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New Tools for Examining Neurons and Glia Using Quantum Dot

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ABSTRACT: Quantum dot nanotechnologies will need simple methods that are easily replicable in a standard neurobiology lab. These findings mark the first application of quantum dots in glial cells. Given the special qualities that quantum dots have to offer in the brain, their future appears to be rather promising.

KEYWORDS: Neuroscience, Glial Cell, Quantum Dots, Nan robots Quantum Mechanics.

I. INTRODUCTION

Semiconductor fluorescent quantum dots are nanometer-sized functionalized particles with distinct physical characteristics that make them especially well-suited for seeing and monitoring cellular molecular processes using conventional fluorescence microscopy (Jaiswal et al., 2003; Watson et al., 2003; Michalet et al., 2005). They exhibit little photobleaching, which enables molecular tracking over long periods of time. They also exhibit a blinking property that enables the identification of individual quantum dots. They are easily excitable, have broad absorption spectra with very narrow emission spectra, and can be multiplexed with many different coloured quantum dots. Because single molecule binding events can be recognised and followed using optical fluorescence microscopy, research that would be challenging or impossible using traditional experimental approaches may now be conducted. Applications for quantum dots that are specialised to neuroscience are beginning to appear. While other research is advancing the technology's development, other research has focused on leveraging this nanotechnology to address interesting cellular and molecular problems. A heavy metal core, such as cadmium selenide or cadmium telluride, an intermediate, inert zinc sulphide shell, and a bespoke outer coating of various bioactive molecules suited to a particular use make up quantum dots, which are nanometer-sized particles. Quantum dots (5–8 nm) have a unique and extremely stable set of fluorescent optical characteristics that are easily adjustable by altering their physical makeup or size. Similar to traditional immunocytochemistry, the photochemical characteristics of quantum dots enable the selective fluorescent tagging of proteins. Quantum dots also result in significantly lower photobleaching and a greater signal-to-noise ratio. It is impossible to multiplex numerous quantum dots of various colours in the same material using conventional fluorophores because of their wide absorption spectra but relatively restricted emission spectra. The physics behind these phenomena are outside the scope of this brief introduction, however due to the quantum dot particles' tiny size, there are huge yet precise energy jumps between excited electron-hole pairs' energy band gaps in the semi-conductor core. This phenomenon causes scaling changes in absorption and emission wavelengths as a function of particle size, such that minute variations in quantum dot radius result in noticeably different colour changes (Arya et al., 2005; Vanmaekelbergh and Liljeroth, 2005). This physical characteristic is another significant benefit over conventional organic fluorophores, which often need separate chemistries to create diverse hues. Quantum dots may be chemically functionalized to target proteins at high ligand-receptor concentrations for biological purposes. Recent research has demonstrated that quantum dots conjugated with natural ligands are easily internalised into cells, do not interfere with intracellular signalling, and are harmless, at least in some biological systems (Chan et al., 2002; Murphy, 2002; Jain, 2003; Watson et al., 2003; West and Halas, 2003).

II. NEUROLOGY AND QUANTUM DOTS

A novel tool with significant potential for brain research is quantum dot technology. They not only provide an alternative to conventional immunocytochemistry but are also very helpful for research on neurons and glia. Using fluorescent microscopy, quantum dots may be utilised to see, quantify, and track individual molecular events. They also

enable the visualisation and long-term monitoring of dynamic molecular processes (e.g., from seconds to many minutes). Other methods or approaches make it challenging to acquire these features. Quantum dots, for instance, can be used for experiments that are constrained by the altered architecture of neuronal and glial interactions, such as the synaptic cleft's tiny size or the interaction between an astrocyte process and a neuron. They are also ideally suited for tracking the molecular dynamics of intracellular and/or intercellular molecular events over extended time periods because to their very tiny size and optical resolution. However, it should be understood that functionalized quantum dots' hydrodynamic radius is bigger (15–20 nm) than their real size (5–8 nm) (Larson et al., 2003). The promise of this technology is demonstrated by recent neuroscience studies utilising quantum dots. In cultures of primary spinal cord neurons, Triller and colleagues (Dahan et al., 2003) employed antibody functionalized quantum dots to monitor the lateral diffusion of glycine receptors. They were able to show that the diffusion dynamics differed depending on whether the receptors were synaptic, peri-synaptic, or extrasynaptic by following the journey of individual glycine receptors for tens of minutes at spatial resolutions of 5–10 nm. Nerve growth factor (NGF) was attached to quantum dots by Vu et al. (2005), who then employed them to encourage neuronal-like development in PC12 cells in culture. These methods might ultimately be utilised to observe and monitor the functional responses in neurons. There are, however, warnings as with any new technology. For instance, NGF conjugated to quantum dots displayed lower activation compared to NGF that was free, according to Vu et al. (2005). Other organisations are advancing the technology and offering fresh tools based on quantum dots. A method to create biocompatible, water-soluble quantum dot micelles while preserving the optical characteristics of individual quantum dots was developed by Brinker and colleagues (Fan et al., 2005). Hippocampal neurons in vitro exhibited uptake and intracellular dispersion of these micelles. A modified quantum dot labelling strategy is being developed by Ting and colleagues (Howarth et al., 2005) in order to address the relatively high size of antibody-quantum-dot conjugates and the instability of some quantum-dot-ligand interactions. Their method directly biotinylates a 15 aa polypeptide known as an acceptor protein (GLNDIFEAQKIEVWHE) onto cell surface proteins, making it a target for streptavidin-conjugated quantum dots. They were able to selectively identify and monitor AMPA receptors on cultured hippocampus neurons using this method.

III. CONCLUSION

In the end, quantum dot nanotechnologies will need simple methods that are easily replicable in a standard neurobiology lab. However, most quantum dot methods we have encountered in the peer-reviewed literature and in instructions from commercial sources are designed for non-neural mammalian cells and do not always easily function with primary neurons, glia, and similar cell lines. It is noteworthy that, as far as we are aware, these findings mark the first application of quantum dots in glial cells. Given the special qualities that quantum dots have to offer in the field of brain research, their future appears to be rather promising (and stable)

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