

# We are IntechOpen, the world's leading publisher of Open Access books Built by scientists, for scientists

**4,800**

Open access books available

**122,000**

International authors and editors

**135M**

Downloads

Our authors are among the

**154**

Countries delivered to

**TOP 1%**

most cited scientists

**12.2%**

Contributors from top 500 universities



**WEB OF SCIENCE™**

Selection of our books indexed in the Book Citation Index  
in Web of Science™ Core Collection (BKCI)

Interested in publishing with us?  
Contact [book.department@intechopen.com](mailto:book.department@intechopen.com)

Numbers displayed above are based on latest data collected.

For more information visit [www.intechopen.com](http://www.intechopen.com)



# Pharmacology of 5-HT<sub>2</sub> Modulation of Amygdala & Hypothalamus in Anxiety Disorders

Xiaolong Jiang<sup>1</sup>, Aiqin Chen<sup>2</sup>, Stanley Smerin<sup>3</sup>, Lei Zhang<sup>3</sup> and He Li<sup>3</sup>

<sup>1</sup>*Department of Pharmacology University of Virginia*

<sup>2</sup>*Fujian Medical University,*

*Department of Psychiatry and Centre for the Study of Traumatic Stress*

<sup>3</sup>*Uniformed Services University of the Health Sciences*

<sup>1,3</sup>USA

<sup>2</sup>PRC

## 1. Introduction

“Anxiety disorders” is a blanket term covering several different forms of abnormal and pathological fear and anxiety, and is often comorbid with other mental disorders, particularly clinical depression. These conditions are often related to stressful life experiences, especially when chronic and traumatic. Stress appears to act as a predisposing and precipitating factor in these psychiatric conditions (Strohle and Holsboer, 2003). One particular, extreme case is post traumatic stress disorder (PTSD), a chronic anxiety disorder developed in the aftermath of traumatic stress exposure and persisting long after the removal of the participating stressors.

Advances in cellular and molecular biology and imaging technology have opened several lines of inquiry into the pathogenesis and pharmacotherapy of the anxiety disorders. Dysregulation of neurotransmitter systems, alteration of signal transduction pathways, and reshaping of brain circuitry are all being explored. The availability of animal models of anxiety disorders developed from the “learned helplessness” stress paradigm, in particular, has been a great aid in elucidation of disease etiology and pathophysiology, as well as in the development of more efficacious pharmacological interventions (Drevets, 2003; Maier and Watkins, 2005; Minor and Hunter, 2002). Among several hypotheses for the pathogenesis of anxiety disorders, dysregulation of the serotonergic system has received particular attention in the field since the evidence from both preclinical and animal model studies is substantial and often complementary. In this chapter, we focus on a subset of the serotonergic system, the 5-HT<sub>2</sub> receptor system, and review both clinical and preclinical evidence regarding the involvement of this receptor in the pathophysiology of anxiety disorders.

## 2. Neuronal circuitry associated with anxiety disorders

The phenotypic complexity of anxiety disorders indicates that multiple neurotransmitter systems and brain structures are involved in the pathogenesis of such disorders. The

neuronal circuits associated with anxiety disorders appear to involve distributed and interconnected brain structures, including the amygdala, frontal cortex, and amygdala. These structures are also principal recipient regions of the ascending serotonergic pathway originating in the dorsal raphé nucleus (DRN), and with this innervation, form the important DRN-corticolimbic pathway in the brain, a critical component of the neuronal network associated with regulation of stress/emotional response (Graeff et al., 1993;Spannuth et al., 2011;Hale et al., 2010;Kawano et al., 1992). Dysregulation of this pathway has long been recognized in the occurrence of stress-related psychiatric syndromes, including depressive disorders and anxiety disorders (Southwick et al., 1999;van Praag, 2004a). Among various serotonin (5-hydroxytryptamine 5-HT) receptor systems, alterations of the postsynaptic 5-HT<sub>2</sub> receptor system in the forebrain may be particularly relevant to the pathophysiology of stress-related psychiatric conditions. There is a general consensus among many PET scan studies that there is decreased forebrain 5-HT<sub>2A</sub> receptor density in drug-naïve depressed patients (Akin et al., 2004;Malone et al., 2006;Messa et al., 2003;Mintun et al., 2004;Sheline et al., 2004). Several studies also showed that the therapeutic action of antidepressants is associated with an increase and/or normalization in brain 5-HT<sub>2A</sub> receptor density (Massou et al., 1997;Messa et al., 2003;Sheline et al., 2004;Zanardi et al., 2001). Thus, it is hypothesized that diminished 5-HT<sub>2A</sub> receptor signaling in the forebrain is associated with the cognitive syndrome observed in PTSD and certain subgroups of depressive illnesses (van Praag, 2004a;van Praag, 2004b).

Animal studies also suggest the involvement of forebrain 5-HT<sub>2</sub> receptor signaling in stress-related psychiatric conditions. For example, activation of 5-HT<sub>2C</sub> receptors in the amygdala during traumatic stress is necessary for the expression of anxiety-like behaviors after traumatic stress exposure (Christianson et al., 2010). Inescapable stress induces a decrease in 5-HT<sub>2A</sub> receptor expression in the amygdala, and hippocampus (Dwivedi et al., 2005), and hypothalamus (Dwivedi et al., 2005;Petty et al., 1997;Wu et al., 1999), and the decrease in the number of 5-HT<sub>2A</sub> receptors in the hypothalamus and hippocampus appears to be specifically associated with behavioral depression after exposure to stress (Dwivedi et al., 2005). In addition, alterations of 5-HT<sub>2A</sub> receptor signaling in the amygdala have been specifically implicated in the initiation of lasting changes in anxiety-like behavior following predator stress and traumatic stress (Adamec et al., 2004;Jiang et al., 2009). Thus stress-related psychiatric syndromes, including various anxiety disorders, may evolve from altered 5-HT<sub>2</sub> receptor signaling in the forebrain (Graeff et al., 1996;Menard and Treit, 1999).

