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(54) Titre : MODULATEURS DOUBLES DU RECEPTEUR FARNESOIDE X ET DE L'EPOXYDE HYDROLASE SOLUBLE
(54) Title: DUAL MODULATORS OF FARNESOID X RECEPTOR AND SOLUBLE EPOXIDE HYDROLASE

(57) Abrégé/Abstract:
The present invention pertains to novel dual modulators of farnesoid X receptor (FXR) and soluble epoxide hydrolase (sEH). The modulators of the invention were designed to provide compounds which harbor a dual activity as agonists of FXR and inhibitors (antagonists) of sEH. The invention also provides methods for treating subjects suffering from diseases associated with FXR and sEH, such as metabolic disorders, in particular non-alcoholic fatty liver or nonalcoholic steatohepatitis (NASH).

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(54) Title: DUAL MODULATORS OF FARNESOID X RECEPTOR AND SOLUBLE EPOXIDE HYDROLASE

(57) Abstract: The present invention pertains to novel dual modulators of farnesoid X receptor (FXR) and soluble epoxide hydrolase (sEH). The modulators of the invention were designed to provide compounds which harbor a dual activity as agonists of FXR and inhibitors (antagonists) of sEH. The invention also provides methods for treating subjects suffering from diseases associated with FXR and sEH, such as metabolic disorders, in particular non-alcoholic fatty liver or nonalcoholic steatohepatitis (NASH).

DUAL MODULATORS OF FARNESOID X RECEPTOR AND SOLUBLE EPOXIDE HYDROLASE

FIELD OF THE INVENTION

The present invention pertains to novel dual modulators of farnesoid X receptor (FXR) and soluble epoxide hydrolase (sEH). The modulators of the invention were designed to provide compounds which harbor a dual activity as agonists of FXR and inhibitors (antagonists) of sEH. The invention also provides methods for treating subjects suffering from diseases associated with FXR and sEH, such as metabolic disorders, in particular non-alcoholic fatty liver or non-alcoholic steatohepatitis (NASH).

DESCRIPTION

Non-alcoholic fatty liver disease (NAFLD) resulting from over-nutrition and sedentary lifestyle increasingly affects adults especially in western civilizations and all over the world. Recent estimates assume that up to every third adult in the world carries NAFLD and that up to 15% proceed to non-alcoholic steatohepatitis (NASH). Most alarmingly, up to 11% of adolescents are thought to be affected by NAFLD. The disease complex of NAFLD and NASH - often considered as hepatic manifestation of the metabolic syndrome – therefore constitutes a serious health thread. However, current NAFLD treatment is limited and pharmacological options are insufficient. Hence, novel pharmacological interventions to treat NAFLD and NASH are urgently required (Rinella, M. E. Nonalcoholic Fatty Liver Disease: A Systematic Review. JAMA 2015, 313 (22), 2263–2273; Gawrieh, S.; Chalasani, N. Pharmacotherapy for Nonalcoholic Fatty Liver Disease. Semin. Liver Dis. 2015, 35 (3), 338–348; Chalasani, N.; Younossi, Z.; Lavine, J. E.; Diehl, A. M.; Brunt, E. M.; Cusi, K.; Charlton, M.; Sanyal, A. J. The Diagnosis and Management of Non-Alcoholic Fatty Liver Disease: Practice Guideline by the American Association for the Study of Liver Diseases, American College of Gastroenterology, and the American Gastroenterological Association. Hepatology 2012, 55 (6), 2005–2023).

In vivo models and clinical trials have identified several strategies with therapeutic potential for the treatment of NAFLD/NASH. Particularly the nuclear farnesoid X receptor (FXR) (Arab, J. P.; Karpen, S. J.; Dawson, P. A.; Arrese, M.; Trauner, M. Bile Acids and Nonalcoholic Fatty Liver Disease: Molecular Insights and Therapeutic Perspectives. Hepatology 2017, 65 (1), 350–362) seems a very promising target for NAFLD/NASH therapy since obeticholic acid (6α-ethyl-CDCA, OCA, **1a**) which was developed from the endogenous FXR agonist chenodeoxycholic acid

(CDCA, **1b**) has already revealed clinical efficacy in NASH treatment (Adorini, L. et al. Farnesoid X Receptor Targeting to Treat Nonalcoholic Steatohepatitis. Drug Discov. Today 2012, 17 (17–18), 988–997; Neuschwander-Tetri, B. et al. Farnesoid X Nuclear Receptor Ligand Obeticholic Acid for Non-Cirrhotic, Non-Alcoholic Steatohepatitis (FLINT): A Multicentre, Randomised, Placebo-Controlled Trial. Lancet 2014, 385 (9972), 956–965). FXR is a ligand-activated transcription factor mainly found in liver, intestine and kidney and is physiologically activated by bile acids (Makishima,et al. Identification of a Nuclear Receptor for Bile Acids. Science 1999, 284 (5418), 1362–1365; Parks, D. J.et al. Bile Acids: Natural Ligands for an Orphan Nuclear Receptor. Science 1999, 284 (5418), 1365–1368; Wang, H. et al. Endogenous Bile Acids Are Ligands for the Nuclear Receptor FXR/BAR. Mol. Cell 1999, 3 (5), 543–553). It acts as metabolic regulator by controlling several genes involved in bile acid, lipid and glucose homeostasis and as an important liver protector by sensing toxic levels of accumulating bile acids (Gadaleta, R. M et al. Tissue-Specific Actions of FXR in Metabolism and Cancer. Biochim. Biophys. Acta 2014, 1851, 30–39; Pellicciari, R. et al; Farnesoid X Receptor: From Structure to Potential Clinical Applications. J Med Chem 2005, 48 (17), 5383–5403).

Clinical trials have reported improved histological features and clinical markers of NAFLD/NASH as well as improved metabolic parameters after OCA (**1a**) treatment which has validated FXR as target to treat fatty liver disorders and, potentially, other metabolic diseases (Mudaliar, S et al. Efficacy and Safety of the Farnesoid X Receptor Agonist Obeticholic Acid in Patients with Type 2 Diabetes and Nonalcoholic Fatty Liver Disease. Gastroenterology 2013, 145 (3), 574–582.e1). However, full activation of FXR might cause undesirable accumulation of cholesterol since FXR activation leads to repression of cholesterol 7α-hydroxylase (CYP7A1) which is the rate-limiting enzyme in metabolic conversion of cholesterol to bile acids. Partial FXR agonism with lower maximum efficacy than typical FXR agonists such as **1c** seems a promising concept to exploit desirable effects of FXR activation without disturbing cholesterol homeostasis (Merk, D et al. Anthranilic Acid Derivatives as Novel Ligands for Farnesoid X Receptor (FXR). Bioorg. Med. Chem. 2014, 22 (8), 2447–2460; Merk, et al. Extending the Structure – Activity Relationship of Anthranilic Acid Derivatives As Farnesoid X Receptor Modulators: Development of a Highly Potent Partial Farnesoid X Receptor Agonist. J. Med. Chem. 2014, 57 (19), 8035–8055; Merk, D. et al. Medicinal Chemistry of Farnesoid X Receptor Ligands: From Agonists and Antagonists to Modulators. Future Med. Chem. 2012, 4 (8), 1015–1036).

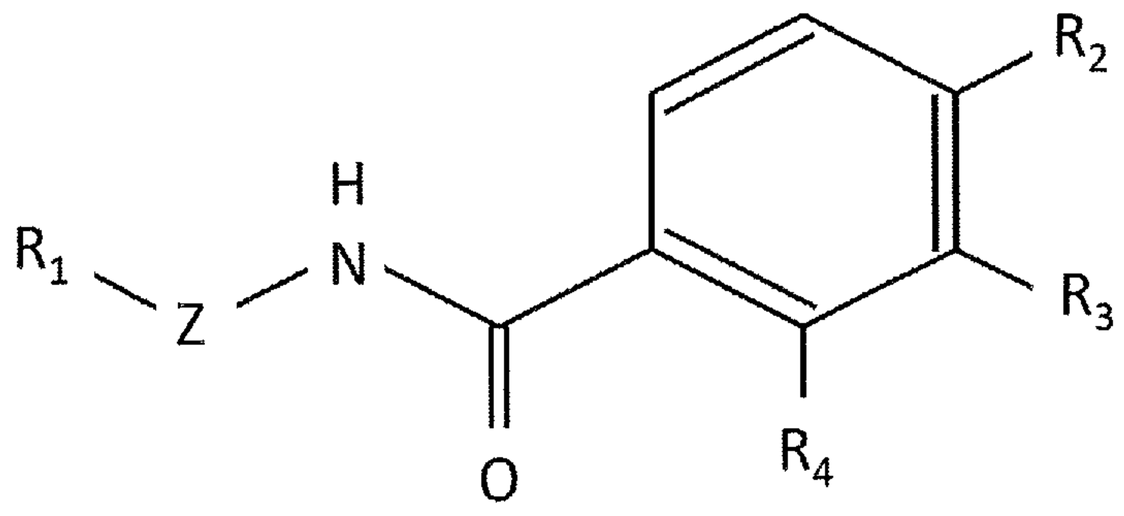
The soluble epoxide hydrolase (sEH) is a downstream enzyme of the CYP pathway of arachidonic acid metabolism and also holds promise in the treatment of NAFLD/NASH and other metabolic diseases such as type 2 diabetes mellitus (Shen, H. C.; Hammock, B. D. Discovery of Inhibitors of Soluble Epoxide Hydrolase: A Target with Multiple Potential Therapeutic Indications. J. Med. Chem. 2012, 55 (5), 1789–1808; Newman, J. W. et al; Epoxide Hydrolases: Their Roles

and Interactions with Lipid Metabolism. Prog. Lipid Res. 2005, 44 (1), 1–51; Imig, J. D. Epoxides and Soluble Epoxide Hydrolase in Cardiovascular Physiology. Physiol. Rev. 2012, 92 (1), 101–130; Huang, H.; Weng, J.; Wang, M.-H. EETs/sEH in Diabetes and Obesity-Induced Cardiovascular Diseases. Prostaglandins Other Lipid Mediat. 2016, 125, 80–89.). It converts epoxyeicosatrienoic acids (EETs) formed by CYP enzymes from arachidonic acid to the respective dihydroxyeicosatrienoic acids (DHETs). Since EETs exhibit robust anti-inflammatory activities, sEH inhibition constitutes an anti-inflammatory strategy. sEH is expressed throughout the body with especially high levels in heart, liver and kidney. Recent results from mouse models for NASH have revealed that sEH knockout or inhibition reduces hepatic fat accumulation and hepatic inflammation under high fat diet.

NASH is associated with various risk factors such as type 2 diabetes or obesity and possesses diverse manifestations including steatosis, hepatic inflammation and fibrosis. Accordingly, several experimental strategies have revealed a therapeutic efficacy in NASH (Sanyal, A. J. Novel Therapeutic Targets for Steatohepatitis. Clin. Res. Hepatol. Gastroenterol. 2015, 39 Suppl 1, S46-50; Milic, S, et al. Nonalcoholic Steatohepatitis: Emerging Targeted Therapies to Optimize Treatment Options. Drug Des. Devel. Ther. 2015, 9, 4835–4845.) and it seems reasonable to face this multifactorial disease with more than one therapeutic mechanism treating its distinct pathological factors. However, the resulting polypharmacy with a multitude of drugs is disadvantageous suffering e.g. from complex and problematic drug-drug interactions and additional side-effects. Multi-target agents addressing the multitude of the desired therapeutic mechanisms can avoid many drawbacks of poly-pharmacology.

In light of the clinical efficacy of FXR activation in reducing NASH progression and lipid accumulation as well as the hepatic anti-inflammatory and anti-steatotic effects of sEH inhibition, dual modulation of FXR and sEH seems a promising strategy to treat NAFLD/NASH that might generate synergistic effects. Therefore, the object of the present invention is to provide dual modulators with partial agonistic activity on FXR and inhibitory potency on sEH.

The above problem is solved by a compound having the formula I:



(I),

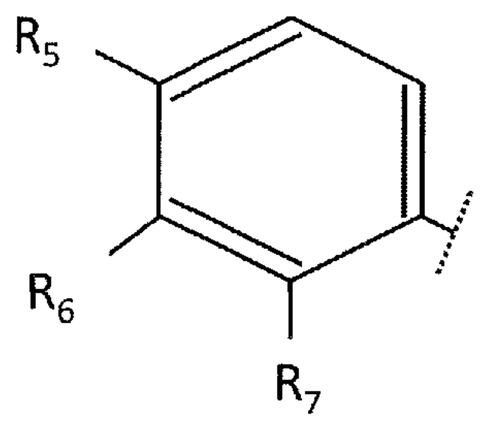
wherein R_1, R_2, R_3 and R_4 are independently selected from H, an unsubstituted, monosubstituted, or polysubstituted C_1-C_{18} alkyl or heteroalkyl, wherein said alkyl is straight, branched or cyclic, a unsubstituted, monosubstituted or polysubstituted C_1-C_{18} alkenyl or heteroalkenyl, wherein said alkenyl is straight, branched or cyclic, an unsubstituted, monosubstituted, or polysubstituted aryl or heteroaryl, an unsubstituted, monosubstituted, or polysubstituted benzyl group, an acyl group, such as formyl, acetyl, trichloroacetyl, fumaryl, maleyl, succinyl, benzoyl, or acyl groups being branched, heteroatom-substituted or aryl-substituted, a sugar or another acetal, and a sulfonyl group, and/or wherein R_2, R_3 and/or R_4 form together a nonsubstituted, monosubstituted, or polysubstituted ring, preferably an aromatic ring,
Z is C with or without any substitution, preferably substituted with H or alkyl;
or an isomer, racemate, prodrug, or derivative thereof, or a pharmaceutically acceptable salt or solvate of these compounds.

In some preferred embodiments R_2 is C_1-C_{10} alkyl, preferably a branched alky, more preferably the group -$C(CH_3)_3$, preferably R_3 is H, -OH or OMe, and preferably R_4 is H, -OH or -OMe.

The compound is in another preferred embodiment the above defined group of compounds excluding the herein disclosed compounds 4a, 4b, 6, 7, 9, 14, 16, 19, 29, 33, 36, 42, and 45. In this regard, further preferred is any single one of the other (excluding the above) compounds disclosed in tables 1 to 8 in the example section of this application. In some embodiments the compounds of table 8 are preferred.

In one preferred embodiment the R_3 and R_4 in the above compound is H.

In some embodiments is R1 a group having the formula II:



(II)

Wherein R_5, R_6 and R_7 are independently selected from H, an unsubstituted, monosubstituted, or polysubstituted C_1-C_{18} alkyl or heteroalkyl, wherein said alkyl is straight, branched or cyclic, a unsubstituted, monosubstituted or polysubstituted C_1-C_{18} alkenyl or heteroalkenyl, wherein said alkenyl is straight, branched or cyclic, an unsubstituted, monosubstituted, or polysubstituted aryl or heteroaryl, an unsubstituted, monosubstituted, or polysubstituted benzyl group, an acyl group, such as formyl, acetyl, trichloroacetyl, fumaryl, maleyl, succinyl, benzoyl, or acyl groups

being branched, heteroatom-substituted or aryl-substituted, a sugar or another acetal, and an unsubstituted, monosubstituted, or polysubstituted amide or sulfonyl group.

