THE INSIDE STORY

*In vitro* and *in vivo* Pharmacology of Synthetic Olivetol- or Resorcinol-Derived Cannabinoid Receptor Ligands

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SYNSTORIES

- Direct Cross-Aldol Reaction: *A syn-* and Enantioselective Organocatalytic Process
- Evidence of Asymmetric Autocatalysis in Organocatalytic Reactions
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Matteo Zanda
Editor of SYNFORM

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ABSTRACT

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In vitro and in vivo Pharmacology of Synthetic Olivetol- or Resorcinol-Derived Cannabinoid Receptor Ligands


Background and Purpose. The same authors previously reported the development of CB-25 and CB-52, two fatty acid and olivetol- or resorcinol-derived ligands of CB1 and CB2 cannabinoid receptors, showing improved metabolic stability and receptor affinity over the parent compounds. In this paper their functional activity is assessed.

Experimental Approach. The effect of the two compounds on forskolin-induced cAMP formation in intact cells or on GTP-γ-S binding to cell membranes, as well as their action on nociception in vivo, was determined.

Key Results. CB-25 enhanced the forskolin-induced cAMP formation in N18TG2 cells (EC50 ca. 20 nM, max. stimulation = 48%), acting like an inverse CB1 agonist, but stimulated the GTP-γ-S binding to mouse brain membranes (EC50 = 11 nM, max. stimulation ~16%). Both CB-25 and CB-52 showed no activity in all assays of CB2-coupled functional activity and antagonized CP55940-induced stimulation of GTP-γ-S binding to hCB2-CHO cell membranes. In vivo, both compounds, administered intraperitoneally, produced dose-dependent nociception in the plantar test carried out in healthy rats, and antagonized the anti-nociceptive effect of intraperitoneal WIN55,212-2. The formalin test in mice revealed, however, that the compounds counteracted both phases of formalin-induced nociception.

Conclusion and Implications. CB-25 and CB-52 behave in vitro mostly as CB1 partial agonists and CB2 neutral antagonists, whereas their activity in vivo might depend on the tonic activity of cannabinoid receptors. Those findings, together with the recently reported results by Yao et al. [Br. J. Pharmacol. 2006, 149(2), 145–154], introduce the concept of “protean agonist”, i.e. compounds whose “functional efficacies in various assay systems may depend on the levels of receptor constitutive activities exhibited in the assay systems, and therefore, whose efficacies in in vitro assays may not predict in vivo activities.”
INTERVIEW
(Questions by L. Pani, answers by V. Di Marzo)

Question 1 | You have recently reported the discovery of the first “hybrid” cannabinoid and vanilloid receptor ligands. Are there any other molecular/therapeutic areas in which you foresee a role for a ligand hybrid with cannabinoid compounds?

Answer 1 | Absolutely! After the first series of “hybrid” agonists of CB, and TRPV1 receptors (arvanil), with potential application in the treatment of pain, emesis, spasticity in multiple sclerosis, cancer and neuronal excitotoxicity, we have already developed: 1) “hybrid” TRPV1 agonists and CB, antagonists, with potential application in inflammation, and 2) “hybrid” inhibitors of the enzyme fatty acid amide hydrolase (FAAH), which catalyze the hydrolysis of endocannabinoids and antagonists of vanilloid receptors. The prototype of the latter compounds is N-arachidonoylserotonin, which proved to be efficacious in an experimental model of neuropathic pain. Others have found that some COX inhibitors can also bind to cannabinoid CB, receptors and/or inhibit FAAH.

Question 2 | Do you see potential drug developing targeted to the signal transduction–nuclear transcription mechanisms of CB, and CB, receptors? Please explain in further detail why you would answer yes or no.

Answer 2 | Honestly, I am not a strong believer in this possibility. Although I think that “hybrid” drugs could be very efficacious and still safe, drugs interfering with intracellular signaling mechanisms might end up being too unselective.

Question 3 | If you were in charge of positioning today a CB, or CB, agonist or antagonist, either peripheral or central (so you have to position 4 lead compounds in the market), what would be your first target pathologies and why? What are the drawbacks and the side effects you would expect for each of these?

