© 2015. Published by The Company of Biologists Ltd | The Journal of Experimental Biology (2015) 218, 504-505 doi:10.1242/jeb.119412

EDITORIAL

On the origins of that most transformative of biological systems – the nervous system

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While small, free-living, multicellular organisms with dimensions akin to those of a colonial choanoflagellate are obviously able to function and survive in the absence of a recognizable nervous system, the emergence of larger body masses and, most importantly, the appearance of long tentacles or other appendages, could probably not have occurred were it not for the emergence of neurons and nervous systems. Indeed, it is arguable that the success of the Metazoa can be attributed, in large part, to the presence of nervous systems.

Nervous systems have been studied extensively for centuries, but despite enormous advances in our understanding of the structural, functional and, now, molecular properties of the components of nervous systems, very little attention has been paid to the questions of when and how did the transformative series of events that manifested itself in a nervous system happen, and whether or not nervous systems evolved independently more than once.

Inherent in any such discussion is the question of what we actually mean by 'a nervous system'. The most immediate answer – a nervous system is an assembly of neurons or nerve cells – then begs the far more profound question: 'what is a neuron'? The 'I know one when I see one' reply that question typically generates, while very unsatisfying, clearly reflects enormous uncertainty as to what actually constitutes a neuron. The ability to produce action potentials is obviously not sufficient as muscles (Huxley, 1974), epithelial cells (for review, see Mackie, 2004) and exocrine cells (Goldring et al., 1983) can all produce fast overshooting action potentials that differ little from those produced by nerve cells. Moreover, non-spiking neurons (Smarandache-Wellmann et al., 2013) are present in diverse organisms. The presence of synaptic structures alone is not sufficient, as many cell types receive synaptic input, and many primary sensory cells convey sensory information to an animal's nervous system through chemical synapses.

Perhaps nowhere is the concept of 'what is a neuron?' more blurred than in certain epithelial conduction systems. In the case of salps, for instance, changes in the swimming frequency and direction of all the individuals in a chain, in response to mechanical stimuli, are achieved using a combination of the animal's nervous system and epithelial conduction through the animal's outer epithelium (Bone et al., 1980; Anderson and Bone, 1980). The epithelium in any one individual is innervated by the animal's CNS and propagates the resulting, fast, overshooting action potentials through that epithelium to discrete populations of epithelial cells that contain small vesicles apposed to the external cell membrane. Fine ciliary processes project from neurons in the adjacent salp through the acellular tunic that separates them, to the immediate vicinity of the modified vesicle-containing epithelial cells. Thus, the outer epithelium of a salp has the ability to receive chemical synaptic input (from the CNS), to use that input to generate fast action potentials, which propagate via electrical synapses to adjacent cells, and to use that activity to release a transmitter substance that excites postsynaptic neurons. These are all functional properties one would normally attribute to neurons, yet there is little doubt that we are talking about epithelial cells as opposed to neurons.

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One obvious feature of neurons that may well explain the 'I know one when I see one' response is the presence of long cellular processes, the axons and dendrites. This is not an exclusive feature of neurons inasmuch as some glial cells and many primary sensory receptors also bear long processes, but is a convenient commonality. For this to be accepted as a defining character, however, one must then address the question of how long a process must be for an (electrically excitable) cell to be called a neuron. Indeed, even in mammals there is a large continuum of process lengths in cells that are recognized as neurons.

The broad question of when and where did the nervous system first appear has not been addressed seriously since the 1989

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The Journal of Experimental Biology

'Evolution of the First Nervous Systems' (Anderson, 1989) meeting. The intervening 25 years have seen a plethora of new information that has derived from the molecular biology revolution, information that has radically altered our understanding of metazoan phylogeny, most importantly that of the early groups in which nervous systems were thought to have first evolved, and our understanding of the origins of the molecular toolbox that enable neuronal function. At the same time, great advances have been made in our understanding of the properties and capabilities of the earliest extant nervous systems, capabilities that often decry their being described as 'simple'.

This special issue reflects the content of the 'Evolution of the First Nervous Systems II' meeting, held in the spring of 2014, and revisits the question of when and where nervous systems as we know them first evolved. It does so through papers that describe our current understanding of the phylogeny of early Metazoa, in particular as it relates to the presence or absence of neurons, together with a series of papers that describe how the behavior of early metazoans is controlled, whether it be by neuronal or non-neuronal mechanisms. The issue also includes a series of papers that highlight the fact that the molecular components of what we would normally associate with neuronal function (e.g. ion channels, receptors, transmitter release mechanisms) evolved far before the emergence of the Metazoa, often for other functions. The Inside JEB article constitutes a synopsis of the meeting and of the organized discussions that focused on several pertinent questions including 'what is a neuron?', 'why did neurons emerge?' and 'did nervous systems evolve independently more than once?'. This summary aims not only to convey the scope of the discussions and any conclusions derived from them but also to provide a framework for future work on these intriguing subjects.

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