Preferably R_6 and R_7 are H or halogen, preferably a halogen selected from F or Cl. Most preferably R_6 is H, and R_7 is H, F or Cl.

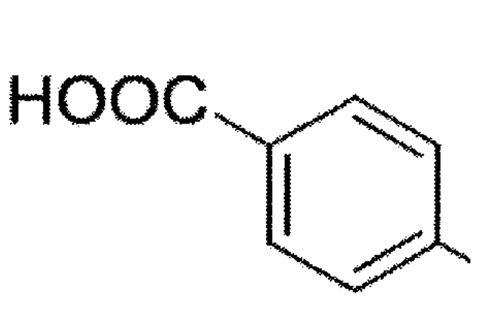
Preferably R_5 is a side chain of any length comprising a carboxylic acid or a suitable carboxylic acid replacement such as a typical bioisoster including but not limited to a tetrazole, a sulfonamide, an amide (such as an organic amide, a sulfonamide, or a phosphoramide) or the like.

The term "bioisoster" as used herein relates to a chemical moiety, which replaces another moiety in a molecule of an active compound without significant influence on its biological activity. Other properties of the active compound, such as for example its stability as a medicament, can be affected in this way.

As bioisoster moieties for carboxy (COOH) group can be mentioned especially 5-membered heterocyclic groups having from 1 to 4 heteroatoms selected from nitrogen, oxygen and sulphur, such as for example 1,3,4-oxadiazolyl, 1,2,3-oxadiazolyl, 1,2,5-oxadiazolyl, 1,2,4-oxadiazolyl, 1,3,4-thiadiazolyl, 1,2,4-thiadiazolyl, 1,2,3-thiadiazolyl, 1,2,5-thiadiazolyl, furyl, thienyl, pyrrolyl, pyrazolyl, imidazolyl, isoxazolyl, isothiazolyl, and N-substituted tetrazolyl. 5-Membered heterocyclic groups can be optionally substituted with 1 or 2 substituents selected from the group comprising phenyl, pyridinyl, straight or branched alkyl group, amino group, hydroxy group, fluoro, chloro, bromo, iodo, trifluoromethyl, trifluoromethoxy, trifluorothiomethoxy, alkoxy, and thioalkoxy.

As bioisoster moieties for carboxy (COOH) group can be also mentioned phenyl and 6-membered heterocyclic groups having from 1 to 4 heteroatoms selected from nitrogen, oxygen and sulphur, such as for example pyridinyl, pyrazinyl, pyridazinyl, pyrimidinyl, triazinyl, tetrazinyl, and others. Phenyl and 6-membered heterocyclic groups can be optionally substituted with 1 or 2 substituents selected from the group comprising phenyl, pyridinyl, straight or branched alkyl group, amino group, hydroxy group, fluoro, chloro, bromo, iodo, trifluoromethyl, trifluoromethoxy, trifluorothiomethoxy, alkoxy, and thioalkoxy.

In some embodiments of the invention R_1 is selected from any of the following substituents: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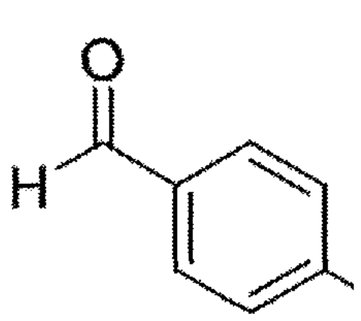
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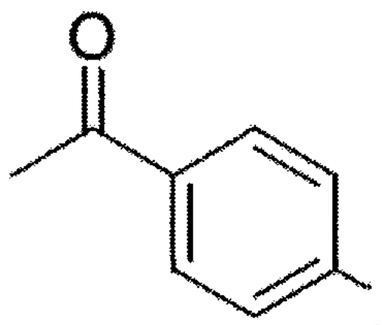
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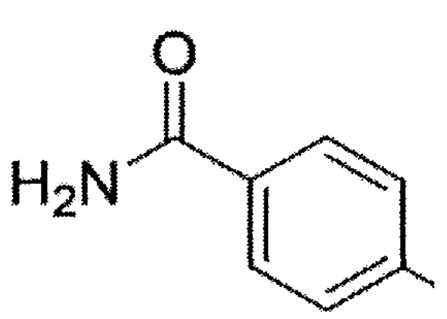
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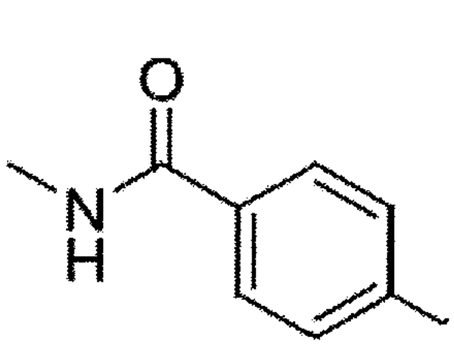
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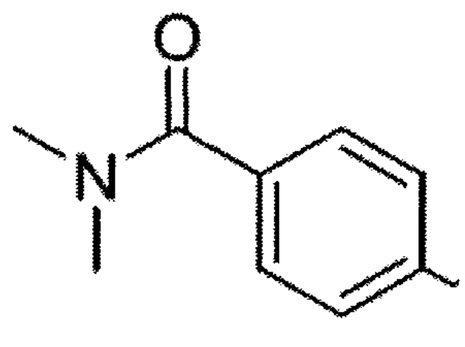
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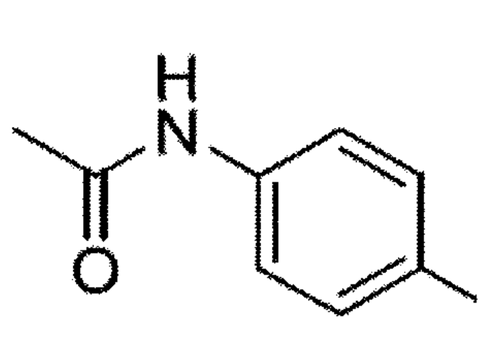
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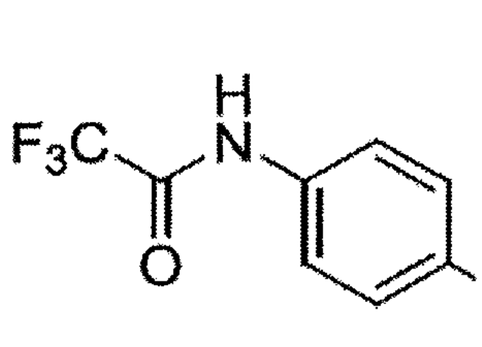
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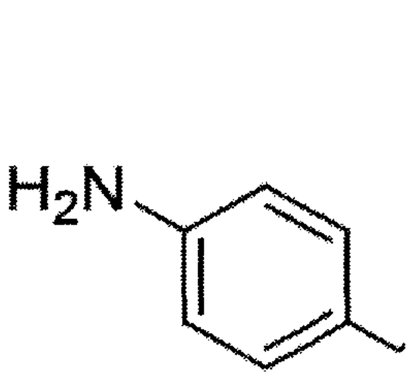
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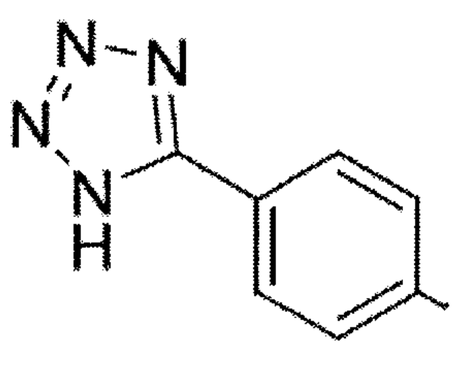
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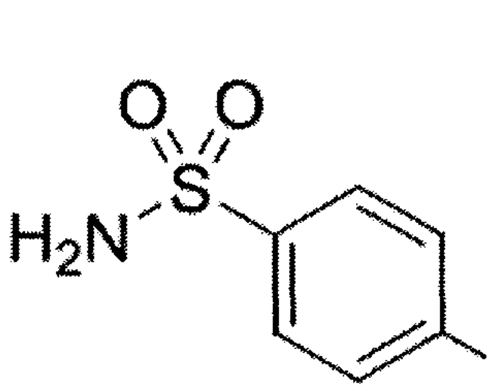
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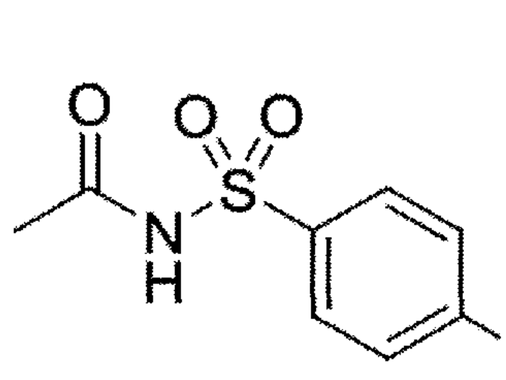
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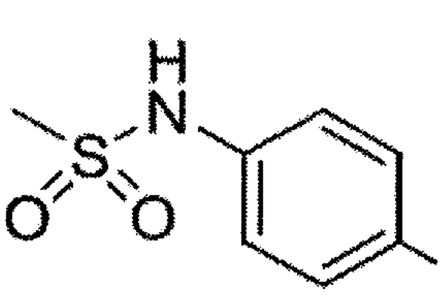
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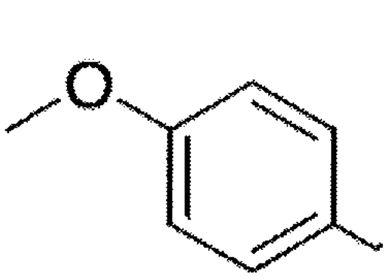
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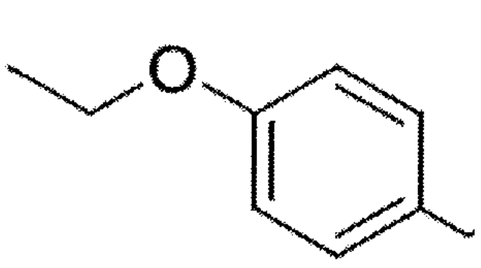
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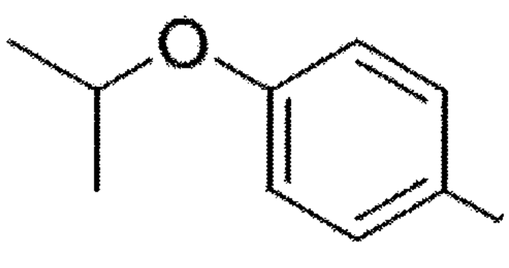
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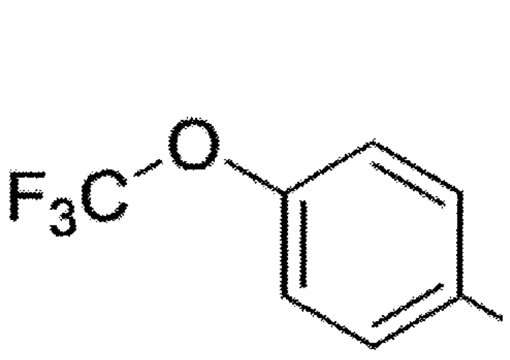
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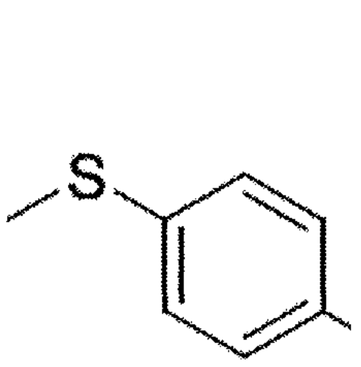
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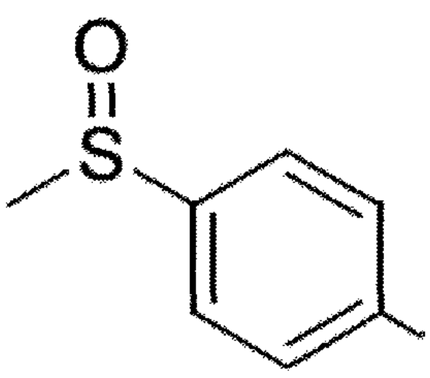
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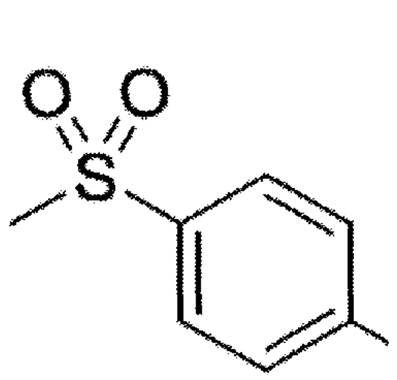
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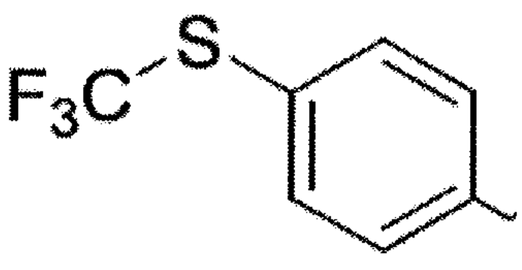
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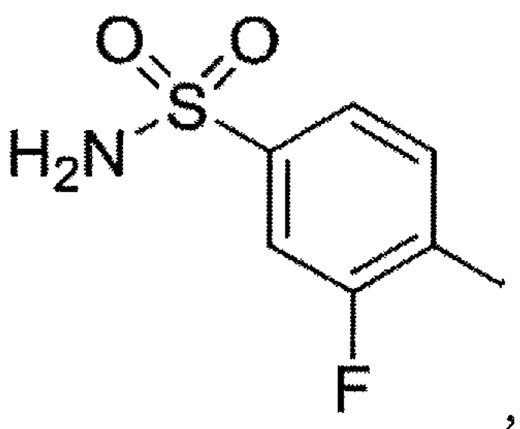
Most preferably the compound of the invention has the above formula I, wherein R_1 is selected from the group consisting of: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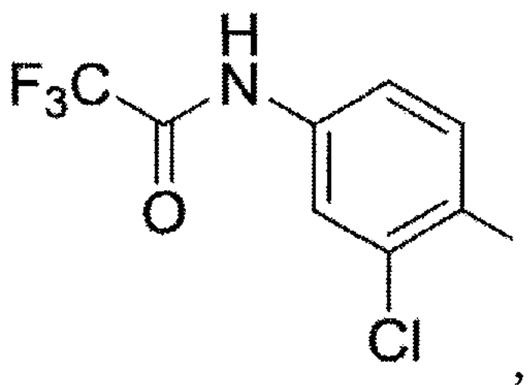
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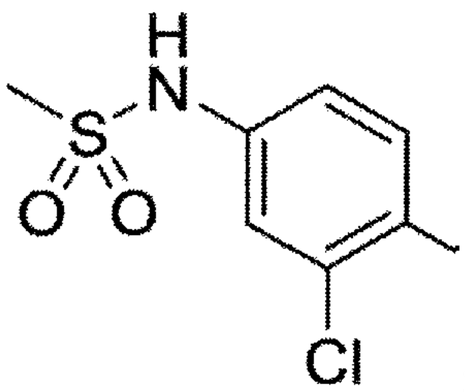
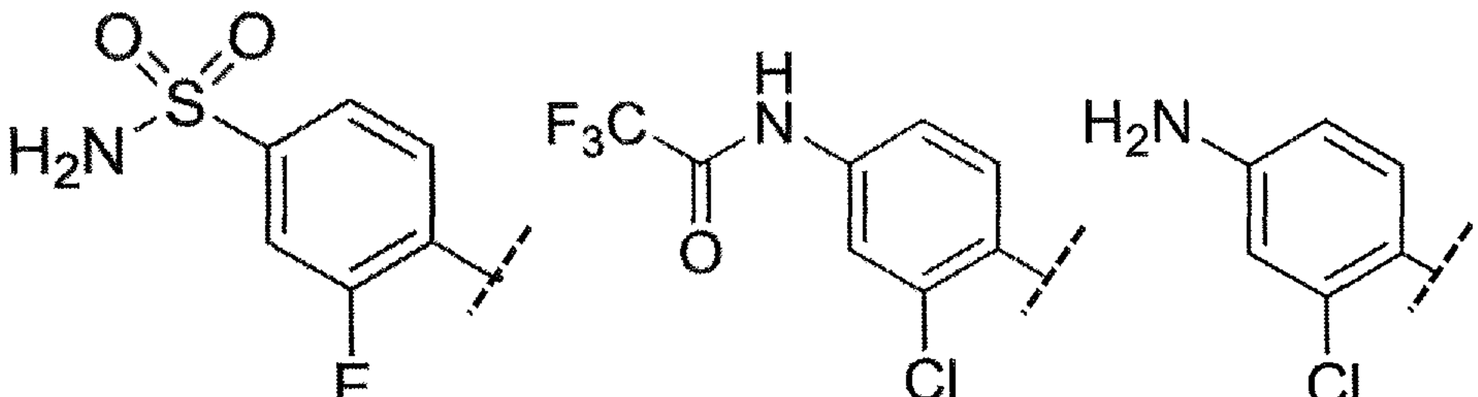
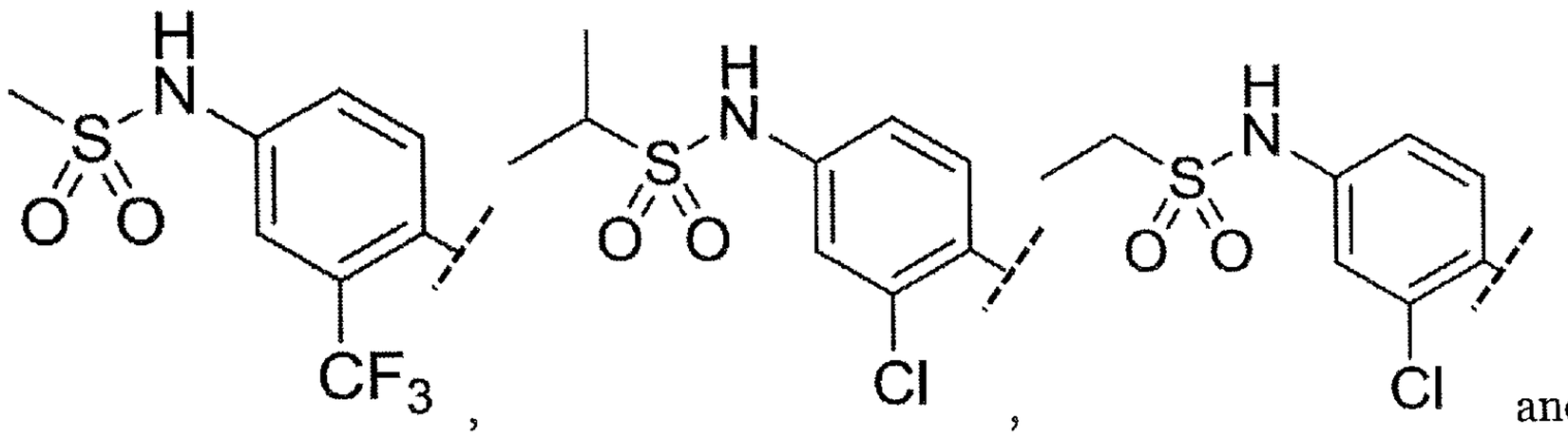

