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Organization, Progress, and Flexibility of Dendritic Spines

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Short Communication

A diverse assortment of spine-like protrusions emerges from dendrites. Most spines in the central nervous system have stubby, thin, mushroom or branched shapes. Multi-lobed structures called 'thorny excresences' have one or more synapses on each lobe and are present, for example, on proximal dendrites of hippocampal CA3 pyramidal cells. Dendritic spines are present at the squid giant synapse, suggesting that they may have developed early in the evolution of the nervous system. We are only just beginning to understand how the structure, formation, and plasticity of relatively simple dendritic spines can influence synaptic function, and it is some of these advances that I will discuss in this review. Dendritic spines are the primary postsynaptic targets of excitatory glutamatergic synapses in the mature brain. Even simple spines have remarkably diverse structures. They range in volume from less than 0.01 pm" for small thin spines to 0.8 pm" for large mushroom spines. Dendritic spines and synapses of different sizes and shapes occur on the same dendrite. Similarly, a single presynaptic varicosity can form synapses with two or more spines of different dimensions. Hence, spine structure is not completely determined by either the presynaptic or the postsynaptic cell.

Spine synapses have a thickened postsynaptic density (PSD), which occupies about 10% of the spine surface. The PSD ranges from a simple disc shape on smaller spines to a highly irregular shape on larger spines. Many structural, receptor, and signalling proteins are anchored in the PSD. The AMPA class of glutamatergic receptors are preferentially located in larger PSDs of hippocampal spines. Cell-cell adhesion junctions, who contain distinct structural and signalling molecules, are present at the edges of about half of the PSDs and also between spines and neighbouring astrocytes processes. Like the molecules of the PSD, those of the cell adhesion junctions modulate synaptic transmission and plasticity. Dendritic spines are further distinguished by their composition of subcellular organelles. For example, about 50% of all hippocampal spines contain smooth endoplasmic reticulum (SER), which is specialized to form the 'spine apparatus' in 80% of the large spines. Some spines contain smooth and/or coated vesicles, multivesicular bodies, or polyribosomes. Thus, remodeling of synaptic structure via insertion of postsynaptic vesicles or via new protein synthesis could take place in or near spines, and degradation could be initiated in spines via the endocytic pathway [1].

Differences in spine structure can be important for synaptic integration and molecular compartmentalization. Both of these functions are especially sensitive to the length and diameter of the spine neck. Theoretical modelling shows that a thinner and longer neck results in greater depolarization of the spine head for a given synaptic input. Depending on the exact configuration of receptors and voltage-dependent channels, the effects of this property can range from strengthening a particular synapse to recruiting neighbouring synapses in a coordinated depolarization of the dendrite. Similarly, imaging shows that the degree to which calcium is elevated in the spine independently from the dendrite is influenced by spine shape. A small calcium signal in a spine can be amplified by an inositol-triphosphate-dependent release of calcium from the SER. This effect is restricted to neighbouring spines along a short dendritic segment. Limiting the spread of calcium may provide both input specificity for the activated synapses and neuroprotection for the dendritic shaft and soma, where high concentrations of calcium can lead to micro tubular breakdown, dendritic swelling, and other degenerative consequences of calcium-induced excitotoxicity.

References

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