### **3. 5-HT<sub>2</sub> receptor expression and its neuronal function in the amygdala**

The region of the forebrain involved in anxiety disorders that will be focused on herein is the amygdala, a brain region located deep in the anterior temporal lobe. It is believed that abnormal neural excitability and plasticity in the amygdala is an essential feature of multiple types of anxiety disorders and may be directly linked with the expression of the symptoms associated with stress-related psychiatric conditions. 5-HT<sub>2</sub> receptors appear to be highly expressed in the amygdala (Morilak et al., 1994;Pompeiano et al., 1994;Wright et al., 1995) and thus may serve an important modulatory role in fear and anxiety response. The 5-HT<sub>2</sub> receptor has three subfamilies, including 5-HT<sub>2A</sub>, 5HT<sub>2B</sub> and 5-HT<sub>2C</sub>. Both 5-HT<sub>2A</sub> and 5-HT<sub>2C</sub> receptors have been shown to be highly expressed in the amygdala(Xu and Pandey,

2000;Pompeiano et al., 1994;Jiang et al., 2009). The immunofluorescence data from several laboratories show that the 5-HT<sub>2A</sub> receptor labeling is primarily localized to the soma and dendrites of interneuron-like cells in the basolateral amygdala (BLA), and that the majority of the 5-HT<sub>2A</sub> signal overlapped with the labeling for the interneuron marker parvalbumin, indicating the 5-HT<sub>2A</sub> receptor is localized to the interneuron. Interestingly, 5-HT<sub>2A</sub> receptor immunofluorescence was found to be rarely observed in the pyramidal cells of the BLA, indicating that 5-HT<sub>2A</sub> receptor expression is restricted to interneurons in the BLA, while the 5-HT<sub>2C</sub> receptor may be primarily expressed on the pyramidal cells. In addition, the receptors density of various subtypes of 5-HT<sub>2</sub> receptor is dynamically regulated by age, gender, hormones and various experimental conditions associated with anxiety (Chen et al., 1995a;Chen et al., 1995b;Jiang et al., 2009).

The specific expression of 5-HT<sub>2A</sub> and 5-HT<sub>2C</sub> receptors in different neuronal components of the amygdala may be related to their specific modulation of neuronal functions in the amygdala and of behavioral responses. Indeed, the observations from several laboratories, particularly our own, support this contention, and activation of 5-HT<sub>2A</sub> and 5-HT<sub>2C</sub> receptors induce different neuromodulation in the amygdala and different behavioral responses. Restriction of 5-HT<sub>2A</sub> receptors to interneurons in the amygdala suggests that 5-HT<sub>2A</sub> receptors participate in inhibitory modulation of the amygdala circuitry. Indeed, a recent publication has shown that the 5-HT<sub>2A</sub> receptor is the primary receptor responsible for the serotonergic facilitation of GABA release in the amygdala (Jiang et al., 2009). Activation of this receptor on amygdala interneurons appears to induce the depolarization of the interneurons and facilitate the GABA release from these neurons (Jiang et al., 2009). Since any mediator facilitating GABAergic synaptic transmission in the BLA should induce an anxiolytic effect, it would be expected that the 5-HT<sub>2A</sub> receptor is anxiolytic. Activation of this receptor has been observed to induce an anxiolytic effect, although that this action is mediated by the amygdala has not been confirmed (Ripoll et al., 2006;Bourin et al., 2005;Nic Dhonnchadha et al., 2003).

Activation of 5-HT<sub>2C</sub> receptors in the BLA, in contrast, induce anxiety-like effects in animals (Hackler et al., 2006;Campbell and Merchant, 2003;Antonio Pedro de Mello Cruz et al., 2005,Christianson et al., 2010), suggesting that 5-HT<sub>2C</sub> receptor activation enhances neuronal excitability in the amygdala. The data from our laboratory suggest that the 5-HT<sub>2C</sub> receptors may play a modulatory role by promoting NMDA function on pyramidal cells in the amygdala. For example, application of the 5HT<sub>2</sub> receptor agonist 1-(2,5)-dimethoxy-4-iodophen-2-aminopropane (DOI) enhances NMDA receptor-mediated excitatory postsynaptic potentials and calcium influx, and as a consequence, transforms theta-burst stimulated synaptic plasticity from short-term potentiation (STP) to long-term potentiation (LTP) in the BLA (Chen et al., 2003). The facilitating effects of DOI were blocked by the 5-HT<sub>2</sub> receptor antagonist, ketanserin, and by the 5-HT<sub>2C</sub>-receptor selective antagonist, RS102221 (Chen et al., 2003). Therefore, activation of the 5HT<sub>2C</sub> receptor may induce anxiety-like effects in animals primarily by enhancing NMDA receptor function in the BLA.

In conclusion, 5-HT<sub>2A</sub> and 5-HT<sub>2C</sub> receptors appear to be expressed in the different components of the amygdala neuronal circuitry and have opposite functional roles in modulating the amygdala circuitry and the behavioral responses associated with this circuitry. Pharmacotherapy tailored to modulating the effect of 5-HT<sub>2A</sub> and 5-HT<sub>2C</sub> receptors in the BLA may have therapeutic implications in anxiety disorders.



#### 4. Anxiety disorders and dysregulation of 5-HT<sub>2</sub> modulated signaling pathways in the amygdala

Since 5-HT<sub>2</sub> receptors in the amygdala play important neuromodulatory roles in fear and stress responses, dysregulation of 5-HT<sub>2</sub> receptor signaling in the amygdala may result in the abnormal and pathological fear and stress responses manifested in different forms of anxiety disorders. Specifically, any condition promoting 5-HT<sub>2C</sub> receptor signaling or decreasing 5-HT<sub>2A</sub> receptor signaling would predispose the amygdala to over-respond to any sensory input, and anxiety status may ensue. Indeed, overexpression of 5-HT<sub>2C</sub> receptors in forebrain, particularly in the amygdala, has been observed to lead to elevated anxiety in animals (Kimura et al., 2009). Clinical data and preclinical data also suggest that diminished 5-HT<sub>2A</sub> receptor signaling in the forebrain, including the amygdala, may contribute to pathogenesis of the cognitive syndrome observed in PTSD and certain subgroups of depressive illnesses (van Praag, 2004a;van Praag, 2004b).