; and

wherein Z is C, R_2 is $-C(CH_3)_3$, and R_4, R_3 is H.

In another embodiment, further preferred is the above compound having formula I and wherein R_1 is selected from the group consisting of:





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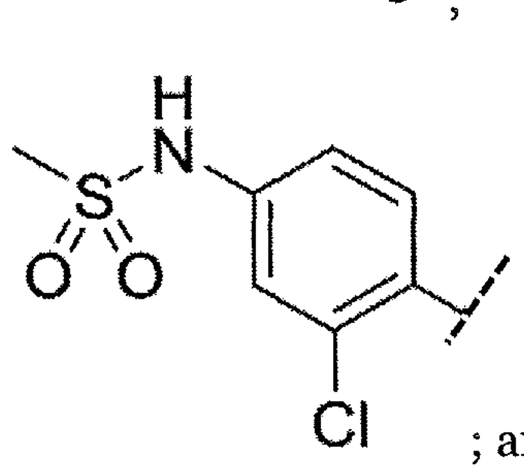
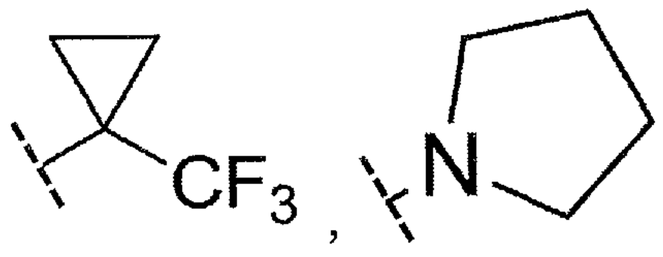


; and

wherein Z is C, R_3 is H or OH, and R_4 is H or OH, in particular R_3 and R_4 are not both OH; and wherein R_2 is selected from $-C(CH_3)_3$, $-N(CH_3)_2$, or the R_2 is any of the following



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The compound according to any one of claims 1 to 5, which is a farnesoid X receptor (FXR) agonist and a soluble epoxide hydrolase (sEH) inhibitor.

Salts with a pharmaceutically unacceptable anion likewise form part of the scope of the invention as useful intermediates for the preparation or purification of pharmaceutically acceptable salts and/or for use in nontherapeutic, for example in vitro, applications. The compounds of the invention may also exist in various polymorphous forms, for example as amorphous and crystalline polymorphous forms. All polymorphous forms of the inventive compounds are within the scope of the invention and are a further aspect of the invention.

As used herein, the term "farnesoid X receptor" or "FXR" refers to all mammalian forms of such receptor including, for example, alternative splice isoforms and naturally occurring isoforms (see e.g. R. M. Huber et al., Gene 2002, 290, 35). Representative FXR species include, without limitation the rat (GenBank Accession No. NM_21745), mouse (Genbank Accession No. NM_09108), and human (GenBank Accession No. NM_05123) forms of the receptor.

The term "soluble epoxide hydrolase (sEH)" is meant to refer to a bifunctional enzyme that in humans is encoded by the EPHX2 gene (HGNC:3402). sEH is a member of the epoxide hydrolase family. This enzyme, found in both the cytosol and peroxisomes, binds to specific epoxides and converts them to the corresponding diols.

In another aspect the invention also provides a method for synthesizing the herein disclosed novel compounds.

The compounds of the invention are in particular useful in a method of treating a disease in a subject. Preferably the disease to be treated according to the invention is a disorder associated with FXR and sEH.

Also provided is, thus, a method for concomitant modulation of FXR and sEH, the method comprising the step of administering to a subject or a cell a dual FXR and she modulator as described herein before.

Another aspect then relates to a method of treating a disease in subject, the method comprising a step of administering to the subject a therapeutically effective amount of the compound of the invention, or of the pharmaceutical composition of the invention.

In context of the present disclosure the term "subject" preferably pertains to a mammal, preferably a mouse, rat, donkey, horse, cat, dog, guinea pig, monkey, ape, or preferably to a human patient, for example a patient suffering from the herein described disorders.

In preferred embodiments the disease or disorder is a metabolic disorder, preferably a metabolic disorder caused by or associated with a high-fat diet.

Liver disease is a type of damage to or disease of the liver. There are more than a hundred kinds of liver disease. The most widely spread are as follows: Fascioliasis; Hepatitis; Alcoholic liver disease; Fatty liver disease; Cirrhosis; liver; biliary; sclerosing cholangitis; Centrilobular necrosis; Budd-Chiari syndrome; Hereditary liver diseases (hemochromatosis, involving accumula-

tion of iron in the body, and Wilson's disease); transthyretin-related hereditary amyloidosis; and Gilbert's syndrome.

As used herein, the term "liver disease" refers to any disease or disorder that affects the liver. Examples of liver disease include, but are not limited to, Alagille Syndrome; Alcohol-Related Liver Disease; Alpha- 1 Antitrypsin Deficiency; Autoimmune Hepatitis; Benign Liver Tumors; Biliary Atresia; Cirrhosis; Galactosemia; Gilbert Syndrome; Hemochromatosis; Hepatitis A; Hepatitis B; Hepatitis C; Hepatocellular Carcinoma; Hepatic Encephalopathy; Liver Cysts; Liver Cancer; Newborn Jaundice; Non- Alcoholic Fatty Liver Disease (including nonalcoholic fatty liver and nonalcoholic steatohepatitis); Primary Biliary Cirrhosis (PBC); Primary Sclerosing Cholangitis (PSC); Reye Syndrome; Type I Glycogen Storage Disease and Wilson Disease.

The terms "Non-alcoholic fatty liver" or "Non-alcoholic fatty liver disease" (NAFLD) refers to a condition which is one cause of a fatty liver, occurring when fat is deposited in the liver not due to excessive alcohol use. NAFLD is related to insulin resistance and the metabolic syndrome and may respond to treatments originally developed for other insulin-resistant states (e.g. diabetes mellitus type 2) such as weight loss, metformin and thiazolidinediones. NAFLD can be sub-classified as non-alcoholic steatohepatitis (NASH) and nonalcoholic fatty liver (NAFL). NASH is the more extreme form of NAFLD, and is regarded as a major cause of cirrhosis of the liver of unknown cause.

Most patients with NAFLD have few or no symptoms. Patients may complain of fatigue, malaise, and dull right-upper-quadrant abdominal discomfort. Mild jaundice may be noticed although this is rare. More commonly NAFLD is diagnosed following abnormal liver function tests during routine blood tests. NAFLD is associated with insulin resistance and metabolic syndrome (obesity, combined hyperlipidemia, diabetes mellitus (type II) and high blood pressure). Common findings are elevated liver enzymes and a liver ultrasound showing steatosis. An ultrasound may also be used to exclude gallstone problems (cholelithiasis). A liver biopsy (tissue examination) is the only test widely accepted as definitively distinguishing NASH from other forms of liver disease and can be used to assess the severity of the inflammation and resultant fibrosis.

Nonalcoholic steatohepatitis (NASH) is a common, often "silent" liver disease. The major feature in NASH is fat in the liver, along with inflammation and damage. Most people with NASH feel well and are not aware that they have a liver problem. Nevertheless, NASH can be severe and can lead to cirrhosis, in which the liver is permanently damaged and scarred and no longer able to work properly.

NASH is usually first suspected in a person who is found to have elevations in liver tests that are included in routine blood test panels, such as alanine aminotransferase (ALT) or aspartate aminotransferase (AST). When further evaluation shows no apparent reason for liver disease and when x rays or imaging studies of the liver show fat, NASH is suspected. The only means of providing a definitive diagnosis of NASH and separating it from simple fatty liver is a liver biopsy. NASH is diagnosed when fat along with inflammation and damage to liver cells is observed from the biopsy. If the tissue shows fat without inflammation and damage, NAFL or NAFLD is diagnosed. Currently, no blood tests or scans can reliably provide this information.

Therefore, preferred diseases to be treated with the compounds of the invention are liver diseases, such as non-alcoholic fatty liver disease or non-alcoholic steatohepatitis (NASH).

As used herein, the term "therapeutically effective amount" means that amount of a compound that will elicit the biological or medical response of a tissue, system, animal or human that is being sought, for instance, by a researcher or clinician. Furthermore, the term "therapeutically effective amount" means any amount which, as compared to a corresponding subject who has not received such amount, results in improved treatment, healing, prevention, or amelioration of a disease, disorder, or side effect, or a decrease in the rate of advancement of a disease or disorder.

In yet another aspect there is provided a pharmaceutical composition comprising a compound of the invention together with a pharmaceutically acceptable carrier and/or excipient.

The compound(s) of the invention can also be administered in combination with further active ingredients. The amount of a compound of the formula I required to achieve the desired biological effect depends on a number of factors, for example the specific compound chosen, the intended use, the mode of administration and the clinical condition of the patient.

The daily dose is generally in the range from 0.3 mg to 100 mg (typically from 3 mg to 50 mg) per day per kilogram of body weight, for example 3-10 mg/kg/day. An intravenous dose may be, for example, in the range from 0.3 mg to 1 .0 mg/kg, which can suitably be administered as infusion of 10 ng to 100 ng per kilogram of body weight per minute. Suitable infusion solutions for these purposes may contain, for example, 0.1 ng to 100 mg, typically 1 ng to 100 mg, per milliliter. Single doses may contain, for example, 1 mg to 10 g of the active ingredient. Thus, ampoules for injections may contain, for example, from 1 mg to 100 mg, and orally administrable single-dose formulations, for example tablets or capsules, may contain, for example, from 1 .0 to 1000 mg, typically from 10 to 600 mg. For treatment of the abovementioned conditions, the compounds of the formula I themselves may be used as the compound, but they are preferably pre-

sent with a compatible carrier in the form of a pharmaceutical composition. The carrier must of course be acceptable in the sense that it is compatible with the other constituents of the composition and is not harmful to the patient's health. The carrier may be a solid or a liquid or both and is preferably formulated with the compound as a single dose, for example as a tablet, which may contain from 0.05% to 95% by weight of the active ingredient. Other pharmaceutically active substances may likewise be present, including other compounds of formula I. The inventive pharmaceutical compositions can be produced by one of the known pharmaceutical methods, which essentially involve mixing the ingredients with pharmacologically acceptable carriers and/or excipients.

Inventive pharmaceutical compositions are those suitable for oral, rectal, topical, peroral (for example sublingual) and parenteral (for example subcutaneous, intramuscular, intradermal or intravenous) administration, although the most suitable mode of administration depends in each individual case on the nature and severity of the condition to be treated and on the nature of the compound of formula I used in each case. Coated formulations or medicament forms are also within the scope of the invention. Sugar-coated formulations and sugar-coated slow-release formulations are also within the scope of the invention. Preference is given to acid- and gastric juice- resistant formulations. Suitable gastric juice-resistant coatings comprise cellulose acetate phthalate, polyvinyl acetate phthalate, hydroxypropylmethylcellulose phthalate and anionic polymers of methacrylic acid and methyl methacrylate. Suitable pharmaceutical compounds for oral administration may be in the form of separate, i.e. single-dose, units, for example capsules, cachets, lozenges, film tablets, sugar-coated tablets, soluble tablets, sublingual tablets, oral tablets or tablets, each of which contains a defined amount of the compound of formula I; as powders or granules; as solution or suspension in an aqueous or nonaqueous liquid; or as an oil-in-water or water-in-oil emulsion. These compositions may, as already mentioned, be prepared by any suitable pharmaceutical method which includes a step in which the active ingredient and the carrier (which may consist of one or more additional ingredients) are brought into contact. The compositions are generally produced by uniform and homogeneous mixing of the active ingredient with a liquid and/or finely divided solid carrier, after which the product is shaped if necessary. For example, a tablet can be produced by compressing or molding a powder or granules of the compound, where appropriate with one or more additional ingredients. Compressed tablets can be produced by tableting the compound in free-flowing form such as, for example, a powder or granules, where appropriate mixed with a binder, glidant, inert diluent (filler) and/or one (or more) surfactant(s)/dispersant(s) in a suitable machine. Molded tablets or granules can be produced by molding the pulverulent compound moistened with an inert liquid diluent in a suitable machine.

