Role of Endocannabinoids in 5-HT2 Receptor-mediated Effects

William M. Connelly and Matthew J. Baggott

1 Department of Pharmacology & Toxicology, Otago School of Medical Sciences, University of Otago, Dunedin, New Zealand

2 Helen Wills Neuroscience Institute, University of California Berkeley

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*Corresponding Author: William M. Connelly, Pharmacology Department, University of Otago, P.O. Box 913, Dunedin NEW ZEALAND. Email: bill.connelly@otago.ac.nz

Post Address for Matthew J. Baggott: Helen Wills Neuroscience Institute, University of California Berkeley Berkeley, CA 94720. Email: matthew@baggott.net

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Abstract

Endocannabinoids are lipid retrograde messengers that can be released by postsynaptic depolarization and/or activation of certain metabotropic receptors. We review a recent report that activation of metabotropic 5-HT2 receptors by endogenous serotonin induces the release of endocannabinoids in the olivary nucleus and suppresses glutamatergic input through a presynaptic action. This serotonin/endocannabinoid interaction has implications in the pathophysiology of pain and mental illness and raises the possibility that drugs targeting the 5-HT2 receptor may act by modulating endocannabinoid release.
Receptor-driven endocannabinoid (eCB) release was first demonstrated in the cerebellum, where glutamate released from climbing fiber terminals acted on metabotropic glutamate subtype 1 receptors (mGluR1) expressed on Purkinje cells. The activation of mGluR1s subsequently caused the release of eCBs, which depresses climbing fiber input. Later research showed receptor-driven eCB release is not confined to mGluRs. Orexin-B and muscarinic acetylcholine M1 and M3 receptors are all capable of inducing eCB release (reviewed by Hashimotodani et al., 2007). eCB release can also be triggered by the Ca transient evoked by strong post-synaptic depolarization.

Because eCBs are lipid molecules and are released as soon as they are synthesized, synthesis is a key event in initiating eCB signaling. The pathways of eCB synthesis are not fully characterized. However, there appear to be independent mechanisms involving phospholipase C (PLC) in some cases (receptor-driven eCB release) and increased intracellular Ca\(^{2+}\) in others (i.e., depolarization-induced eCB synthesis). These two pathways can interact synergistically, so when combined they allow eCBs to be released by levels of depolarization and metabotropic receptor activation that would not produce eCB release on their own (reviewed by Chevaleyre et al., 2006).

eCBs can inhibit neurotransmitter release over both short- and long-term time scales. Short-term depression manifests via CB1R-mediated inhibition of presynaptic Ca\(^{2+}\) channels, enhanced presynaptic K\(^{+}\) conductance and by affecting release machinery downstream of Ca\(^{2+}\) influx. Long-term depression is less well-defined and is thought to involve coactivation of presynaptic NMDA receptors and CB1Rs. eCB-mediated synaptic
plasticity has been implicated in learning and memory and the distribution of CB1Rs in the brain suggests specific roles the control of pain, motivation, emotion, learning and cognition (reviewed by Chevaleyre et al., 2006).

In recent work, Best and Regehr (2008) add serotonin to the list of neurotransmitter systems with receptors able to trigger eCB release. In this study, both 5-hydroxytryptamine 2 receptor (5-HT2Rs) and 5-hydroxytryptamine 1B receptor (5-HT1BRs) activation decreased the probability of glutamate release in the inferior olive and the effect of 5-HT2Rs was prevented by a CB1R antagonist. The authors took advantage of a novel brainstem slice that preserves serotonergic neurons and their synapses onto the inferior olive. Because these serotonergic inputs are physically separated from glutamatergic input from mesodiencephalic regions, they were able to study the interactions of these two inputs on olivary neurons (Fig A). Whole-cell voltage clamp of neurons in the dorsal principal olive revealed that exogenous 5-HT (10µM) depressed the amplitude of evoked excitatory post-synaptic currents (EPSCs) by more than 80%. This effect was mimicked by the high affinity 5-HT2R agonist TCB-2, but was only fully suppressed by a combination of 5-HT2R and 5-HT1BR antagonists. This modulation was presynaptic, as it increased the paired pulse ratio of the evoked EPSCs and had no effect on the amplitude of currents evoked by exogenous glutamate application.

Given that other Gq coupled receptors can evoke eCB release, Best and Regehr investigated whether the serotonergic suppression of evoked EPSC amplitude was
cannabinoid dependent. CB1R agonists depressed the amplitude of evoked EPSCs to a similar extent as serotonergic agonists, and, importantly, the reduction of evoked EPSC amplitude produced by selective activation of 5-HT2R was blocked by selective CB1R antagonists.

Activating receptors with exogenous agonists does not replicate physiological recruitment. First, there is always the risk of non-selective effects caused by ligands straying onto other receptors. Second, 5-HT2A receptors undergo agonist-directed trafficking, meaning that different agonists can preferentially recruit different second messenger cascades (Parrish and Nichols, 2006). Finally, the temporo-spatial characteristics of agonist stimulation will vastly differ between bath application and neuronal release of a neurotransmitter.