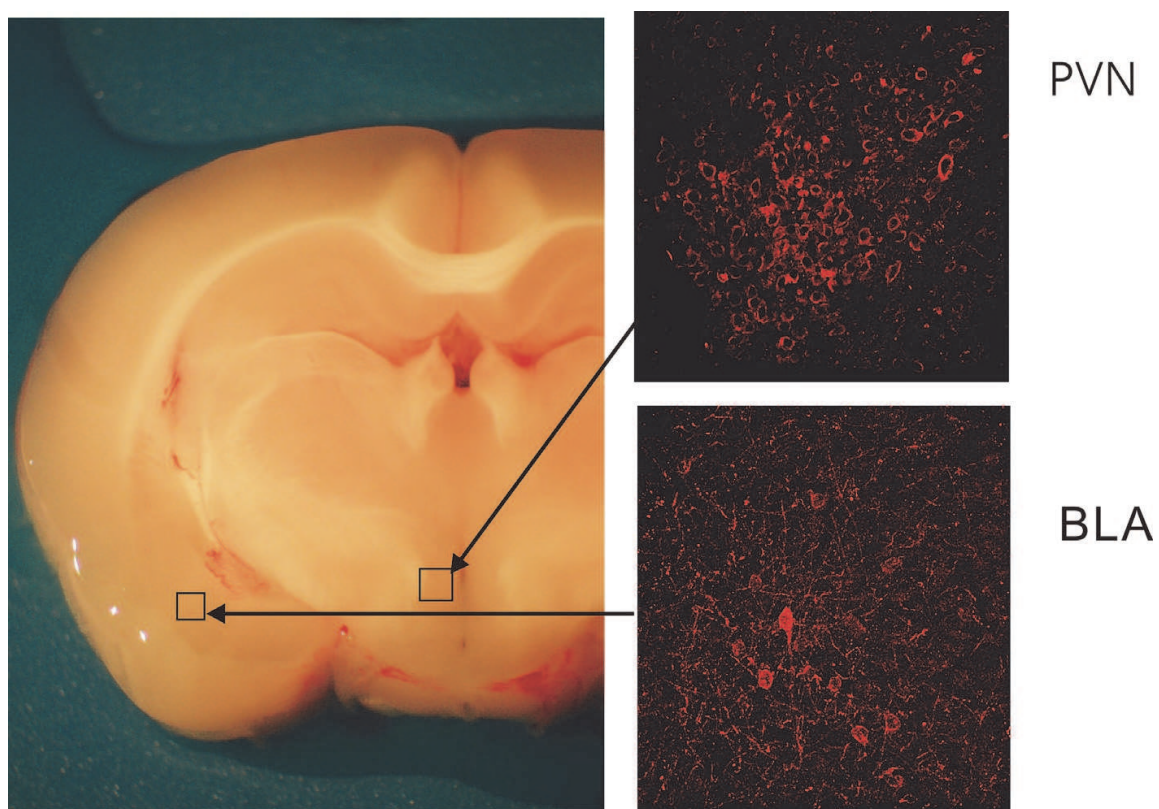


Fig. 1. 5-HT<sub>2</sub> receptors in the BLA and in the paraventricular nucleus (PVN) of the hypothalamus: Immunohistochemistry with specific anti-5HT<sub>2</sub> receptor antibodies reveals 5HT<sub>2</sub> receptors on somata in both the BLA and PVN. In the BLA, 5HT<sub>2</sub> receptors appear on dendrites and axons as well (see text for details.)

More convincing data come from animal studies. Chronic or traumatic stress, a primary etiologic factor for anxiety disorder, particularly PTSD, appears to readily impair central 5-HT<sub>2A</sub> receptor signaling, including in the amygdala (Abi-Saab et al., 1999; Dwivedi et al., 2005; Jiang et al., 2009; Wu et al., 1999), suggesting that stress induces anxiety in animals by impairing 5-HT<sub>2A</sub> signaling in the forebrain, particularly in the amygdala. If this is true, then it would be expected that 5-HT<sub>2A</sub> receptor antagonists, administered during stress, would

prevent the subsequent occurrence of abnormalities reminiscent of anxiety disorders in animals since the antagonists would prevent the receptors being downregulated and impaired. Indeed, several laboratories have observed that administration of 5-HT<sub>2A</sub> receptor antagonists during stress averts several behavioral manifestations of anxiety status in animals, including exaggerated acoustic startle response and open arm avoidance in the plus maze (Adamec et al., 2004; Jiang et al., 2009). In conclusion, alterations of 5-HT<sub>2</sub> receptor signaling, particularly 5-HT<sub>2A</sub> receptor signaling in the amygdala, may be a significant contributor in the pathogenesis of anxiety disorders.

Alterations of 5-HT<sub>2</sub> receptor signaling could result from receptor downregulation and degradation, or the disturbance of downstream signal pathways. The 5-HT<sub>2</sub> receptor is a G protein-coupled receptor and activation of the receptor leads to activation of phosphoinositide phospholipase C (PLC) and accumulation of D-myo-inositol-1,4,5-trisphosphate (IP<sub>3</sub>) and diacylglycerol (DAG), each of which then leads to its own signaling cascade, mediating a diverse array of physiological responses (Hall et al., 1999; Schmid and Bohn, 2009). Several studies suggest that disturbance of downstream signal pathways of 5-HT<sub>2</sub> receptor, including abnormal PLC and

PKC activity, may also be involved in the pathophysiology of stress-related psychiatric conditions (Akin et al., 2004). Other potential candidates involved in stress-related psychiatric syndromes are those molecules associated with receptor desensitization and internalization. Like other similar receptors, 5-HT<sub>2</sub> receptors, require the participation of G protein-coupled receptor kinases (GRKs) and  $\beta$ -arrestin in their desensitization and internalization (Schmid et al., 2008; Whalen et al., 2011; Lefkowitz, 1998; Gray et al., 2003; Gray et al., 2001; Bohn and Schmid, 2010), so these molecules could be novel potentially therapeutic targets for anxiety disorders. The most recent finding indeed reveals that  $\beta$ -arrestin-2 is highly expressed in the amygdala and participates in the acquisition and consolidation of fear memories. Manipulation of this molecular signaling pathway thus may be able to regulate the abnormal fear memory associated with certain anxiety disorders (Li et al., 2009).

## 5. Hypothalamic 5-HT<sub>2</sub> receptors, stress, and energy homeostasis

Another forebrain region critically involved in the pathophysiology of stress-related psychiatric conditions is the hypothalamus. The hypothalamus is a center integrating neuronal and endocrine systems for autonomic functions, including those underlying feeding and behavioral arousal (Jo and Role, 2002a; Gerashchenko and Shiromani, 2004). Different neuronal phenotypes and neurotransmitter systems in the hypothalamus play dynamic roles in maintaining homeostasis and neuroendocrine circadian rhythm in the face of acute and chronic internal and external challenges (Harris et al., 2006a). In addition to multiple neuropeptides, monoamines, and cholinergic and purinergic systems, serotonin plays a critical role in the defensive response to stressful environmental stimuli and energy homeostasis (Jo and Role, 2002a; Jo and Role, 2002b; Pyner, 2009).