Pharmaceutical compositions suitable for peroral (sublingual) administration include lozenges which contain a compound of formula I with a flavoring, typically sucrose, and gum arabic or tragacanth, and pastilles which comprise the compound in an inert base such as gelatin and glycerol or sucrose and gum arabic.

Pharmaceutical compositions suitable for parenteral administration comprise preferably sterile aqueous preparations of a compound of formula I, which are preferably isotonic with the blood of the intended recipient. These preparations are preferably administered intravenously, although administration may also take place by subcutaneous, intramuscular or intradermal injection. These preparations can preferably be produced by mixing the compound with water and making the resulting solution sterile by a suitable sterilization process (e.g. steam sterilization, sterile filtration) and isotonic with blood. Injectable compositions of the invention generally contain from 0.1 to 5% by weight of the active compound. Pharmaceutical compositions suitable for rectal administration are preferably in the form of single-dose suppositories. These can be produced by mixing a compound of formula I with one or more conventional solid carriers, for example cocoa butter, and shaping the resulting mixture.

Pharmaceutical compositions suitable for topical use on the skin are preferably in the form of ointment, cream, powder, lotion, paste, spray, aerosol or oil. Carriers which can be used are petrolatum, lanolin, polyethylene glycols, alcohols and combinations of two or more of these substances. The active ingredient is generally present in a concentration of 0.1 to 15% by weight of the composition, for example 0.5 to 2%.

Transdermal administration is also possible. Pharmaceutical compositions suitable for transdermal uses may be in the form of single patches which are suitable for long-term close contact with the patient's epidermis. Such patches suitably contain the active ingredient in an aqueous solution which is buffered where appropriate, dissolved and/or dispersed in an adhesive or dispersed in a polymer. A suitable active ingredient concentration is about 1 % to 35%, preferably about 3% to 15%. A particular option is for the active ingredient to be released by electrotransport or iontophoresis as described, for example, in Pharmaceutical Research, 2(6): 318 (1986).

The present invention will now be further described in the following examples with reference to the accompanying figures and sequences, nevertheless, without being limited thereto. For the purposes of the present invention, all references as cited herein are incorporated by reference in their entireties. In the Figures:

Figure 1 A potency plot of the dual modulators indicated **30**, **46** and **54** (red) as most potent partial FXR agonists while **31**, **44** and **51** (blue) emerged for highest sEH in-

hibitory potency. Consequently, the structural features of these compounds were combined to increase the dual activity resulting in **55** and **57** (green, table 7).

Figure 2 Molecular docking of **57**: (A) Binding mode of compound **57** in the FXR-LBD (PDB code 4QE8). (B) Binding mode of compound **57** in the sEH (PDB code 3I28). Molecular surface is colored by lipophilicity (green: lipophilic; magenta: hydrophilic). Selected side chains are shown as lines, compound **57** is displayed as sticks.

Figure 3: *In vitro* characterization of **57**: (A) Selectivity profile: except for a moderate activity on PPARγ (EC_{50} = 14.7±0.9 µM, 30±1% max.), **57** was inactive on related nuclear receptors and, therefore highly selective for FXR (values are mean±SEM; n=3). (B) **57** revealed no cytotoxicity in a common WST-1 assay on HepG2 cells up to 100 µM (values are mean±SEM; n=4). (C) **57** displayed an acceptable *in vitro* microsomal stability with more than 50% remaining after 60 minutes incubation with Wistar rat liver microsomes (values are mean±SEM; n=3).

Figure 4: Determination of cellular activity of **57**: (A) FXR target gene mRNA quantification in HepG2 cells after 8 or 16 hours incubation with **57** at 0.1 µM and 1 µM compared to CDCA (**1b**) at 50 µM: **57** caused a concentration-independent partial induction of BSEP, SHP, PPARα, GLUT4, FGF19, PDK4 and FABP1 as well as a concentration-independent partial repression of CYP7A1, SREBP1c and FAS (vehicle treated control cells are defined as 100%; values are mean±SEM; n=4). (B) **57** did not cause significant modulation of PPARγ target genes CD36 and FAM3A (pioglitazone (PIO) as positive control; values are mean±SEM; n=3). (C) Soluble epoxide hydrolase activity in cell homogenates from HepG2 cells: Dual modulator **57** inhibits conversion of 14.15-EET-d11 to 14.15-DHET-d11 by cellular sEH with an IC_{50} value of approximately 10 nM and exerts statistically significant inhibition at concentrations as low as 0.1 nM (values are mean±SEM; n=3). (* $p<0.05$; ** $p<0.01$; *** $p<0.001$)

Figure 5: *In vivo* characterization of **57**: (A) *In vivo* pharmacokinetic evaluation of **57** revealed rapid uptake, high bioavailability and moderate though acceptable half-life of the dual modulator. **57** achieved effective plasma concentrations above IC_{50} (sEH) and EC_{50} (FXR) values for roughly 3.5 hours after a single oral dose of 10 mg/kg body weight. (B) An approximately 2-fold increase in EET/DHET ratios in mouse plasma 8 h post dose indicated that **57** inhibited sEH *in vivo*. (C) Quantification of mRNA levels of FXR target genes BSEP, SHP, CYP7A1, SREBP1c and

FGF15 as well as PPARγ target gene FATP 8 h post dose compared to vehicle treated mice (100%). **57** showed a trend to induction of BSEP and SHP and slightly repressed CYP7A1. Moreover, **57** significantly repressed SREBP1c and significantly induced FGF15 indicating FXR modulation *in vivo* and potentially beneficial effects in NASH. PPARγ target gene FATP was not modulated *in vivo*. (n(vehicle)=3; n(**57**)=6; * p<0.05; ** p<0.01; *** p<0.001).

Figure 6: **(or scheme 10)**: *In vitro* metabolism of **57**. Hydrolysis of the sulfonamide moiety of dual modulator **57** generates metabolite **69a** (confirmed by LC-MS-MS) which displays high dual modulatory potency and can contribute to pharmacodynamics activity. LC-MS-MS analysis also indicates the presence of a metabolite resulting from hydroxylation at the *tert*-butylbenzamide residue Of the three possible isomers **77**, **78** and **79**, **77** and **78** were not detectable confirming metabolic hydroxylation on the *tert*-butyl group leading to **79**. Furthermore, **57** is hydroxylated on the aromatic ring of the benzyl substituent.

Figure 7: **(or scheme 1)** shows Important FXR ligands: obeticholic acid (1a), physiological agonist CDCA (1b) and synthetic reference FXR agonist (1c).

Figure 8: **(or scheme 2)** shows discovery of lead compound 5 by merging the pharmacophores of sEH inhibitor GSK2188931B (2) and partial FXR agonist 3.

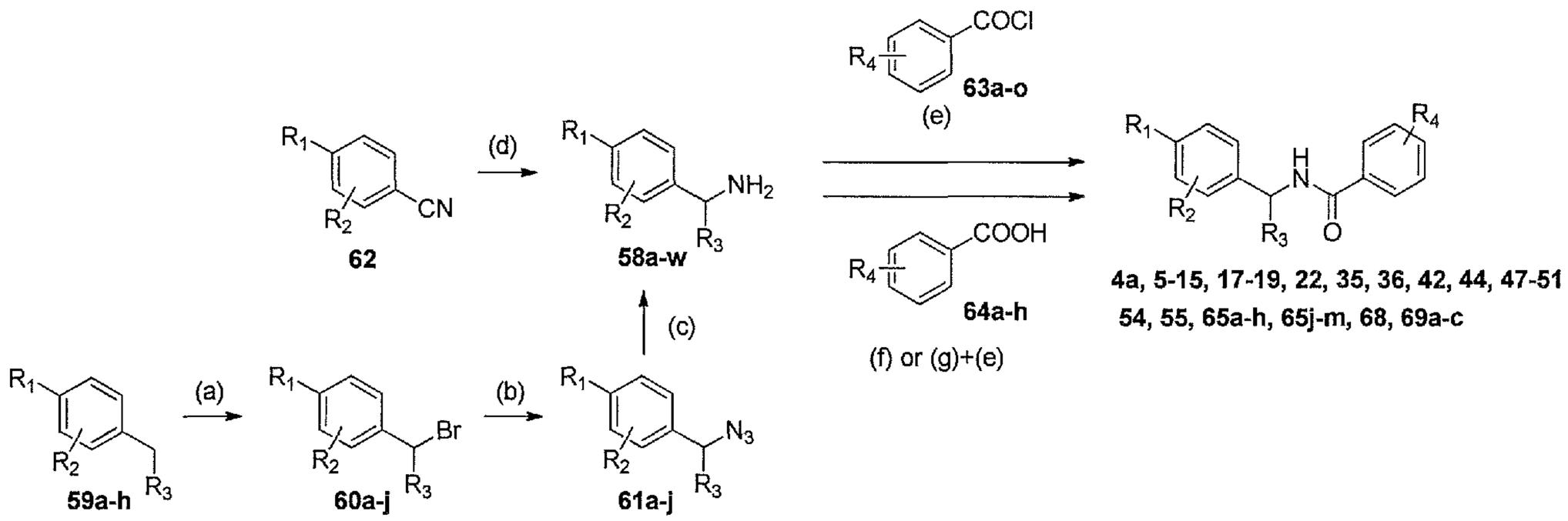
EXAMPLES

In order to develop agents with potent dual activity on FXR and sEH, the inventors initially screened representative compounds of the in-house library of FXR modulators but failed to identify a lead compound with inhibitory potency on sEH amongst them. Therefore, the inventors searched for a merged pharmacophore from known partial FXR agonists and known sEH inhibitors. Several sEH inhibitors contain an amide or urea residue mimicking the epoxide moiety cleaved by the enzyme. The sEH inhibitor GSK2188931B (**2**) comprising an *N*-benzylamide residue as pharmacophore shares some structural similarity with recently reported[15] partial FXR agonists such as **3**. The inventors therefore extracted the similar structural features of both compounds and combined them in the minimal dual pharmacophore **4a** containing the *N*-benzylamide residue for sEH inhibition and a carboxylic acid group for FXR activation (figure 8, scheme 2). Compound **4a** exhibited moderate sEH inhibition of 37±1% at 50 μM but was inactive on FXR. **4b** incorporating the piperidine moiety of template **2** displayed even lower activity and was inactive on sEH and FXR. However, when the inventors replaced the saturated ring in **4a** and **4b** by an aromatic moiety in **5** the inventors achieved the desired dual activity with 12±1% FXR activation and 16±2% sEH inhibition at 50 μM concentration. For the low fragment-like size (MW 255 Da) of **5** the inventors considered this moderate potency sufficient and systematically investigated the structure activity relationship (SAR) of **5** as dual sEH and FXR modulator (figure 2).

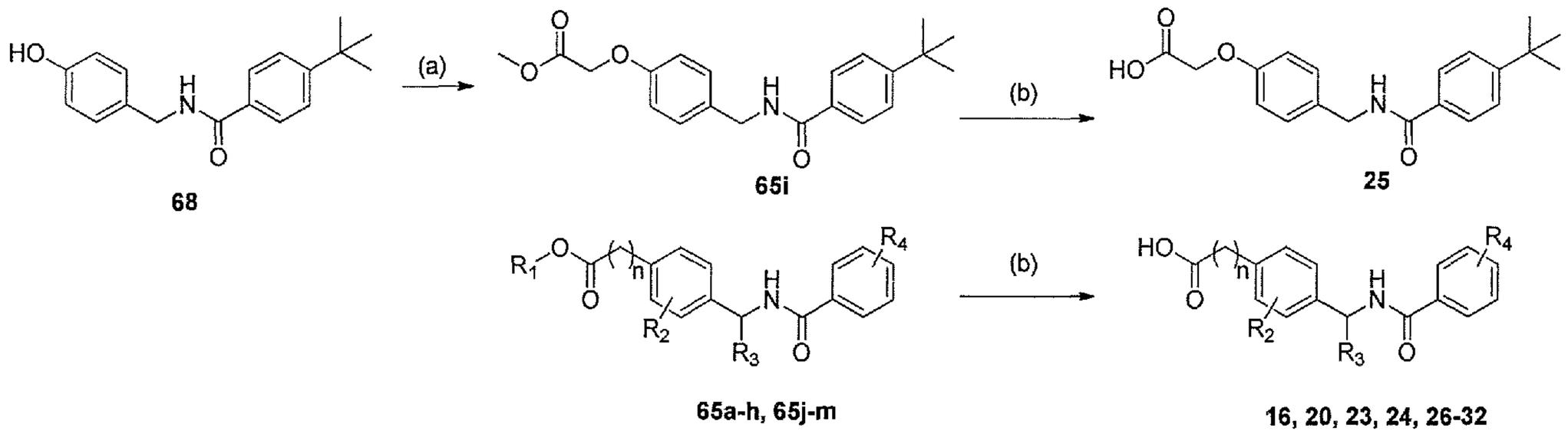
Example 1: Synthesis

N-benzyl benzamides **4-57** and **77-78** were prepared according to schemes 3-9. Synthesis of aminomethylbenzene precursors **58a-j** started with radical bromination of the respective methylbenzene derivatives **59a-j** using NBS and AIBN to bromomethylbenzenes **60a-j**. Subsequently, bromomethylbenzenes **60a-j** were applied to a two-step Staudinger reaction using sodium azide to generate azides **61a-j** and triphenylphosphine in water for their reduction. Aminomethylbenzene derivative **58k** was prepared by reduction of 4-amino-2-chlorobenzonitrile **62** using $LiAlH_4$. Aminomethylbenzene derivatives **58l-w** were commercially available. Subsequently, **58a-w** were reacted with carbonyl chlorides **63a-o** in presence of pyridine or with carboxylic acids **64a-f** in presence of EDC and 4-DMAP to yield compounds **18, 19, 22, 35, 36, 44, 47-51, 54, 55, 68** and **69a-c** or their esters **65a-h** (scheme 3). Compound **68** was treated with $BrCH_2COOCH_3$ to generate the ester **65i**. All esters **65a-i** were hydrolyzed to the final products **16**, **20** and **23-32** under alkaline conditions (scheme 4). Urea **21** was prepared from 4-aminobenzoic acid (**66**) and 4-tert-butylphenylisocyanate (**67**) with NEt_3 and subsequent hydrolysis with lithium hydroxide (scheme 5). The free carboxylic acid **18** served for the preparation of amides **37-39** using ammonium chloride, methylammonium chloride or dime-

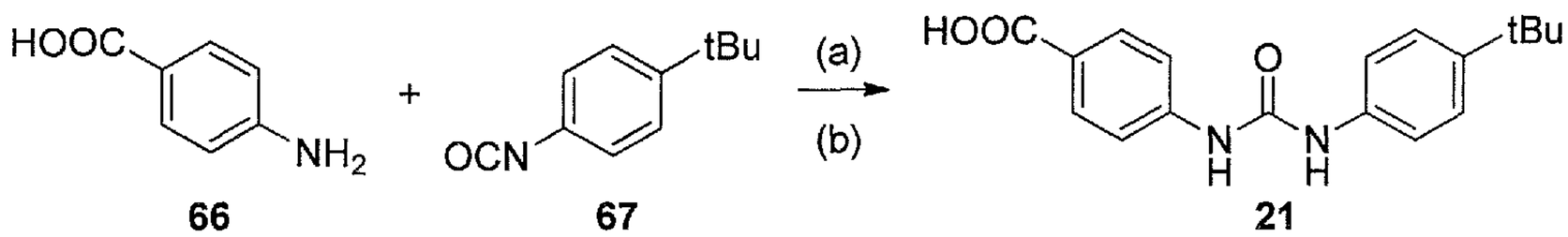
thylammonium chloride and EDC/DMAP. Reduction of **18** with $LiAlH_4$ yielded ethyl alcohol derivative **33** which was further converted to aldehyde **34** with PCC (scheme 6). The inverted amides **40, 41** and **56**, the inverted sulfonamides **46** and **57** as well as *N*-acyl sulfonamide **45** were generated from **42**, **44**, and **69a** with EDC/DMAP for carboxylic acid activation. Tetrazole **43** was available from nitrile **36** by cycloaddition of NaN_3 under Cu_2O catalysis (scheme 7). Oxidation of methylmercaptane **51** to sulfoxide **52** and sulfone **53** was achieved using suitable equivalents of meta-chloroperbenzoic acid (mCPBA, scheme 8) and, finally, preparation of methoxy derivatives **76a-b** according to the standard procedure (scheme 3) and their demethylation with BBr_3 yielded phenolic derivatives 77 and **78** (scheme 9).