Answer 3 | For a CB, agonist there might be several therapeutic indications (neuroprotection, anxiety, multiple sclerosis, pain, emesis, anorexia, cancer), but each of these would still be hampered by the unwanted side effects. For this reason I believe that pharmaceuticals that either do not cross the blood–brain barrier or are developed as soft drugs (i.e. molecules that are active only at the site of administration...
then immediately degraded) might be the answer to this problem. Alternatively, Sativex, a cannabis extract that contains THC together with non-psychotropic cannabinoids that have therapeutic effects per se and attenuate the psychotropic actions of THC, could also be a valid strategy. Indeed, partial agonists of CB1 receptors should also have a lower potential for the development of tolerance and dependence. Perhaps the one type of applications that, with the use of the right dose of compound, might give successful outcome with CB1 agonists are the ones at the level of the gastrointestinal system, i.e. intestinal hypersecretion (diarrhea) and inflammation (inflammatory bowel disorders). Indeed, I think that clinical trials should be done on these disorders as soon as possible.

For a CB2 agonist some new data indicate potential applications in the treatment of osteoporosis, atherosclerosis and liver fibrosis. Inflammatory pain and inflammation, as well as some types of cancer, and perhaps allergies, are other possible additional therapeutic targets. Clearly, although it is now accepted that CB2 receptors are present in the brain, particularly under certain pathological conditions, CB2 agonists would be devoid of psychotropic effects.

Regarding CB1 antagonists/inverse agonists, apart from the already well-established use against obesity and metabolic syndrome (i.e. high triglycerides, low HDL cholesterol, insulin insensitivity and hyperglycemia, atherogenic inflammation, etc.), I see the future use against liver fibrosis and steatosis, some hypotensive states accompanying other diseases (e.g. cirrhosis or septic shock), and perhaps some neurodegenerative disorders where endocannabinoids seem to contribute to symptoms, such as Alzheimer’s and Parkinson’s disease.

Finally, so far CB1 antagonists/inverse agonists have been tested mostly against inflammation, as it seems that endocannabinoids, apart from attenuating this pathological condition, can also paradoxically participate in it.

I would like to conclude that I also very much believe in the use of “indirect” agonists of cannabinoid receptors (i.e. inhibitors of endocannabinoid inactivation) and “indirect” antagonists (i.e. inhibitors of endocannabinoid biosynthesis), which in theory should be more selective, as endocannabinoids are produced and degraded under pathological conditions only in the tissues involved in the disorder.

Question 4 | Let me ask you to expand a little more on this last point. Why would you think that “indirect” agonists and antagonists may represent a more promising approach in the cannabinoid system, given the fact that for other neurotransmitters and neuromodulators, the indirect compounds have usually presented themselves with little and rather nonselective action?

Answer 4 | Because of the way they are made and their chemical nature, endocannabinoids, unlike classical neurotransmitters and peptide mediators, are produced and released from cells “on demand” and then immediately degraded after their action at cannabinoid receptors. This means that during a certain pathological state endocannabinoids are produced only “when and where needed”, i.e. at the onset of the pathology (and often throughout its progress) and only in the tissues (and sometimes the cells) involved in the pathology. Compounds that manipulate pharmacologically their degradation or biosynthesis will act only when and where the endocannabinoids are produced and degraded and, therefore, only at the site of, and during, the pathology. This differs from direct agonists or antagonists of cannabinoid receptors, which will act everywhere, and until they are degraded in the liver. For these reasons, inhibitors of endocannabinoid biosynthesis and degradation are more likely to be selective and safe.
The aldol reaction is one of the most powerful tools for stereoselective carbon–carbon bond formation, and hence, it is widely used in organic synthesis. However, the cross-aldol reaction between two different aldehydes is all but a trivial process, due to undesired side reactions such as dehydration of the product, self-aldol reaction and multiple addition of the enolate to the aldol product. Thus, not surprisingly, only a few examples of catalytic asymmetric cross-aldol reactions have been developed to date. Very recently, L-proline was found to enantioselectively catalyze the cross-aldol reaction between aldehydes to give the aldol product without prior formation of activated enolate species. This methodology was applied to the facile synthesis of carbohydrates (see for example: D. W. C. MacMillan and coworkers Angew. Chem. Int. Ed. 2004, 43, 2152).

The proline-catalyzed cross-aldol reaction, however, provided only anti aldol products as the major isomer because of the core structure of the catalyst. Now Prof. Keiji Maruoka, Dr. Taichi Kano and coworkers from the University of Tokyo (Japan) have reported a syn-selective and enantioselective direct cross-aldol reaction between two different aldehydes by using the axially chiral amino sulfonamide catalyst (S)-1.

“The present success crucially depends on the design of (S)-1 wherein the acid center is remote from the amine base,” said Prof. Maruoka to Synform. “In other words, while the proline catalyst controls the diastereoselectivity by generating the anti enamine intermediate exclusively, our catalyst is designed to form both anti and syn enamines and only the syn enamine reacts with the acceptor aldehyde activated by the distal acidic triflamide group. Consequently, the direct cross-aldol reaction between aldehydes proceeded smoothly to give the corresponding syn aldol adduct as a major isomer with excellent enantioselectivity.”