The paraventricular nucleus (PVN) of the hypothalamus secretes corticotropin releasing factor (CRF), a key mediator in the stress response, and receives heavy innervation from the serotonergic projection. This nucleus expresses both 5-HT<sub>2A</sub> and 5-HT<sub>2C</sub> receptors (Kawano et al., 1992; Li et al., 2003) (Figure 1) and secretion of CRF appears to be regulated by both 5-HT<sub>2A</sub> and 5-HT<sub>2C</sub> receptor ligands (Heller and Baraban, 1987; Heisler et al., 2007). These receptors in the PVN are also part of the mechanism mediating feeding and body weight

(Leibowitz et al., 1989; Tachibana et al., 2001). Dysregulation of 5-HT<sub>2</sub> receptor systems in the PVN is thus implicated in anxiety disorders and several affective disorders associated with loss of energy homeostasis.

Indeed, chronic or traumatic stress, a primary etiologic factor for anxiety disorders, readily decreases central 5-HT<sub>2A</sub> receptor signaling in the hypothalamus, in addition to other forebrain regions (Dwivedi et al., 2005; Petty et al., 1997; Wu et al., 1999), suggesting that stress induces certain physiological abnormalities associated with anxiety disorders, possibly by impairing 5-HT<sub>2A</sub> signaling in the hypothalamus. One such physiological abnormality is sustained reduced body weight resulting from stress. Sustained body weight loss is a prominent feature observed in animals exposed to different stress paradigms. Weight loss has also been long regarded as a prominent symptom in certain patients with depression and anxiety disorders (Evers and Marin, 2002; Hirschfeld et al., 2005; Hopkinson, 1981). This includes children with anxiety and stress disorder whose growth is stunted (Richards et al., 2006; Yorbik et al., 2004). Since the hypothalamic 5-HT<sub>2A</sub> receptor is particularly important in stress-related body weight change (Tao et al., 2002; Bah et al., 2010; Rosmond et al., 1998) and mediation of energy homeostasis (Halder et al., 2007), reduced hypothalamic 5-HT<sub>2A</sub> receptors may be a determining factor in the occurrence of severe weight loss (Kaye et al., 2005; Kaye et al., 2001; Bailer et al., 2004; Halder et al., 2007). Therefore, stress-induced decrease of 5-HT<sub>2A</sub> receptors in the hypothalamus may be the underlying mechanism for the sustained body weight loss in stressed animals.

If this is the case, it would be expected that any condition preventing 5-HT<sub>2A</sub> receptor down regulation, such as administration of a 5-HT<sub>2A</sub> antagonist during stress, would be able to avert the subsequent occurrence of sustained body loss in animals. One recent observation appears to support this contention; administration of the 5-HT<sub>2A</sub> antagonist MDL 11939 during traumatic stress exposure reverses the sustained body weight loss in stressed subjects (Jiang et al., 2009), suggesting that the mechanisms underlying the long-lasting reduction in body weight involve a disturbance of 5-HT<sub>2A</sub> receptor signaling in certain brain regions, particularly the hypothalamus.

## 6. Pharmacotherapy for anxiety disorders

Since 5-HT<sub>2A</sub> receptor and 5-HT<sub>2C</sub> receptor signaling in the amygdala and hypothalamus may be critically involved in the pathophysiology of anxiety disorders, any agent which is able to specifically modulate 5-HT<sub>2A</sub> or 5-HT<sub>2C</sub> receptor signaling in the amygdala and hypothalamus has the potential to treat symptoms associated with various forms of anxiety disorders, including PTSD. Indeed, several clinical studies have shown that the 5-HT<sub>2</sub> receptor antagonist, nefazodone, is effective in improving symptoms of intrusion, avoidance and hyperarousal in a group of Vietnam veterans with chronic-refractory, combat-related PTSD (Neylan et al., 2003; Hertzberg et al., 2002; Garfield et al., 2001; Domon and Andersen, 2000; Zisook et al., 2000; Davis et al., 2000; Mellman et al., 1999; Hidalgo et al., 1999; Davidson et al., 1998). In particular, substantial evidence supports 5-HT<sub>2A</sub> receptor antagonists for preventing the development of behavioral and physiological changes associated with anxiety disorders, suggesting that these antagonists are promising preventive agents in the fight against stress-associated disorders. Several novel, more selective 5-HT<sub>2A</sub> antagonists have recently been developed (Bartoszyk et al., 2003) and have been entered into clinical trials for treatments of schizophrenia and insomnia (de Paulis, 2001; Fish et al., 2005). These



drugs appear to be well tolerated by all study participants (David et al., 2004) and thus should also be entered into trials for anxiety disorders, especially PTSD. Among these antagonists, R-96544, a drug metabolized from an orally administered predrug, R-102444, should be paid particular attention (Ogawa et al., 2005; Ogawa et al., 2004; Ogawa et al., 2002; Tanaka et al., 2008). The pharmacological profile of R-96544 suggests this 5-HT<sub>2A</sub> receptor antagonist for easy oral administration in the battle field and on site of traumatic events, thus potentially making it an ideal drug for preventing the psychiatric consequences of trauma.

## 7. Conclusion

Evidence from different disciplines suggests that alterations of 5-HT<sub>2</sub> receptor signaling may be a critical link in the pathogenesis of anxiety disorders. 5-HT<sub>2</sub> receptor signaling in the amygdala and hypothalamus is particularly important in this respect since alterations of receptor signaling in these areas may be directly related to certain symptoms associated with anxiety disorders. Pharmacotherapy tailored to modulating the effect of 5-HT<sub>2A</sub> and HT<sub>2C</sub> receptors in these areas thus represents an important future direction in developing novel, more efficacious pharmacological agents for the symptoms associated with anxiety disorders, including PTSD.

## 8. Acknowledgement

This work was supported by the CDMRP, USUHS Grants G188LE, G188MG, and G188QC (to HL), and the USUHS Center for the Study of Traumatic Stress.