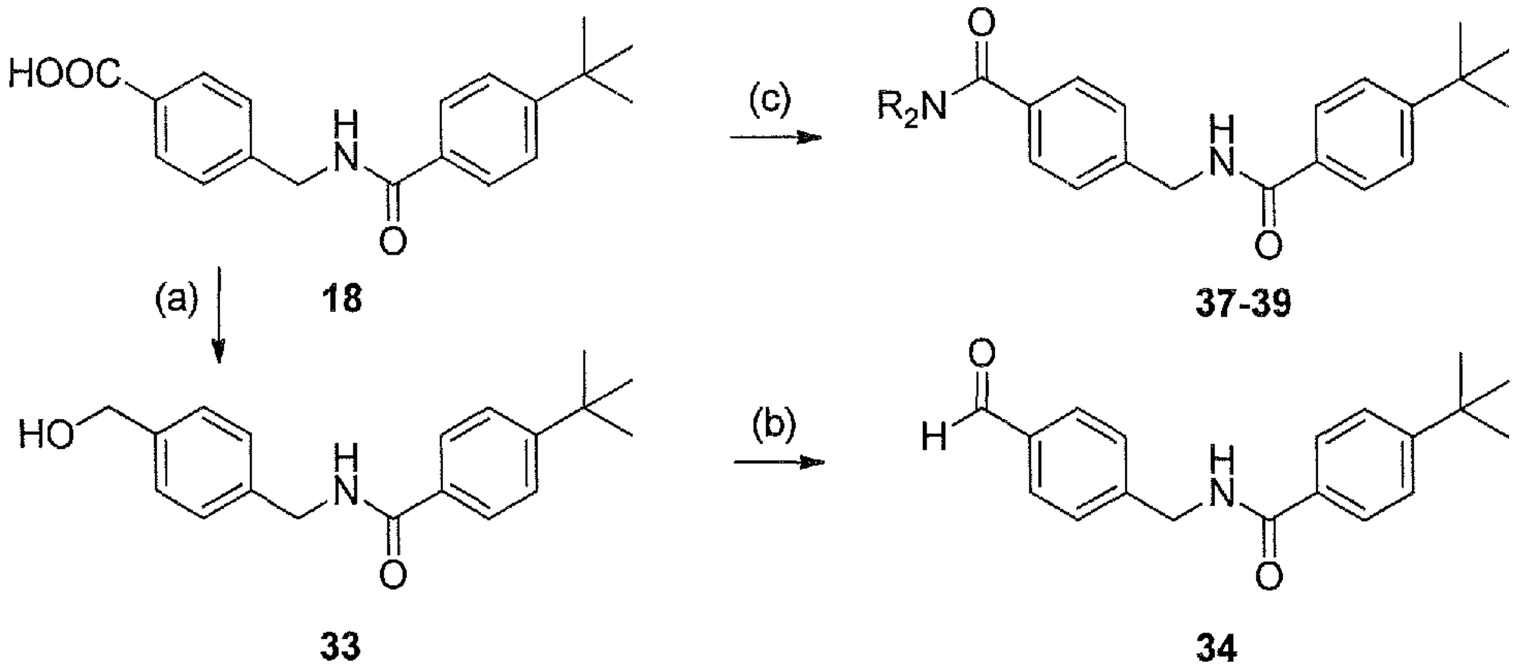
Scheme 3: Reagents and conditions (a) NBS, AIBN, $CHCl_3$, reflux, 4 h (b) NaN_3, DMF, 80 °C, 16 h (c) PPh_3, H_2O, THF, RT, 12 h (d) $LiAlH_4$, THF, reflux, 18 h (e) pyridine, THF, RT, 2 h (f) EDC·HCl, DMAP, $CHCl_3$, 50 °C, 6 h (g) $SOCl_2$, DCM, DMF, reflux, 4 h.



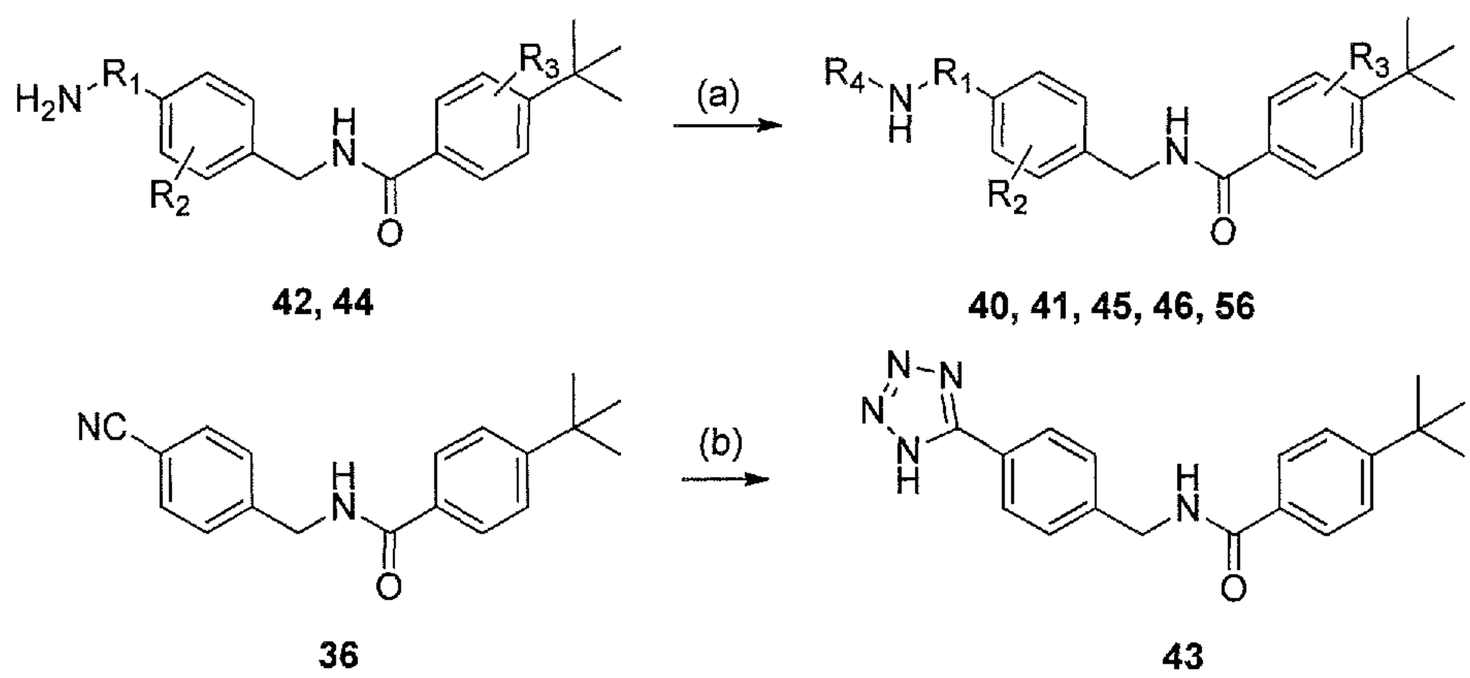
Scheme 4: Reagents and conditions (a) $BrCH_2COOCH_3$, DMF, K_2CO_3, RT, 18 h (b) KOH, H_2O, MeOH, μw, 15 min.



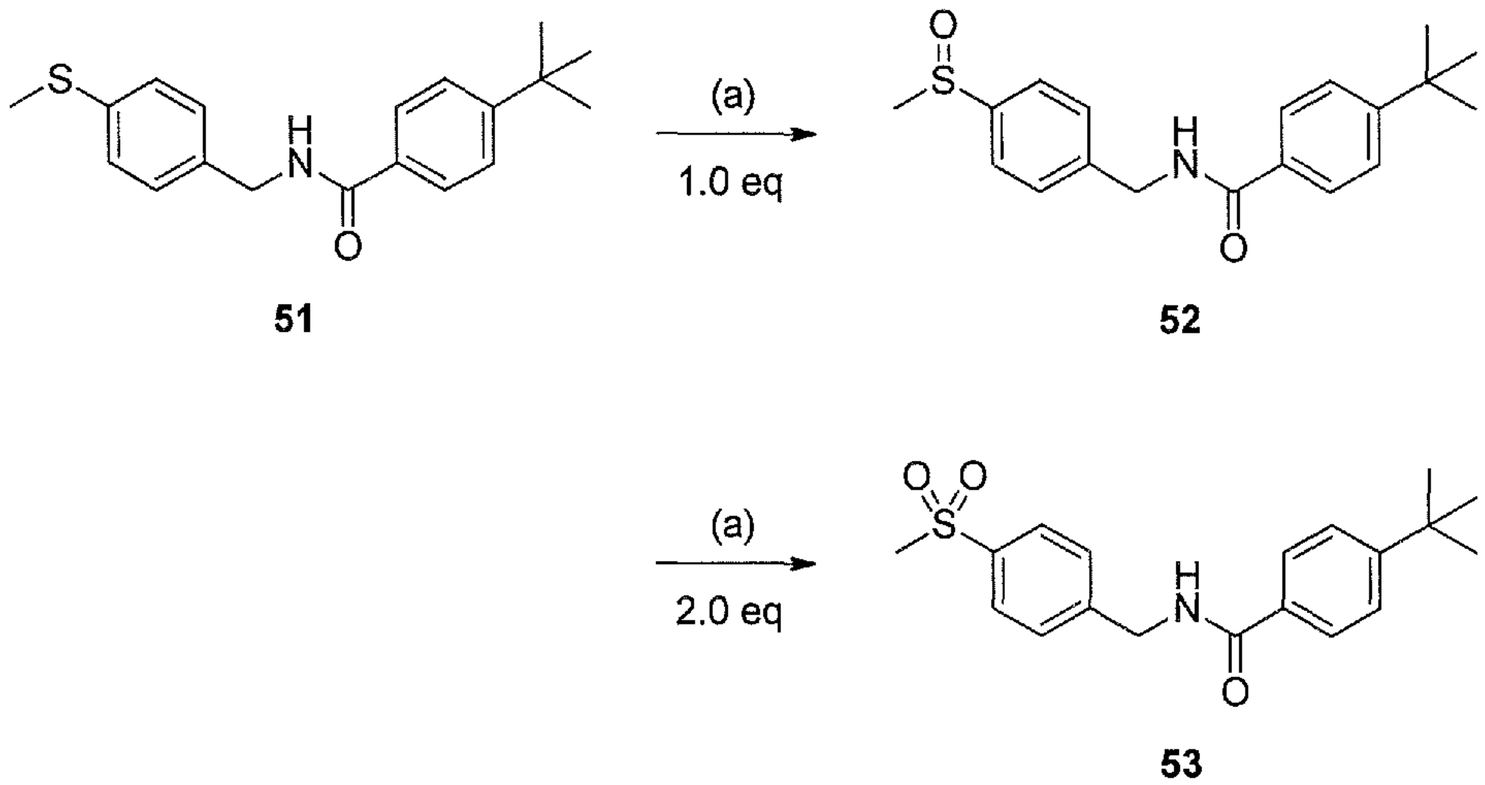
Scheme 5: Reagents and conditions (a) DCM, NEt_3, RT, 24 h (b) LiOH, THF, MeOH, H_2O, RT, 15 h.



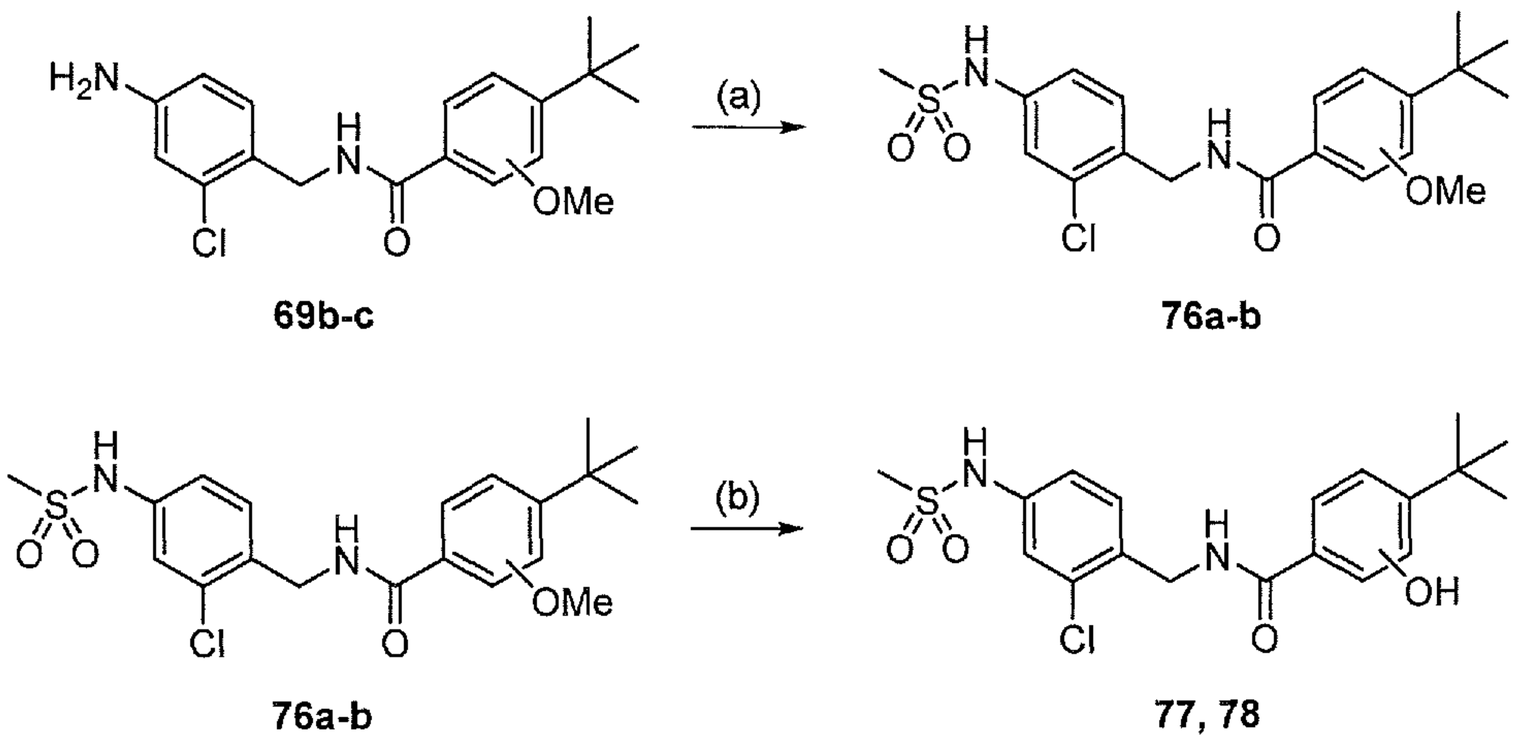
Scheme 6: Reagents and conditions (a) $LiAlH_4$, THF, RT, 18 h (b) PCC, DCM, RT, 2 h (c) $R_2NH_2 \cdot Cl$, EDC·HCl, DMAP, $CHCl_3$, 50 °C, 4 h.



