspicuous physiological function in the electrophysiological behaviour of the nervous system. Indeed, while neurons were relatively easy to identify using electrophysiological techniques due to their ability to fire action potentials, astrocytes can be depolarized but no action potential or other significant active electrical behaviour can be elicited.

In the last years, it has been shown that, in addition to the relevant functions in brain homeostasis (e.g., supplying energy to neurons, controlling the concentration of ions and neurotransmitters in the extracellular space, and synthesizing and releasing neurotrophic factors), astrocytes have the capacity to monitor synaptic activity, to sense the composition of the extracellular space and the blood serum, to integrate the information obtained, and to influence neuronal activity and synaptic transmission by regulating the extracellular concentration of neurotransmitters and by releasing neuroactive substances (called gliotransmitters) (for reviews see Araque et al., 2001; Volterra, Magistretti, & Haydon, 2002).

In this chapter, we will provide an overview of our current knowledge of astroglial physiology and their impact in the neuronal physiology, and we