## 9. References

- Abi-Saab WM, Bubser M, Roth RH, Deutch AY (1999) 5-HT<sub>2</sub> receptor regulation of extracellular GABA levels in the prefrontal cortex. *Neuropsychopharmacology* 20:92-96.
- Adamec R, Creamer K, Bartoszyk GD, Burton P (2004) Prophylactic and therapeutic effects of acute systemic injections of EMD 281014, a selective serotonin 2A receptor antagonist on anxiety induced by predator stress in rats. *Eur J Pharmacol* 504:79-96.
- Akin D, Manier DH, Sanders-Bush E, Shelton RC (2004) Decreased serotonin 5-HT<sub>2A</sub> receptor-stimulated phosphoinositide signaling in fibroblasts from melancholic depressed patients. *Neuropsychopharmacology* 29:2081-2087.
- Bah J, Westberg L, Baghaei F, Henningsson S, Rosmond R, Melke J, Holm G, Eriksson E (2010) Further exploration of the possible influence of polymorphisms in HTR2C and 5HTT on body weight. *Metabolism* 59:1156-1163.
- Bailer UF, Price JC, Meltzer CC, Mathis CA, Frank GK, Weissfeld L, McConaha CW, Henry SE, Brooks-Achenbach S, Barbarich NC, Kaye WH (2004) Altered 5-HT<sub>2A</sub> receptor binding after recovery from bulimia-type anorexia nervosa: relationships to harm avoidance and drive for thinness. *Neuropsychopharmacology* 29:1143-1155.
- Bartoszyk GD, Van AC, Bottcher H, Seyfried CA (2003) EMD 281014, a new selective serotonin 5-HT<sub>2A</sub> receptor antagonist. *Eur J Pharmacol* 473:229-230.
- Bohn LM, Schmid CL (2010) Serotonin receptor signaling and regulation via beta-arrestins. *Crit Rev Biochem Mol Biol* 45:555-566.



- Bourin, M., Masse, F., Dailly, E., and Hascoet, M. (2005). Anxiolytic-like effect of milnacipran in the four-plate test in mice: mechanism of action *Pharmacol. Biochem. Behav.* 81, 645-656.
- Campbell, B.M. and Merchant, K.M. (2003). Serotonin 2C receptors within the basolateral amygdala induce acute fear-like responses in an open-field environment *Brain Res.* 993, 1-9.
- Chen A, Hough CJ, Li H (2003) Serotonin type II receptor activation facilitates synaptic plasticity via N-methyl-D-aspartate-mediated mechanism in the rat basolateral amygdala. *Neuroscience* 119:53-63.
- Chen H, Li H, Chuang DM (1995a) Role of second messengers in agonist up-regulation of 5-HT<sub>2A</sub> (5-HT<sub>2</sub>) receptor binding sites in cerebellar granule neurons: involvement of calcium influx and a calmodulin-dependent pathway. *J Pharmacol Exp Ther* 275:674-680.
- Chen H, Zhang L, Rubinow DR, Chuang DM (1995b) Chronic buspirone treatment differentially regulates 5-HT<sub>1A</sub> and 5-HT<sub>2A</sub> receptor mRNA and binding sites in various regions of the rat hippocampus. *Brain Res Mol Brain Res* 32:348-353.
- Christianson JP, Ragole T, Amat J, Greenwood BN, Strong PV, Paul ED, Fleshner M, Watkins LR, Maier SF (2010) 5-hydroxytryptamine 2C receptors in the basolateral amygdala are involved in the expression of anxiety after uncontrollable traumatic stress. *Biol Psychiatry* 67:339-345.
- Davidson JR, Weisler RH, Malik ML, Connor KM (1998) Treatment of posttraumatic stress disorder with nefazodone. *Int Clin Psychopharmacol* 13:111-113.
- David, S.P. (2004). Pharmacogenetics *Prim. Care* 31, 543-59, ix.
- Davis LL, Nugent AL, Murray J, Kramer GL, Petty F (2000) Nefazodone treatment for chronic posttraumatic stress disorder: an open trial. *J Clin Psychopharmacol* 20:159-164.
- de Mello Cruz, A.P., Pinheiro, G., Alves, S.H., Ferreira, G., Mendes, M., Faria, L., Macedo, C.E., Motta, V., and Landeira-Fernandez, J. (2005). Behavioral effects of systemically administered MK-212 are prevented by ritanserin microinfusion into the basolateral amygdala of rats exposed to the elevated plus-maze *Psychopharmacology (Berl)* 182, 345-354.
- de Paulis T (2001) M-100907 (Aventis). *Curr Opin Investig Drugs* 2:123-132.
- Domon SE, Andersen MS (2000) Nefazodone for PTSD. *J Am Acad Child Adolesc Psychiatry* 39:942-943.
- Drevets WC (2003) Neuroimaging Abnormalities in the Amygdala in Mood Disorders. *Ann NY Acad Sci* 985:420-444.
- Dwivedi Y, Mondal AC, Payappagoudar GV, Rizavi HS (2005) Differential regulation of serotonin (5HT)<sub>2A</sub> receptor mRNA and protein levels after single and repeated stress in rat brain: role in learned helplessness behavior. *Neuropharmacology* 48:204-214.
- Evers MM, Marin DB (2002) Mood disorders. Effective management of major depressive disorder in the geriatric patient. *Geriatrics* 57:36-40.
- Fish LR, Gilligan MT, Humphries AC, Ivarsson M, Ladduwahetty T, Merchant KJ, O'Connor D, Patel S, Philipps E, Vargas HM (2005) 4-Fluorosulfonylpiperidines: Selective 5-HT<sub>2A</sub> ligands for the treatment of insomnia. *Bioorganic & Medicinal Chemistry Letters* 15:3665-3669.
- Garfield DA, Fichtner CG, Leveroni C, Mahableshwarkar A (2001) Open trial of nefazodone for combat veterans with posttraumatic stress disorder. *J Trauma Stress* 14:453-460.
- Gerashchenko D, Shiromani PJ (2004) Different neuronal phenotypes in the lateral hypothalamus and their role in sleep and wakefulness. *Mol Neurobiol* 29:41-59.