Scheme 7: Reagents and conditions (a) R-OH, EDC·HCl, DMAP, $CHCl_3$, 50 °C, 4 h or mesyl chloride, THF, RT, 2 h, (b) Cu_2O, NaN_3, DMF, MeOH, 90 °C, 24 h, (c) BBr_3, DCM, 0 °C to RT, 2 h.



Scheme 8: Reagents and conditions (a) mCPBA, $CHCl_3$, 0 °C for 2 h or RT for 18 h.



69b-c **76a-b** **76a-b** **77, 78**

Scheme 9: Reagents and conditions (a) mesyl chloride, THF, RT, 2 h, (b) BBr_3, DCM, 0 °C to RT, 2 h.

Example 2: Biological Evaluation

To determine FXR agonistic activity, test compounds **4-57** were characterized in a full-length (fl) FXR reporter gene assay in HeLa cells. This assay is based on a reporter construct containing a firefly luciferase under the control of the FXR response element from bile salt export protein (BSEP). FXR and its hetero dimer partner retinoid X receptor (RXR) as expression constructs under the control of a CMV promoter as well as a constitutively expressed renilla luciferase (SV40 promoter) for normalization and toxicity control were co-transfected. The synthetic FXR agonist GW4064 (**1c**) was used as reference agonist and its transactivation activity at 3 µM was defined as 100% activation. The assay was validated with diverse known FXR agonists which yielded potencies in good agreement with literature (GW4064 (**1c**): EC_{50}=0.51±0.16 µM, OCA (**1a**): EC_{50}=0.16±0.02 µM and CDCA (**1b**): EC_{50}=18±1 µM). The well-characterized sEH inhibitor CIU[36] had no activity in this assay at 10 µM excluding unspecific effects of sEH inhibitors. The sEH inhibitory potency of the test compounds was quantified in a fluorescence-based assay using recombinant enzyme and the fluorogenic sEH substrate PHOME[37] that is hydrolyzed to a fluorescent 6-methoxynaphtaldehyde by sEH.

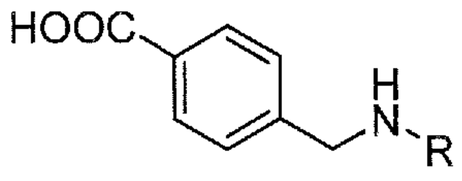
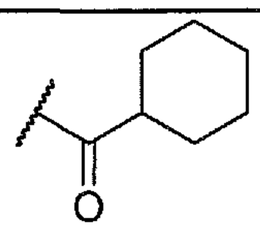
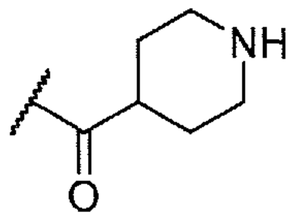
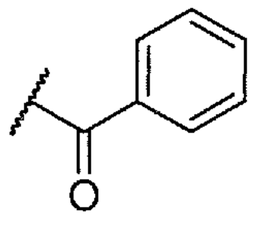
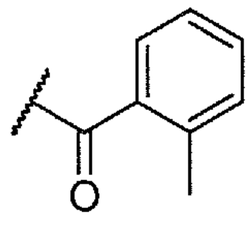
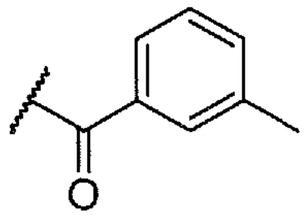
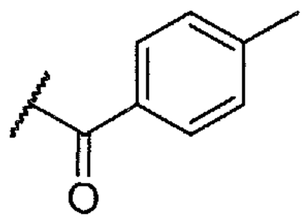
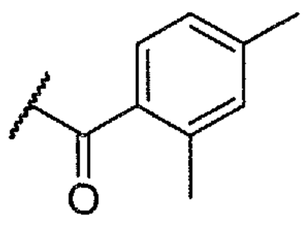
Example 3: Structure activity relationship & structural optimization

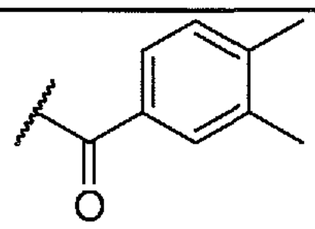
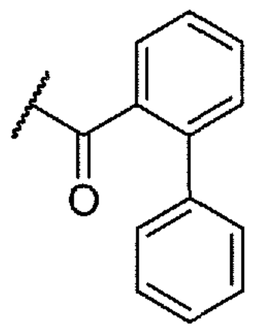
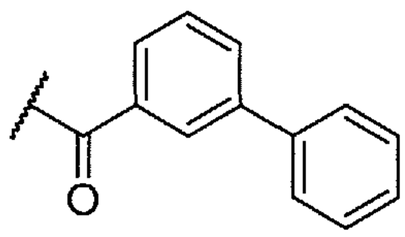
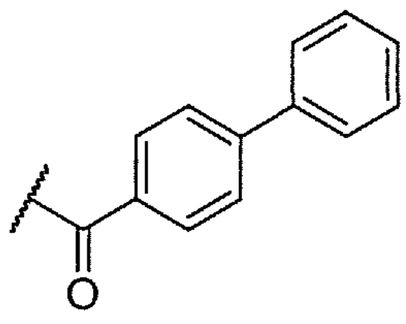
As first step in the SAR study (table 1), the inventors introduced additional methyl groups (**6-8**) in every position of the benzamide partial structure of **5**. While all methylated derivatives **6-8** exhibited weak sEH inhibitory activity, FXR only tolerated a 4-methyl group in **8** indicating that the FXR binding pocket offers additional space especially in this direction. A 3-methyl group (7) generated the highest sEH inhibition amongst the methylated derivatives and therefore the inventors prepared compounds (**9**, **10**) comprising two methyl substituents in order to combine

the improvements on both targets. 2,4-dimethyl derivative **9** was nearly inactive while 3,4-dimethyl derivative **10** exhibited improved dual activity although its maximum relative activation on FXR was rather low.

As the additional methyl groups did not significantly improve the potency on either target the inventors also investigated the introduction of larger residues on the benzamide moiety and characterized biphenyl derivatives **11-13**. All three biphenyls **11-13** revealed considerably higher potency than the respective methylbenzamides **6-8** while the rank order of potency remained unchanged. FXR tolerated 3-substitution (**12**) but favored 4-substitution (**13**) and sEH could equally be inhibited by the 3- (**12**) and the 4-biphenyl derivative (**13**).

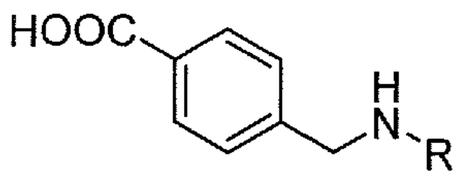
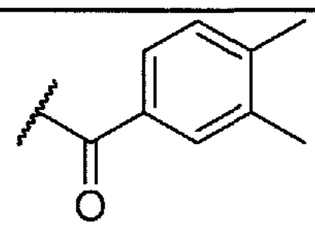
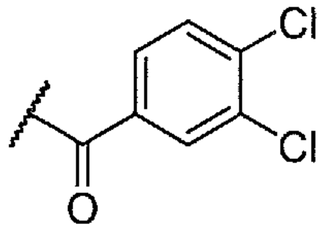
Table 1: *In vitro* activity of **4-13** on FXR and sEH (data represents mean±SEM, n=3-6)

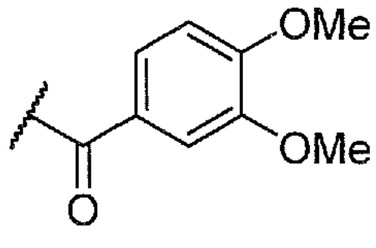
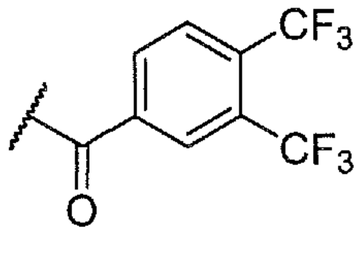
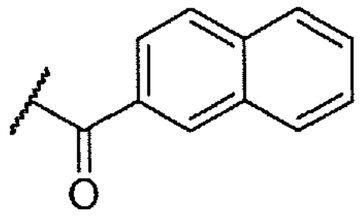
#	 **R =**	***FXR activation*** EC_{50} (max. rel. activation) or % activation at indicated conc.	***sEH inhibition*** IC_{50} or % inhibition at indicated conc.
4a		inactive (50 µM)	37±1% inhibition (50 µM)
4b		inactive (50 µM)	inactive (50 µM)
5		12±1% activation (50 µM)	16±2% inhibition (50 µM)
6		inactive (50 µM)	14±1% inhibition (50 µM)
7		inactive (50 µM)	37±1% inhibition (50 µM)
8		15±3% activation (50 µM)	24±1% inhibition (50 µM)
9		inactive (50 µM)	7±2% inhibition (50 µM)

10		0.32±0.03 μM (12±1%)	52±1% inhibition (50 μM)
11		22±1% activation (50 μM)	19±2% inhibition (50 μM)
12		0.67±0.17 μM (14±1%)	10.0±1.2 μM
13		0.44±0.04 μM (24±1%)	8.1±0.1 μM

The initial SAR results suggested that 3- and 4-substitution at the benzamide residue in **5** was tolerated by both targets eventually improving the dual potency and, therefore, the inventors investigated various 3,4-disubstitutions (**14-16**) as well as 2-naphtyl derivative **17** (table 2). However, **14-17** failed to produce a significant improvement in the dual potency on FXR and sEH. 3,4-dichloro (**14**) and 3,4-bis(trifluoromethyl) substitution (**16**) were only tolerated by sEH and 2-naphtyl derivative **17** was less active on FXR than **10**. Only 3,4-dimethoxybenzamide **15** was favorable since it improved the maximum relative activation on FXR without affecting the EC_{50} value and weakly inhibited sEH activity.

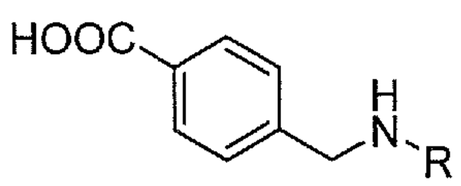
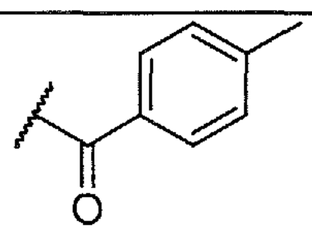
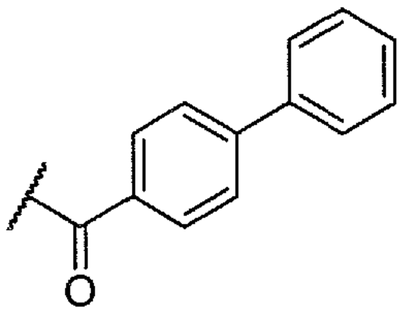
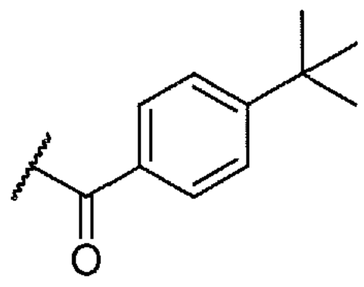
Table 2: *In vitro* activity of **14-17** on FXR and sEH (data represents mean±SEM, n=3-6)

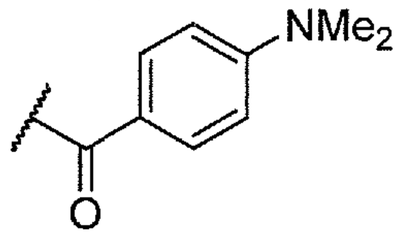
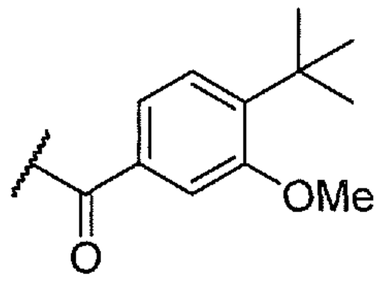
#	 **R =**	***FXR activation*** EC_{50} (max. rel. activation) or % activation at indicated conc.	***sEH inhibition*** IC_{50} or % inhibition at indicated conc.
10		0.32±0.03 μM (12±1%)	52±1% inhibition (50 μM)
14		inactive (50 μM)	10.5±0.3 μM

15		0.37±0.02 µM (18±1%)	26±2% inhibition (50 µM)
16		inactive (50 µM)	55±1% inhibition (50 µM)
17		1.36±0.08 µM (18±1%)	45±1% inhibition (50 µM)

So far, 4-biphenyl derivative **13** revealed the highest dual potency indicating that both targets tolerated bulky 4-substituents at the benzamide residue (table 3). Introduction of a 4-*tert*-butyl moiety in **18** led to further improvement of the dual activity while the more polar 4-dimethylaminobenzamide **19** as *tert*-butyl mimic was considerably less active. Combination of the favorable bulky *tert*-butyl residue of **18** and the 3-methoxy group of **15** in **20** did not generate additive effects and, therefore, the inventors selected 4-*tert*-butyl derivative **18** for further optimization.