The present reaction is complementary to the proline-catalyzed reaction in terms of the diastereoselectivity, and therefore represents a rare example of the highly syn-selective and enantioselective direct cross-aldol reaction with a non-proline-derived artificial organocatalyst. “Our axially chiral amino sulfonamide (S)-1 offers the possibility of a new catalyst design for the various asymmetric reactions catalyzed by proline and its derivatives,” concluded Prof. Maruoka.
“Synlett, Synthesis, Synfacts and the other journals are full of organocatalytic aldol reactions. So, one might wonder whether we really need another example. How can the answer be yes?” commented Prof. Carsten Bolm from the University of Aachen (Germany), editorial advisory board member of Synthesis. “Well, Maruoka and co-workers followed a very concise concept and devised a new axially chiral diamine with exceptional properties. Instead of the commonly obtained anti aldol products, this novel organocatalyst provides syn stereoisomers in cross-aldol reactions between aldehydes. Furthermore, it does so with excellent enantioselectivities in good yields. Solvent and concentration effects makes one wonder about design and predictability in asymmetric organocatalysis. However, who cares at this stage? Outstanding discoveries like the one reported here are certainly needed!” concluded Prof. Bolm.

Evidence of Asymmetric Autocatalysis in Organocatalytic Reactions

Asymmetric catalytic reactions aim at an efficient transfer of the chiral environment of a reaction to the transition state. In principle, any asymmetric structure or influence may contribute to this, including the product itself. Such asymmetric autocatalysis, i.e. the process of automultiplication of a chiral compound in which the chiral product acts as a chiral catalyst for its own formation, was introduced by K. Soai et al. [Nature (London) 1995, 378, 767] and was demonstrated to occur for the alkylation reactions of aldehydes with i-Pr₂Zn, involving a zinc alkoxide of the product as the catalytically active species.

Now, Prof. Svetlana Tsogoeva and coworkers from the Friedrich-Alexander-Universität Erlangen-Nürnberg, Germany, have decided to investigate how general this concept is in the realm of organic synthesis.

“We asked ourselves whether the chiral product alone and in
any asymmetric organic reaction could act as an inductor of chirality,” said Prof. Tsogoeva. “In order to answer this question and without restriction of generality, we put a Mannich reaction in the addition of acetone (1) to N-protected α-amino ethylglyoxylate (2), which we were currently investigating in our laboratory, and which is known as a route to functionalized α-amino acids, to the test.” The chiral product of the asymmetric Mannich reaction (3), studied under various experimental conditions and by computations at B3LYP/6-31G, was shown to act as a rather efficient chiral catalyst for its own formation.

For example, when 0.3 equivalents of Mannich product at 99% ee were added to a mixture of acetone and the prochiral substrate, newly formed product could be isolated with 94% ee. A generally applicable catalytic cycle was proposed on the basis of quantum-chemical computations and involving hydrogen-bonded substrate–product-complex equilibria. In contrast to autoinductive reactions, where the catalytically active species is not the product alone, but rather a complex of the product with a reagent, here only the product alone influences the transition state for its formation by attack of acetone on the prochiral aldimine.

“The mechanism we anticipated here is fully general,” continued Prof. Tsogoeva, “and, in our opinion, not restricted to the investigated Mannich reaction. This is corroborated by similar observations for the asymmetric aldol reaction of p-nitrobenzaldehyde with acetone. We believe that asymmetric autocatalysis, within the boundaries of organocatalysis, could possibly be a rather widespread phenomenon, possessing the additional advantage of being environmentally benign. Stereochemists might also think of their products as asymmetric catalysts. This lifts the necessity to separate the product from the catalyst, which could save costs in commercial applications. In principle, it involves the comfortable condition that the catalyst could be self-multiplied to any extent. What remains is to find the proper conditions for higher ee values and yields. Extensions of the concept in which the spectrum of the reactions with active product catalysis are further explored are presently being carried out in our laboratory.”

Clearly, not every product might constitute a good catalyst for its formation reaction and not every asymmetric organic reaction might be tractable to product catalysis. “On the other hand,” concluded Prof. Tsogoeva, “asymmetric product catalysis in organocatalytic reactions might become a promising and fruitful new direction of research in the asymmetric organocatalysis field in the forthcoming years, combining the advantages of organocatalysis and asymmetric autocatalysis.”