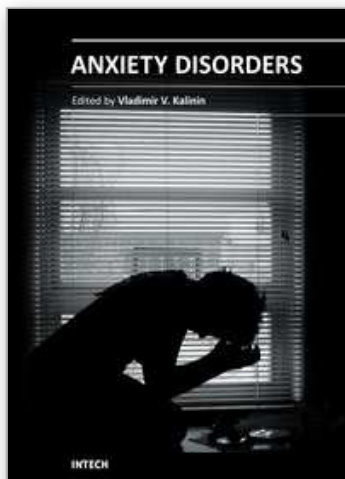
- Graeff FG, Guimaraes FS, De Andrade TG, Deakin JF (1996) Role of 5-HT in stress, anxiety, and depression. *Pharmacol Biochem Behav* 54:129-141.
- Graeff FG, Silveira MC, Nogueira RL, Audi EA, Oliveira RM (1993) Role of the amygdala and periaqueductal gray in anxiety and panic. *Behav Brain Res* 58:123-131.
- Gray JA, Bhatnagar A, Gurevich VV, Roth BL (2003) The interaction of a constitutively active arrestin with the arrestin-insensitive 5-HT(2A) receptor induces agonist-independent internalization. *Mol Pharmacol* 63:961-972.
- Gray JA, Sheffler DJ, Bhatnagar A, Woods JA, Hufeisen SJ, Benovic JL, Roth BL (2001) Cell-type specific effects of endocytosis inhibitors on 5-hydroxytryptamine(2A) receptor desensitization and resensitization reveal an arrestin-, GRK2-, and GRK5-independent mode of regulation in human embryonic kidney 293 cells. *Mol Pharmacol* 60:1020-1030.
- Hackler, E.A., Airey, D.C., Shannon, C.C., Sodhi, M.S., and Sanders-Bush, E. (2006). 5-HT(2C) receptor RNA editing in the amygdala of C57BL/6J, DBA/2J, and BALB/cJ mice. *Neurosci. Res.* 55, 96-104.
- Halder I, Muldoon MF, Ferrell RE, Manuck SB (2007) Serotonin Receptor 2A (HTR2A) Gene Polymorphisms Are Associated with Blood Pressure, Central Adiposity, and the Metabolic Syndrome. *Metab Syndr Relat Disord* 5:323-330.
- Hale MW, Johnson PL, Westerman AM, Abrams JK, Shekhar A, Lowry CA (2010) Multiple anxiogenic drugs recruit a parvalbumin-containing subpopulation of GABAergic interneurons in the basolateral amygdala. *Prog Neuropsychopharmacol Biol Psychiatry* 34:1285-1293.
- Hall RA, Premont RT, Lefkowitz RJ (1999) Heptahelical receptor signaling: beyond the G protein paradigm. *J Cell Biol* 145:927-932.
- Harris RB, Palmondon J, Leshin S, Flatt WP, Richard D (2006a) Chronic disruption of body weight but not of stress peptides or receptors in rats exposed to repeated restraint stress. *Horm Behav* 49:615-625.
- Heisler LK, Pronchuk N, Nonogaki K, Zhou L, Raber J, Tung L, Yeo GS, O'Rahilly S, Colmers WF, Elmquist JK, Tecott LH (2007) Serotonin activates the hypothalamic-pituitary-adrenal axis via serotonin 2C receptor stimulation. *J Neurosci* 27:6956-6964.
- Heller WA, Baraban JM (1987) Potent agonist activity of DOB at 5-HT<sub>2</sub> receptors in guinea pig trachea. *Eur J Pharmacol* 138:115-117.
- Hertzberg MA, Feldman ME, Beckham JC, Moore SD, Davidson JR (2002) Three- to four-year follow-up to an open trial of nefazodone for combat-related posttraumatic stress disorder. *Ann Clin Psychiatry* 14:215-221.
- Hidalgo R, Hertzberg MA, Mellman T, Petty F, Tucker P, Weisler R, Zisook S, Chen S, Churchill E, Davidson J (1999) Nefazodone in post-traumatic stress disorder: results from six open-label trials. *Int Clin Psychopharmacol* 14:61-68.
- Hirschfeld RM, Mallinckrodt C, Lee TC, Detke MJ (2005) Time course of depression-symptom improvement during treatment with duloxetine. *Depress Anxiety* 21:170-177.
- Hopkinson G (1981) A neurochemical theory of appetite and weight changes in depressive states. *Acta Psychiatr Scand* 64:217-225.
- Jiang X, Xing G, Yang C, Verma A, Zhang L, Li H (2009) Stress impairs 5-HT<sub>2A</sub> receptor-mediated serotonergic facilitation of GABA release in juvenile rat basolateral amygdala. *Neuropsychopharmacology* 34:410-423.
- Jiang X, Zhang ZJ, Zhang S, Gamble EH, Jia M, Ursano RJ, Li H (2009) 5-HT<sub>2A</sub> receptor antagonism by MDL 11,939 during inescapable stress prevents subsequent