To stimulate 5-HT2 receptors with greater physiological validity than afforded by exogenous agonists, the researchers electrically stimulated the slice dorsal to the inferior olive with a one-second 50Hz train. This initiated a slow 5-HT2R-mediated postsynaptic inward current (presumably by activating serotonergic fibers from the nucleus reticularis paragigantocellularis; Figure 1B). A single train induced a serotonergic current that lasted for ~10s but depressed evoked EPSCs for approximately 25s in a manner that was sensitive to 5-HT2/5-HT1B antagonist coapplication. The inhibition of glutamate release induced by endogenous serotonin was mediated by eCB release as a CB1R antagonist blocked it. Thus, one effect of serotonin in the inferior olive is 5HT2R-mediated eCB release, which acts retrogradely via CB1R to suppress glutamate release.
Unfortunately, the role the 5-HT1B R plays in the 5-HT evoked depression of glutamate release remains unclear. The authors repeatedly demonstrate that the blockade of both 5-HT1B and 5-HT2 receptors is required to block the effect of serotonergic agonists (either 5-HT or TCB-2). While the suppression of glutamate release by 5-HT2 R activation is clearly shown to be CB1 receptor dependent, the study does not address whether the suppression of glutamate release by 5-HT1B receptor activation also relies on CB1 receptor function.

It is also worth considering the 50Hz stimulation frequency used to recruit a bundle of serotonergic fibers. How well this models the physiological firing rates of the individual neurons in these fibers remains unclear. Limited recordings from putative serotonergic neurons in the nucleus reticularis paragigantocellularis have shown rates between 30 and 70Hz during or after painful stimuli (Leung and Mason, 1995). Nonetheless, it would have been informative to see a ‘frequency-response’ relationship between serotonergic fiber stimulation frequency and evoked EPSC depression, to document how hard one needs to stimulate 5-HT release in order to produce eCB release.

The finding that 5-HT2R activation triggers eCB release is consistent with past evidence of possible functional recruitment of eCBs by 5-HT2Rs. For example, 5-HT2AR agonists cause a PLC-dependent increase in the release of the eCB 2-arachydonylglycerol in cultured fibroblasts (Parrish and Nichols, 2006). 5-HT2AR agonists induce a stereotypic
"wet dog shake" in rats and these behaviors are abolished in the presence of CB1 receptor antagonists (Gorzalka et al., 2005).

Previous studies have also suggested a possible functional recruitment of eCBs by 5-HT2Rs in pain states. eCB and 5-HT concentrations are elevated in many brain regions in models of neuropathic pain (Hohmann et al., 2005; Palzo et al., 2006). Both cannabinoids and SSRIs have analgesic effects, the latter putatively through 5-HT2Rs mechanism (Honda et al., 2006). Indeed, stress-induced analgesia is both dependent on eCBs and blocked by 5-HT2R antagonism (Tokuyama et al., 1993; Hohmann et al., 2005). It would accordingly be interesting to see if the increase in eCB levels during the stress-induced analgesia paradigm were blocked by 5-HT2R antagonism.

In their discussion, Best and Regehr suggest that many of the clinically significant effects of 5-HT2R may be mediated by eCBs. This is an intriguing idea. 5-HT2AR agonists, such as LSD, and high doses of CB1R agonists, such as Δ9-tetrahydrocannabinol (THC), have similar hallucinogenic effects that may model some aspects of schizophrenia, and recreational use of cannabinoids may increase susceptibility to schizophrenia/psychosis (reviewed in Roser et al. 2008). This raises the natural question of whether cannabinoid manipulations might have a role in treatment of psychosis. A 4-week, controlled, double-blind clinical trial of cannabidiol, a weak partial CB1R antagonist, in 42 schizophrenic patients, showed that cannabidiol reduced acute psychotic signs and symptoms to a degree that did not differ from the antipsychotic D2/D3 receptor antagonist amisulpride. However, the selective CB1 antagonist rimonabant (SR141716) was no more effective than a placebo in a trial of 72 patients with schizophrenia or schizoaffective disorder
(reviewed in Roser et al 2008). Even if CB1R blockade does not prove useful on its own, it is possible that this approach may find use as an adjunct to dopamine D2 receptor antagonism, much in the same way as atypical antipsychotics derive additional efficacy from 5-HT2R antagonism.

The interaction between serotonin and eCB systems reported by Best and Regehr suggests that therapeutic drugs acting via 5-HT2Rs may produce their action, at least in part, by modulating eCB release. Because there are many (patho)physiological states that involve heightened serotonergic activity, it may prove fruitful to investigate the role of eCB release in these states. One may also ask how many more Gq linked receptors may directly activate eCB synthesis. This study opens new vistas for understanding the serotonin system and reveals a potential rationale for therapeutic approaches to treating psychosis and neuropathic pain.
References


Figure 1. Schematic of the experimental protocol and the pathway by which eCB release is caused by 5-HT2Rs. A: Diagram showing the position of the stimulating electrode for recruiting glutamatergic input into the inferior olive (left electrode), location of the whole-cell recording (bottom right electrode) and area where stimulation activated serotonergic fibers (top right electrode). Inset: Plane and angle of the inferior olivary slice. B: By activating serotonergic fibers a 5-HT2 mediated current could be induced which produced a depression in glutamate release. 1 shows the slow serotonergic current and the fast glutamatergic currents before, during and after the evoked serotonin release. 2 shows the sensitivity of the serotonergic current to a 5HT2R antagonist, ritanserin. 3 shows the depression of EPSC amplitude by the serotonergic current (time 0) and its sensitivity to the CB1 receptor antagonist AM251. C, 5-HT is released by serotonergic neurons and activates 5-HT2Rs which produce diacylglycerol (DAG), via the action of phospholipase c (PLC). DAG is metabolized by DAG lipase (DAGL) to eCBs, which in turn cause eCB release which act in a retrograde fashion to depress glutamate release. Depolarization, presumably by activating voltage sensitive Ca\(^{2+}\) channels and increasing intracellular Ca\(^{2+}\) concentration can also generate eCBs. Pathways outlined in grey were not directly demonstrated by Best and Regehr (2008) but exist in other brain regions and potentially act here too. A-B, modified from Best and Regehr (2008) with permission.