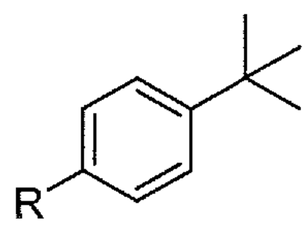
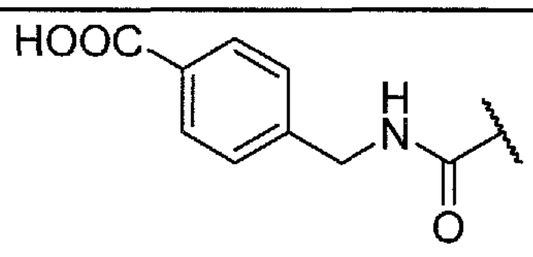
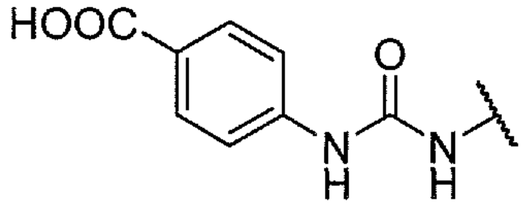
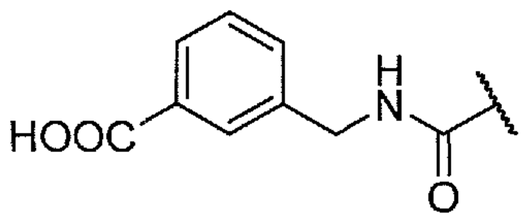
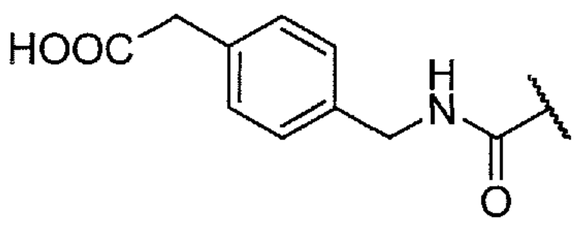
Table 3: *In vitro* activity of **18-20** on FXR and sEH (data represents mean±SEM, n=3-6)

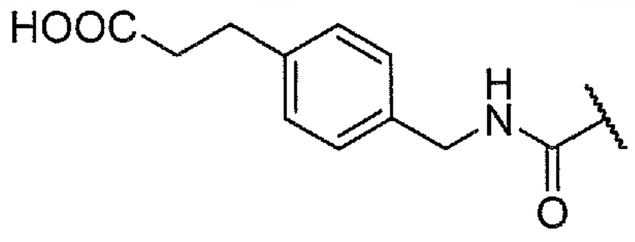
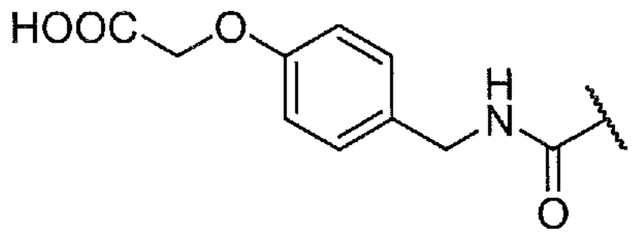
#	 **R =**	***FXR activation*** EC_{50} (max. rel. activation) or % activation at indicated conc.	***sEH inhibition*** IC_{50} or % inhibition at indicated conc.
8		15±3% activation (50 µM)	24±1% inhibition (50 µM)
13		0.44±0.04 µM (24±1%)	8.1±0.1 µM
18		0.37±0.04 µM (13±1%)	4.2±0.8 µM

19		inactive (50 µM)	19±1% inhibition (50 µM)
20		1.2±0.4 µM (23±1%)	5.04±0.30 µM

With **18** as new lead the inventors then focused on optimization of the *N*-benzyl substituent (table 4). Exchanging the *N*-benzylbenzamide structure of **18** by a diphenylurea in **21** as classical sEH pharmacophore was poorly tolerated by both targets. Similarly, shifting the carboxylic acid moiety from 4-position in **18** to 3-position in **22** caused a marked decline in potency. Variation of the side chain length from benzoic acid (**18**) to phenylacetic acid (**23**) diminished potency on both targets while phenylpropionic acid **24** exerted about equal activity as **18**. This SAR might eventually explained by a water-mediated interaction of **18** and displacement of the water by **24** as observed in previous studies.[15] Phenoxyacetic acid **25** exhibited similar activity on FXR as phenylpropionic acid **24** but the ether residue was poorly tolerated by sEH and significantly diminished inhibitory potency by about a factor 10.

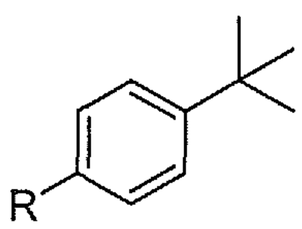
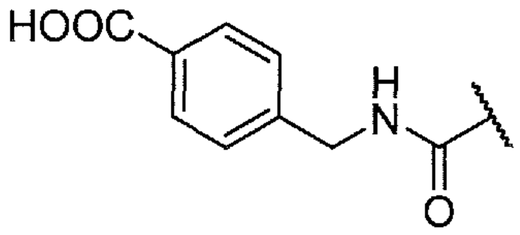
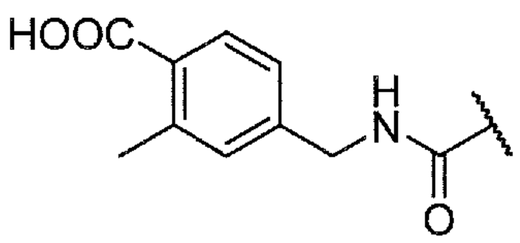
Table 4: *In vitro* activity of **21-25** on FXR and sEH (data represents mean±SEM, n=3-6)

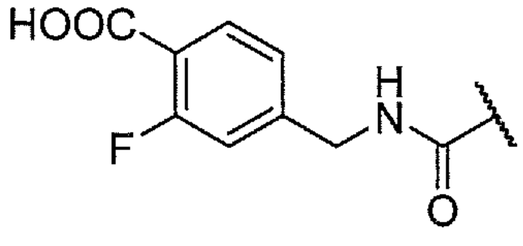
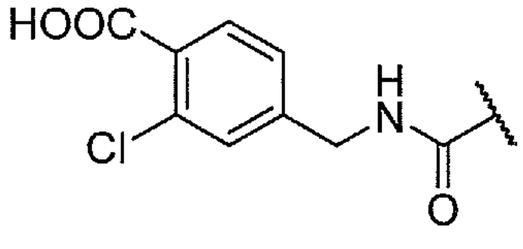
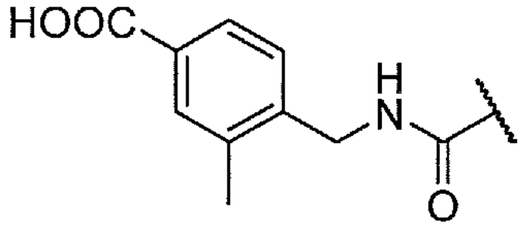
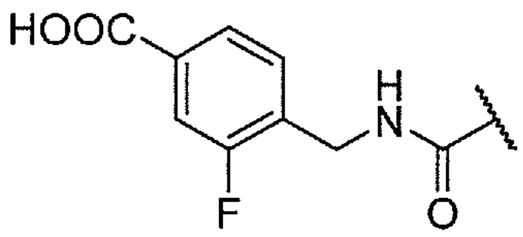
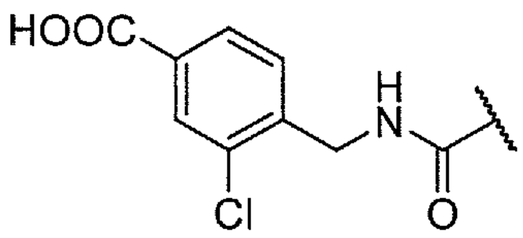
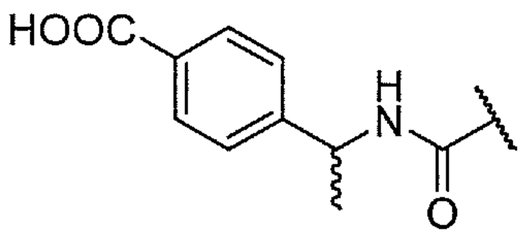
#	 **R =**	***FXR activation*** EC_{50} (max. rel. activation) or % activation at indicated conc.	***sEH inhibition*** IC_{50} or % inhibition at indicated conc.
18		0.37±0.04 µM (13±1%)	4.2±0.8 µM
21		3.8±1.7 µM (14±1%)	18.5±2.8 µM
22		1.70±0.03 µM (14±1%)	26±2% inhibition (50 µM)
23		6.4±1.2 µM (19±1%)	20.0±5.1 µM

24		0.35±0.03 µM (16±1%)	1.63±0.02 µM
25		0.73±0.18 µM (21±1%)	19.0±0.7 µM

As no significant improvement in dual potency was achieved by variations in the molecular geometry and distance between pharmacophoric features (**21-25**) the inventors then explored the possibility of introducing additional substituents at the benzoic acid aromatic ring of **18** (table 5). Substituents in 2-position (**26-28**) remarkably increased potency on FXR with 2-chloro derivative **28** as highly potent partial FXR agonist. However, sEH inhibitory activity simultaneously dropped significantly. In contrast, 3-substitution (**29-31**) with increasing substituent size was beneficial for inhibitory potency on sEH with 3-chlorobenzoic acid **31** as highly potent sEH inhibitor. On FXR, 3-methyl substitution (**29**) entirely abolished activity, while 3-chloro derivative **31** was still active but with considerably lower potency. 3-flourobenzoic acid **30** was highly potent on FXR. Methylation in benzylic position (**32**) significantly enhanced agonistic activity on FXR but, not surprisingly, it was not tolerated by sEH. As the amide moiety mimics the epoxide of EETs and an attacking water molecule in the enzyme's active site[34], steric hindrance in benzylic position remarkably diminishes inhibitory potency on sEH. Altogether, several additional residues on the benzoic acid residue improved the activity on FXR or sEH but no position could be identified where further substitution generated enhanced and balanced dual potency.

Table 5: *In vitro* activity of **26-32** on FXR and sEH (data represents mean±SEM, n=3-6)

#	**R** = 	***FXR activation*** EC_{50} (max. rel. activation) or % activation at indicated conc.	***sEH inhibition*** IC_{50} or % inhibition at indicated conc.
18		0.37±0.04 µM (13±1%)	4.2±0.8 µM
26		0.16±0.05 µM (14±1%)	53±1% inhibition (50 µM)

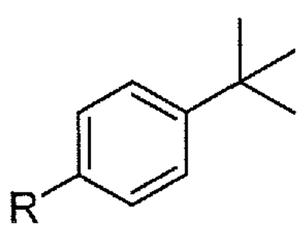
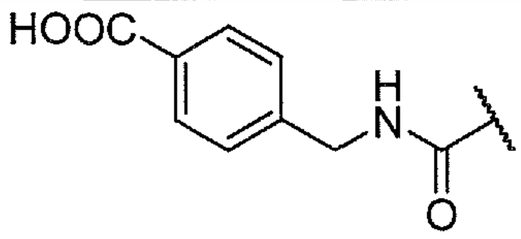
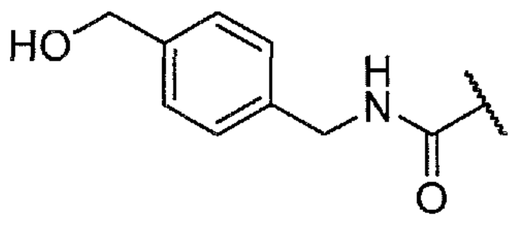
27		0.14±0.06 µM (28±2%)	20.3±1.2 µM
28		0.0088±0.0033 µM (21±2%)	50±1% inhibition (50 µM)
29		inactive (50 µM)	0.68±0.06 µM
30		0.0078±0.0007 µM (26±1%)	1.43±0.10 µM
31		7.5±0.4 µM (25±1%)	0.17±0.01 µM
32		0.076±0.027 µM (24±1%)	37±1% inhibition (50 µM)

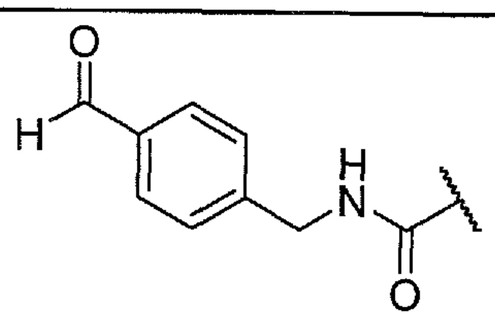
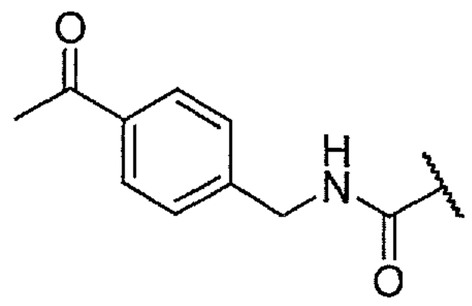
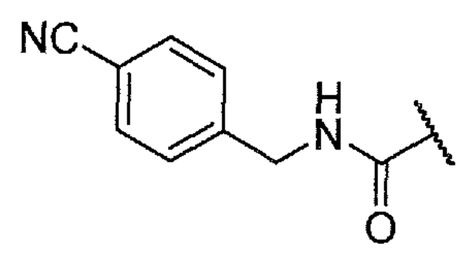
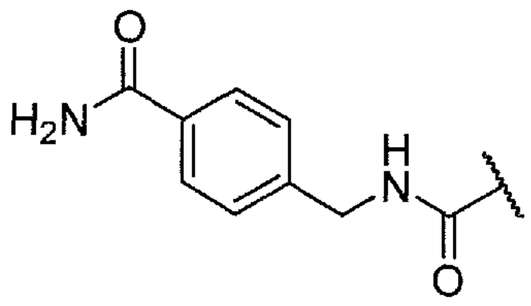
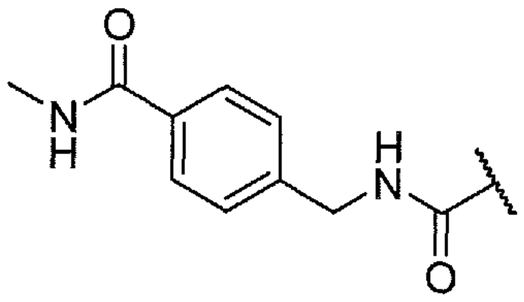
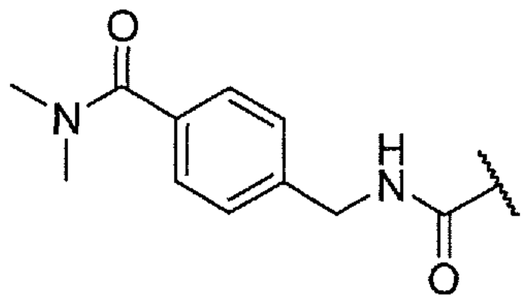
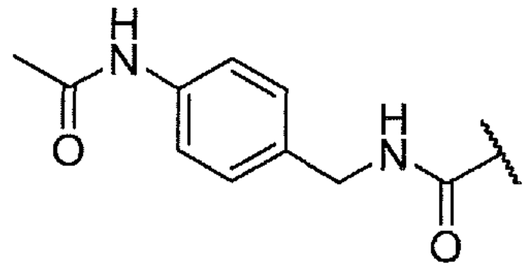
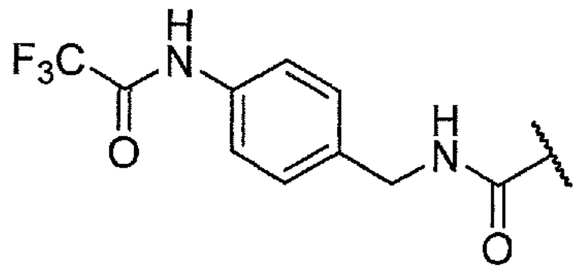
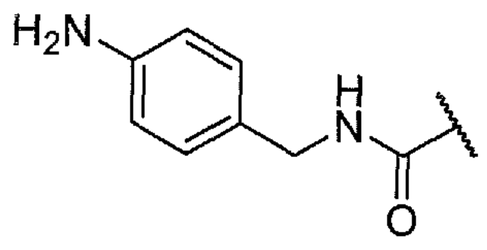
Therefore, the inventors investigated the SAR of the carboxylic acid in **18** and introduced several alternative polar residues and bioisosters (table 6). Alcohol **33** was equally potent as **18** on sEH but inactive on FXR whereas aldehyde **34** still activated FXR with about 10-fold lower potency but was significantly more potent on sEH compared to **18**. Methylketone **35** showed remarkably improved activity on both targets and was the first dual modulator with nanomolar potency on FXR and sEH. This SAR indicated that a carbonyl moiety but not an alcohol instead of the carboxylic acid was sufficient for FXR activation and that sEH preferred less polar groups in this position. The reduced potency of aldehyde **34** might be due to low stability in the cellular context of the flFXR assay. Nitrile **36** inhibited sEH with nanomolar potency but was inactive on FXR. The amides **37-39** were only moderately potent sEH inhibitors which again indicated that more polar residues in this position were disadvantageous. On FXR, the amides **37-39** significantly gained in potency with increasing substitution on the nitrogen atom. Primary amide **37** was considerably less active than carboxylic acid **18** while *N*-methylamide **38** comprised equal potency as **18**. Another methyl group in *N*,*N*-dimethylamide **39** further enhanced the potency. Inversion of the amide in *N*-acetylaniline **40** reduced FXR agonistic activity but introduction of three fluorine atoms in *N*-trifluoroacetylaniline **41** was very favorable and generated a balanced nanomolar dual modulator. Free aniline **42** still inhibited sEH but was inactive on FXR.