- exaggeration of acoustic startle response and reduced body weight in rats. *J Psychopharmacol*.
- Jo YH, Role LW (2002a) Cholinergic modulation of purinergic and GABAergic co-transmission at in vitro hypothalamic synapses. *J Neurophysiol* 88:2501-2508.
- Jo YH, Role LW (2002b) Coordinate release of ATP and GABA at in vitro synapses of lateral hypothalamic neurons. *J Neurosci* 22:4794-4804.
- Kawano S, Osaka T, Kannan H, Yamashita H (1992) Excitation of hypothalamic paraventricular neurons by stimulation of the raphe nuclei. *Brain Res Bull* 28:573-579.
- Kaye WH, Frank GK, Bailer UF, Henry SE, Meltzer CC, Price JC, Mathis CA, Wagner A (2005) Serotonin alterations in anorexia and bulimia nervosa: New insights from imaging studies. *Physiology & Behavior* 85:73-81.
- Kaye WH, Frank GK, Meltzer CC, Price JC, McConaha CW, Crossan PJ, Klump KL, Rhodes L (2001) Altered Serotonin 2A Receptor Activity in Women Who Have Recovered From Bulimia Nervosa. *Am J Psychiatry* 158:1152-1155.
- Kimura A, Stevenson PL, Carter RN, Maccoll G, French KL, Paul SJ, Al-Shawi R, Kelly V, Chapman KE, Holmes MC (2009) Overexpression of 5-HT<sub>2C</sub> receptors in forebrain leads to elevated anxiety and hypoactivity. *Eur J Neurosci* 30:299-306.
- Lefkowitz RJ (1998) G protein-coupled receptors. III. New roles for receptor kinases and beta-arrestins in receptor signaling and desensitization. *J Biol Chem* 273:18677-18680.
- Leibowitz SF, Weiss GF, Walsh UA, Viswanath D (1989) Medial hypothalamic serotonin: role in circadian patterns of feeding and macronutrient selection. *Brain Res* 503:132-140.
- Li Q, Wichems CH, Ma L, Van de Kar LD, Garcia F, Murphy DL (2003) Brain region-specific alterations of 5-HT<sub>2A</sub> and 5-HT<sub>2C</sub> receptors in serotonin transporter knockout mice. *J Neurochem* 84:1256-1265.
- Li Y, Li H, Liu X, Bao G, Tao Y, Wu Z, Xia P, Wu C, Li B, Ma L (2009) Regulation of amygdalar PKA by beta-arrestin-2/phosphodiesterase-4 complex is critical for fear conditioning. *Proc Natl Acad Sci U S A* 106:21918-21923.
- Maier SF, Watkins LR (2005) Stressor controllability and learned helplessness: the roles of the dorsal raphe nucleus, serotonin, and corticotropin-releasing factor. *Neurosci Biobehav Rev* 29:829-841.
- Malone KM, Ellis SP, Currier D, John MJ (2006) Platelet 5-HT<sub>2A</sub> receptor subresponsivity and lethality of attempted suicide in depressed in-patients. *Int J Neuropsychopharmacol* 1-9.
- Massou JM, Trichard C, Ittar-Levy D, Feline A, Corruble E, Beaufils B, Martinot JL (1997) Frontal 5-HT<sub>2A</sub> receptors studied in depressive patients during chronic treatment by selective serotonin reuptake inhibitors. *Psychopharmacology (Berl)* 133:99-101.
- Mellman TA, David D, Barza L (1999) Nefazodone treatment and dream reports in chronic PTSD. *Depress Anxiety* 9:146-148.
- Menard J, Treit D (1999) Effects of centrally administered anxiolytic compounds in animal models of anxiety. *Neurosci Biobehav Rev* 23:591-613.
- Messa C, Colombo C, Moresco RM, Gobbo C, Galli L, Lucignani G, Gilardi MC, Rizzo G, Smeraldi E, Zanardi R, Artigas F, Fazio F (2003) 5-HT<sub>2A</sub> receptor binding is reduced in drug-naive and unchanged in SSRI-responder depressed patients compared to healthy controls: a PET study. *Psychopharmacology (Berl)* 167:72-78.
- Minor TR, Hunter AM (2002) Stressor controllability and learned helplessness research in the United States: sensitization and fatigue processes. *Integr Physiol Behav Sci* 37:44-58.

- Mintun MA, Sheline YI, Moerlein SM, Vlassenko AG, Huang Y, Snyder AZ (2004) Decreased hippocampal 5-HT<sub>2A</sub> receptor binding in major depressive disorder: in vivo measurement with [18F]altanserin positron emission tomography. *Biol Psychiatry* 55:217-224.
- Morilak DA, Somogyi P, Lujan-Miras R, Ciaranello RD (1994) Neurons expressing 5-HT<sub>2</sub> receptors in the rat brain: neurochemical identification of cell types by immunocytochemistry. *Neuropsychopharmacology* 11:157-166.
- Nic Dhonnchadha, B.A., Hascoet, M., Jolliet, P., and Bourin, M. (2003). Evidence for a 5-HT<sub>2A</sub> receptor mode of action in the anxiolytic-like properties of DOI in mice. *Behav. Brain Res.* 147, 175-184.
- Neylan TC, Lenoci M, Maglione ML, Rosenlicht NZ, Leykin Y, Metzler TJ, Schoenfeld FB, Marmar CR (2003) The effect of nefazodone on subjective and objective sleep quality in posttraumatic stress disorder. *J Clin Psychiatry* 64:445-450.
- Ogawa T, Sugidachi A, Tanaka N, Fujimoto K, Asai F (2002) Pharmacological profiles of R-96544, the active form of a novel 5-HT<sub>2A</sub> receptor antagonist R-102444. *Eur J Pharmacol* 457:107-114.
- Ogawa T, Sugidachi A, Tanaka N, Fujimoto K, Asai F (2004) Effects of R-102444, an orally active 5-HT<sub>2A</sub> receptor antagonist, in rat models of peripheral vascular disease. *Vascul Pharmacol* 41:7-13.
- Ogawa T, Sugidachi A, Tanaka N, Fujimoto K, Fukushige J, Tani Y, Asai F (2005) Effects of R-102444 and its active metabolite R-96544, selective 5-HT<sub>2A</sub> receptor antagonists, on experimental acute and chronic pancreatitis: Additional evidence for possible involvement of 5-HT<sub>2A</sub> receptors in the development of experimental pancreatitis. *Eur J Pharmacol* 521:156-163.
- Petty F, Kramer GL, Wu J (1997) Serotonergic modulation of learned helplessness. *Ann N Y Acad Sci* 821:538-541.
- Pompeiano M, Palacios JM, Mengod G (1994) Distribution of the serotonin 5-HT<sub>2</sub> receptor family mRNAs: comparison between 5-HT<sub>2A</sub> and 5-HT<sub>2C</sub> receptors. *Brain Res Mol Brain Res* 23:163-178.
- Pyner S (2009) Neurochemistry of the paraventricular nucleus of the hypothalamus: implications for cardiovascular regulation. *J Chem Neuroanat* 38:197-208.
- Richards MM, Banez GA, Dohil R, Stein MT (2006) Chronic constipation, atypical eating pattern, weight loss, and anxiety in a 19-year old youth. *J Dev Behav Pediatr* 27:338-340.
- Ripoll, N., Hascoet, M., and Bourin, M. (2006). Implication of 5-HT<sub>2A</sub> subtype receptors in DOI activity in the four-plates test-retest paradigm in mice. *Behav. Brain Res.* 166, 131-139.
- Rosmond R, Dallman MF, Bjorntorp P (1998) Stress-related cortisol secretion in men: relationships with abdominal obesity and endocrine, metabolic and hemodynamic abnormalities. *J Clin Endocrinol Metab* 83:1853-1859.
- Schmid CL, Bohn LM (2009) Physiological and pharmacological implications of beta-arrestin regulation. *Pharmacol Ther* 121:285-293.
- Schmid CL, Raehal KM, Bohn LM (2008) Agonist-directed signaling of the serotonin 2A receptor depends on beta-arrestin-2 interactions in vivo. *Proc Natl Acad Sci U S A* 105:1079-1084.
- Sheline YI, Mintun MA, Barch DM, Wilkins C, Snyder AZ, Moerlein SM (2004) Decreased hippocampal 5-HT<sub>2A</sub> receptor binding in older depressed patients using [18F]altanserin positron emission tomography. *Neuropsychopharmacology* 29:2235-2241.



