Parvalbumin-expressing basket cells: From fast signaling to gamma oscillations

Parvalbumin-expressing basket cells (BCs) play a key role in the operation of neuronal networks, controlling action potential initiation in principal neurons by feedforward and feedback inhibition. Previous studies revealed that these interneurons behave as fast signaling devices. However, the mechanisms underlying the generation of fast and temporally precise GABA release at BC output synapses are poorly understood. To address this question, we made paired recordings between synaptically connected BCs and granule cells in the dentate gyrus of acute hippocampal slices and organotypic slice cultures. Our results revealed that the mechanisms of transmitter release differ substantially from those at other synapses. First, BCs exclusively use P/Q-type Ca^{2+} channels for transmitter release. Second, Ca^{2+} source and Ca^{2+} sensor appear to be tightly coupled, with distances in the range of 20 nm. Finally, inhibitory synaptic transmission at BC output synapses is maintained in synaptotagmin 1-deficient mice, suggesting that BCs use a Ca^{2+} sensor different from that of other synapses.

Parvalbumin-expressing BCs also play a key role in the generation of network oscillations in the gamma frequency range. These oscillations are thought to provide a temporal structure for information processing in the brain. As inhibitory synapses between interneurons are thought to be particularly important in this context, we studied the properties of BC-BC synapses, again using paired recordings. In contrast to previous views, which suggested that inhibition is slow, weak, and hyperpolarizing, we found that inhibition at BC-BC synapses was fast, strong, and shunting. Based on these experimental observations, we have developed a ‘reality-based’ interneuron network model and studied the ability of this model to generate coherent gamma oscillations when exposed to a tonic excitatory drive. Surprisingly, we found that fast, strong, and shunting synapses led to efficient synchronization if combined with a short synaptic delay. Realistic synaptic properties made the model more robust against heterogeneity in the excitatory drive.

In conclusion, several mechanisms converge on the generation of fast signaling at BC output synapses. Also, fast signaling at these synapses plays a key role for the generation of gamma oscillations in neuronal networks. Thus, BC output synapses provide a nice example how synaptic properties shape complex functions of neuronal networks.