Prof. P. G. Cozzi from the chemistry department at the University of Bologna, Italy was contacted by Synform for a comment. “It is quite embarrassing, the ‘chiral imbalance’ of our world,” said Prof. Cozzi. “Objects are chiral, meaning they exist in two forms that are mirror images of each other. Biology prefers to play with one single form. The amino acids that make up proteins, for example, are left-handed. In 1953, Charles Frank suggested that our ‘imbalanced Chiral World’ might derive from autocatalytic processes – reactions in which the product acts as a catalyst. In certain cases, a left-handed autocatalytic molecule becomes capable of domina-
The development of syntheses leading to α-amino acids has intrigued generations of chemists who have delivered a diversity of methodologies based on carbon–carbon bond-forming reactions. In addition to the classic Strecker reaction (path a), there are two more recent versatile approaches consisting of the addition of nucleophilic species, either organometallic reagents (path b) or alkyl radicals (path d), to electrophilic glycine equivalents. Recently, the group of Ombretta Porta at the Chemistry Department of Politecnico di Milano reported on a conceptually new radical approach to α-amino acids. “Following our previously established addition of nucleophilic radicals to simple aldmines formed in situ (Tetrahedron 2006, 62, 5986),” stated Prof. Porta, “we reasoned that a carbamoyl radical, instead of a cyanide ion, might serve as a carboxylate synthon for a new approach (path c) leading to α-amino acid amides which are one step ahead on the route to α-amino acids with respect to the less easily hydrolyzable α-amino nitriles obtained by the classical ionic Strecker reaction.”

Indeed, notwithstanding the formamide–aqueous co-solvent, imines derived from either aliphatic or aromatic aldehydes were all found to undergo carbamoylation in good yields, due to the manifold roles played by Ti(III) and Ti(IV) ions in generating the intermediate reactive partners in a one-pot multicomponent reaction (MCR). “The reaction, which readily assembles an amine, an aldehyde and formamide in a few
minutes at room temperature in the presence of Ti(III) chloride, can be visually monitored by observing the change of color (from blue to yellow) that occurs upon addition of H₂O₂ to the reaction mixture," added Prof. Porta.

This MCR strategy, whose elementary reactions are equilibria, is preparatively advantageous because the last step (in addition to several others) is irreversible. Both an ultimately non-toxic TiO₂ metal residue and the reduction of waste solvents contribute to the significance of this methodology from an environmental and economically point of view with respect to multistep sequential syntheses, and appeal for the concept of combinatorial chemistry.

“With this general protocol of α-H-α-amino acid derivatives in hand, we are now turning our attention to extend its applicability to α-quaternary α-amino acid units, which display a wide assortment of interesting biological properties," added Prof. Porta.

The authors are aware that the equilibria leading to the precursor ketimines are not favorable under aqueous conditions. Therefore, they are now focusing their efforts on an alternative strategy based upon the use of an anhydrous TiCl₄/Zn system in a formamide-non-aqueous co-solvent. “Preliminary screening is encouraging and shows that this approach is even more convenient since Ti(IV) chloride can be employed in catalytic amounts, the zero-valent Zn metal being the sacrificial reductant,” concluded Prof. Porta. “Furthermore, there is considerable interest to extend this radical Strecker-type reaction toward asymmetric synthesis by using chiral ligands on the metal for the production of optically active α-amino acids and, in particular, the non-proteinogenic analogues which are often used as key building blocks in pharmaceuticals.”

Matteo Zanda
The role of chemistry in the Seventh Research Framework Programme – FP7

Interviewed: Dr. Frédéric Gouardères, European Commission
Interviewer: Matteo Zanda, SYNFORM Editor

SYNSTORIES

- Polyprenoids by Enantioselective Halocyclization Induced by Nucleophilic Phosphoramidites
  (Focus on Synfact of the Month)
- Total Synthesis of (±)-Vigulariol
  (Focus on SYNTHESIS Special Topic on Copper in Organic Synthesis)
- Functionalized Cyclopentanes through a Novel Gold(I)-Catalyzed Cyclization of Enynes
  (Focus on SYNLETT Cluster on Gold in Organic Synthesis)
- Professor Qian Wang, University of South Carolina, USA
  (Young Career Focus)

FURTHER HIGHLIGHTS

SYNTHESIS
Special Topic on “Copper in Organic Synthesis” in issue 8/2007

SYNLETT
Account on: Controlling Competing Pathways in Palladium-Catalyzed Tandem/Domino Reactions of Hindered Grignard Reagents with 1,2-Dihaloarenes and 2-Haloaryl Tosylates
(by Q.-S. Hu)

SYNFACTS
Synfact of the Month in category “Synthesis of Materials and Unnatural Products”: Robust Nanocoatings for Nanoparticles

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