- Southwick SM, Paige S, Morgan CA, III, Bremner JD, Krystal JH, Charney DS (1999) Neurotransmitter alterations in PTSD: catecholamines and serotonin. *Semin Clin Neuropsychiatry* 4:242-248.
- Spannuth BM, Hale MW, Evans AK, Lukkes JL, Campeau S, Lowry CA (2011) Investigation of a central nucleus of the amygdala/dorsal raphe nucleus serotonergic circuit implicated in fear-potentiated startle *Neuroscience* 179:104-119.
- Strohle A, Holsboer F (2003) Stress responsive neurohormones in depression and anxiety. *Pharmacopsychiatry* 36 Suppl 3:S207-S214.
- Tachibana T, Tazawa M, Sugahara K (2001) Feeding increases 5-hydroxytryptamine and norepinephrine within the hypothalamus of chicks. *Comp Biochem Physiol A Mol Integr Physiol* 130:715-722.
- Tanaka N, Nakamura E, Ohkura M, Kuwabara M, Yamashita A, Onitsuka T, Asada Y, Hisa H, Yamamoto R (2008) Both 5-hydroxytryptamine 5-HT<sub>2A</sub> and 5-HT<sub>1B</sub> receptors are involved in the vasoconstrictor response to 5-HT in the human isolated internal thoracic artery. *Clin Exp Pharmacol Physiol* 35:836-840.
- Tao R, Fray A, Aspley S, Brammer R, Heal D, Auerbach S (2002) Effects on serotonin in rat hypothalamus of D-fenfluramine, aminorex, phentermine and fluoxetine. *Eur J Pharmacol* 445:69-81.
- van Praag HM (2004a) Can stress cause depression? *Progress in Neuro-Psychopharmacology and Biological Psychiatry* 28:891-907.
- van Praag HM (2004b) The cognitive paradox in posttraumatic stress disorder: a hypothesis. *Progress in Neuro-Psychopharmacology and Biological Psychiatry* 28:923-935.
- Whalen EJ, Rajagopal S, Lefkowitz RJ (2011) Therapeutic potential of beta-arrestin- and G protein-biased agonists. *Trends Mol Med* 17:126-139.
- Wright DE, Seroogy KB, Lundgren KH, Davis BM, Jennes L (1995) Comparative localization of serotonin<sub>1A</sub>, 1C, and 2 receptor subtype mRNAs in rat brain. *J Comp Neurol* 351:357-373.
- Wu J, Kramer GL, Kram M, Steciuk M, Crawford IL, Petty F (1999) Serotonin and learned helplessness: a regional study of 5-HT<sub>1A</sub>, 5-HT<sub>2A</sub> receptors and the serotonin transport site in rat brain. *J Psychiatr Res* 33:17-22.
- Xu T, Pandey SC (2000) Cellular localization of serotonin(2A) (5HT(2A)) receptors in the rat brain. *Brain Res Bull* 51:499-505.
- Yorbik O, Birmaher B, Axelson D, Williamson DE, Ryan ND (2004) Clinical characteristics of depressive symptoms in children and adolescents with major depressive disorder. *J Clin Psychiatry* 65:1654-1659.
- Zanardi R, Artigas F, Moresco R, Colombo C, Messa C, Gobbo C, Smeraldi E, Fazio F (2001) Increased 5-hydroxytryptamine-2 receptor binding in the frontal cortex of depressed patients responding to paroxetine treatment: a positron emission tomography scan study. *J Clin Psychopharmacol* 21:53-58.
- Zisook S, Chentsova-Dutton YE, Smith-Vaniz A, Kline NA, Ellenor GL, Kodsí AB, Gillin JC (2000) Nefazodone in patients with treatment-refractory posttraumatic stress disorder. *J Clin Psychiatry* 61:203-208.



## **Anxiety Disorders**

Edited by Prof. Vladimir Kalinin

ISBN 978-953-307-592-1

Hard cover, 324 pages

**Publisher** InTech

**Published online** 01, August, 2011

**Published in print edition** August, 2011

During the last 2-3 decades drastic research progress in anxiety issues has been achieved. It concerns mostly the study of different subtypes of anxiety and their treatment. Nevertheless, the data on anxiety pathogenesis is less elaborated, although here a multidimensional approach exists. It includes neurochemistry, pathophysiology, endocrinology and psychopharmacology. Again, we are able to recognize the multifarious sense of anxiety, and the present collective monograph composed of 16 separate chapters depicting the different aspects of anxiety. Moreover, a great part of book includes chapters on neurochemistry, physiology and pharmacology of anxiety. The novel data on psychopathology and clinical signs of anxiety and its relationship with other psychopathological phenomena is also presented. The current monograph may represent an interest and be of practical use not only for clinicians but for a broad range of specialists, including biochemists, physiologists, pharmacologists and specialists in veterinary.

### **How to reference**

In order to correctly reference this scholarly work, feel free to copy and paste the following:

Xiaolong Jiang, Aiqin Chen, Stanley Smerin, Lei Zhang and He Li (2011). Pharmacology of 5-HT<sub>2</sub> Modulation of Amygdala & Hypothalamus in Anxiety Disorders, Anxiety Disorders, Prof. Vladimir Kalinin (Ed.), ISBN: 978-953-307-592-1, InTech, Available from: <http://www.intechopen.com/books/anxiety-disorders/pharmacology-of-5-ht2-modulation-of-amygdala-hypothalamus-in-anxiety-disorders1>

**INTECH**  
open science | open minds

### **InTech Europe**

University Campus STeP Ri  
Slavka Krautzeka 83/A  
51000 Rijeka, Croatia  
Phone: +385 (51) 770 447  
Fax: +385 (51) 686 166  
[www.intechopen.com](http://www.intechopen.com)

### **InTech China**

Unit 405, Office Block, Hotel Equatorial Shanghai  
No.65, Yan An Road (West), Shanghai, 200040, China  
中国上海市延安西路65号上海国际贵都大饭店办公楼405单元  
Phone: +86-21-62489820  
Fax: +86-21-62489821

© 2011 The Author(s). Licensee IntechOpen. This chapter is distributed under the terms of the [Creative Commons Attribution-NonCommercial-ShareAlike-3.0 License](#), which permits use, distribution and reproduction for non-commercial purposes, provided the original is properly cited and derivative works building on this content are distributed under the same license.

IntechOpen

IntechOpen