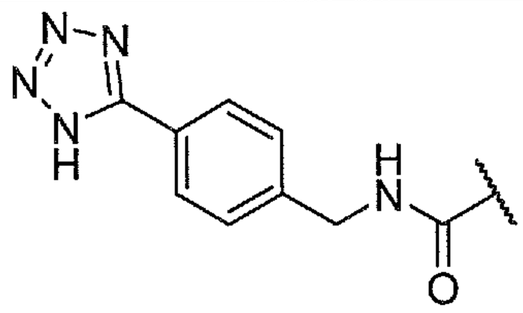
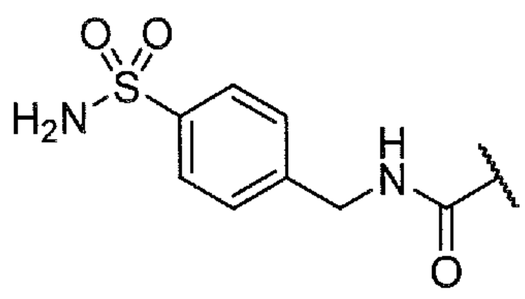
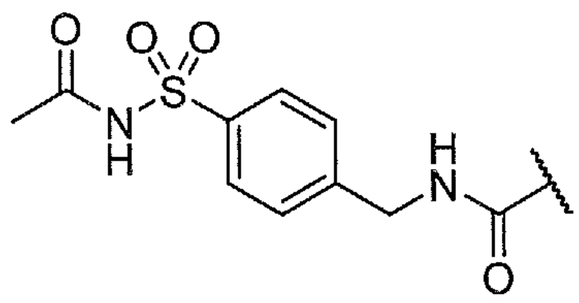
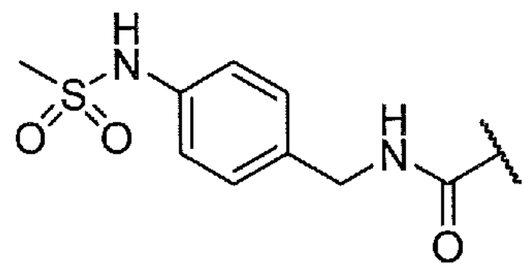
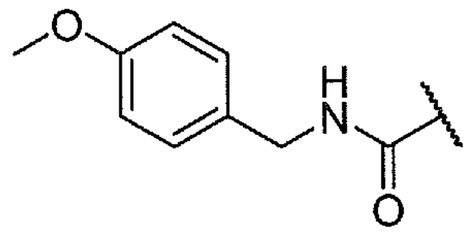
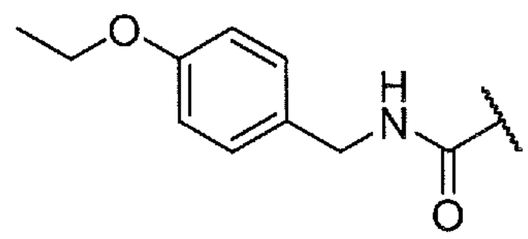
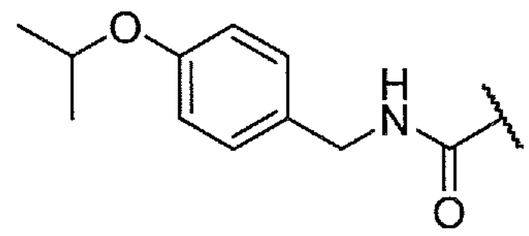
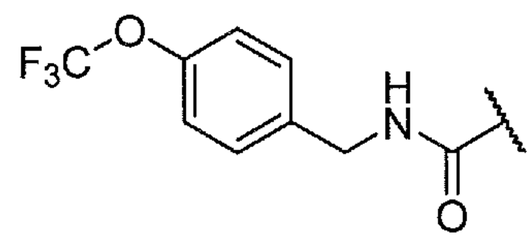
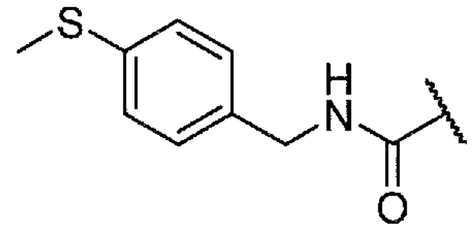
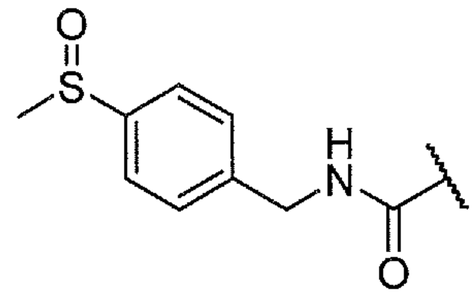
Tetrazole **43** as classical bioisoster of the carboxylic acid possessed slightly enhanced potency on FXR accompanied by reduced sEH inhibitory activity compared to **18**. The considerably less acidic sulfonamide **44** somewhat inverted the activity profile of **18** and was more potent on sEH than on FXR. In order to increase the acidity of **44**, the inventors prepared *N*-acetylsulfonamide **45** but it was inactive on FXR and remarkably lost potency on sEH compared to **44**. Inversion of the sulfonamide residue in **46** had a similar effect as inversion of the amide in **40** and also yielded a potent dual modulator.

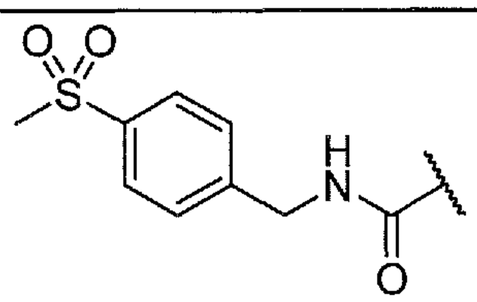
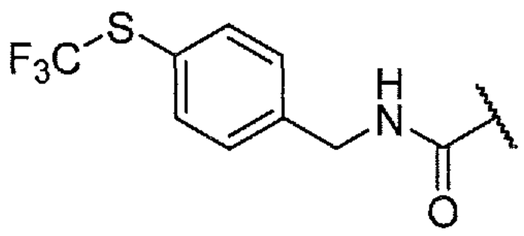
Finally, the inventors exchanged the carboxylic acid of **18** by a methoxy group in **47** which surprisingly resulted in considerable potency on both targets. Ethoxy derivative **48** revealed equal potency on FXR and sEH while isopropyloxy analogue **49** was equally active on FXR but could not be characterized on sEH due to insolubility. A slight improvement in potency on sEH was achieved with trifluoromethoxy derivative **50** which revealed high and well-balanced dual potency. Replacement of oxygen by sulfur in methylmercaptane **51** generated an even more potent dual modulator with half-maximal activity on both targets at approximately 0.1 µM. When mercaptane **51** was oxidized to sulfoxide **52** or sulfone **53**, potency on FXR dropped remarkably while **52** was still quite active on sEH and only **53** revealed significantly diminished inhibitory potency. In case of the mercaptane as carboxylic acid replacement, introduction of a trifluoromethyl group in **54** led to a marked increase in potency on FXR and generated a sub-nanomolar partial agonist. However, trifluoromethylmercaptane **54** revealed slightly diminished activity on sEH compared to methylmercaptane **51** and, therefore comprised a high but poorly balanced dual potency.

Table 6: *In vitro* activity of **33-54** on FXR and sEH (data represents mean±SEM, n=3-6)

#	 **R =**	***FXR activation*** EC_{50} (max. rel. activation) or % activation at indicated conc.	***sEH inhibition*** IC_{50} or % inhibition at indicated conc.
18		0.37±0.04 µM (13±1%)	4.2±0.8 µM
33		inactive (50 µM)	2.05±0.31 µM

34		5.3±1.5 μM (22±2%)	0.51±0.04 μM
35		0.10±0.01 μM (29±1%)	0.157±0.009 μM
36		inactive (50 μM)	0.91±0.07 μM
37		3.8±0.3 μM (27±1%)	1.2±0.2 μM
38		0.34±0.03 μM (29±1%)	1.9±0.3 μM
39		0.17±0.01 μM (17±1%)	4.6±0.5 μM
40		2.9±0.2 μM (31±1%)	1.12±0.02 μM
41		0.26±0.11 μM (20±1%)	0.66±0.01 μM
42		inactive (50 μM)	3.5±0.2 μM

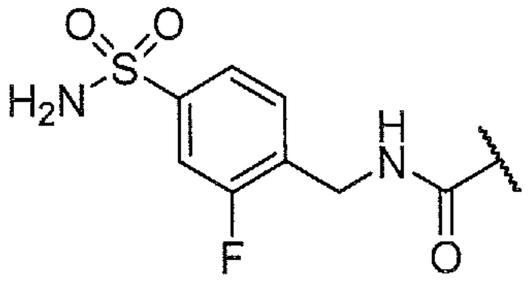
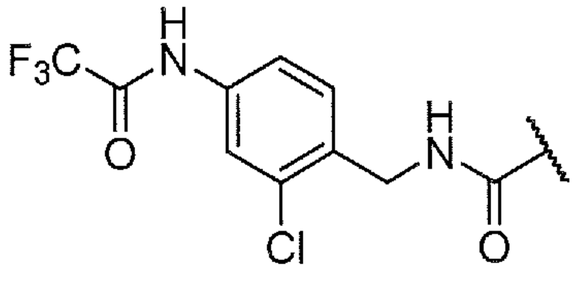
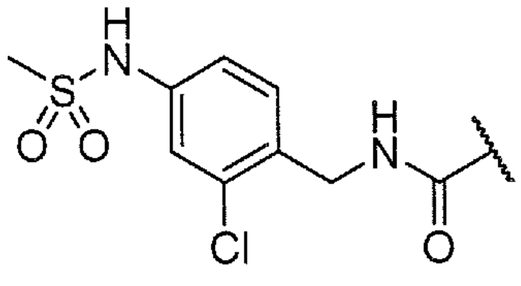
43		0.12±0.02 µM (23±1%)	18.2±3.2 µM
44		1.4±0.2 µM (16±1%)	0.28±0.12 µM
45		inactive (50 µM)	12.7±0.4 µM
46		0.044±0.009 µM (22±1%)	0.65±0.04 µM
47		0.15±0.04 µM (19±1%)	0.43±0.01 µM
48		0.16±0.01 µM (31±1%)	0.57±0.05 µM
49		0.17±0.01 µM (26±1%)	n.d. (poor solubility)
50		0.16±0.04 µM (26±1%)	0.22±0.06 µM
51		0.10±0.01 µM (33±1%)	0.12±0.01 µM
52		1.3±0.4 µM (24±1%)	0.22±0.03 µM

53		3.8±0.5 µM (34±1%)	1.2±0.1 µM
54		0.00040±0.00004 µM (19±1%)	0.39±0.05 µM

Since neither single modification of our optimized lead compound **18** alone was able to improve potency on both targets to low nanomolar values, the inventors evaluated the possibility of combining the most favorable structural alterations for each target in one molecule. To identify derivatives with outstanding activity on one of the targets, the inventors plotted pIC_{50} (sEH) versus pEC_{50} (FXR) values of the most potent compounds (figure 1). This potency plot revealed a 3-fluorosubstitution at the benzyl moiety (**30**), the trifluoromethylmercaptane residue (**54**) and the inverted sulfonamide **46** as very favorable on FXR. Since trifluoroacetamide **41** structurally resembled **46** and also possessed high potency on FXR, it was additionally selected for combination. Concerning sEH inhibition, 3-chlorosubstitution at the benzyl moiety (**31**), the methylmercaptane residue (**51**) and sulfonamide **44** protruded from the other derivatives. **51** and **54** were omitted for recombination for their proportionally poor solubility and because the two moieties could not be merged. Instead, **30**, **31**, **41**, **44** and **46** were selected for structural recombination (table 7).

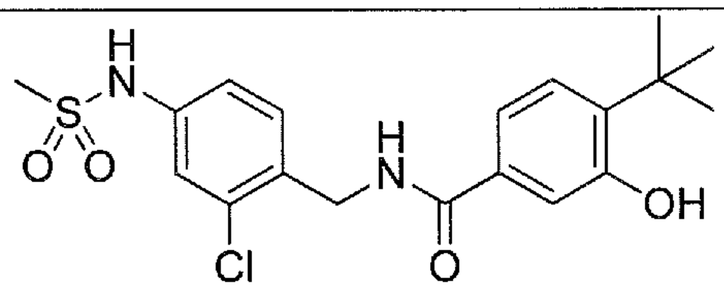
Introduction of the 3-fluorine atom of **30** in sulfonamide **44** yielded the dual modulator **55** that revealed the anticipated increase in FXR potency. However, this improvement was merely moderate and did not produce the desired dual modulator with low nanomolar potency. In contrast, merging of **31** and **41** in *N*-(3-chlorophenyl)trifluoroacetamide **56** and combination of **31** and **46** in *N*-(3-chlorophenyl)methanesulfonamide **57** was accompanied by a remarkable rise in potency on both targets. With respective EC_{50} values of 14±1 nM and 20.4±4.2 nM for partial FXR activation as well as IC_{50} values of 8.9±1.6 nM and 4.1±0.4 nM for sEH inhibition, the dual modulators **56** and **57** finally comprised the desired low nanomolar potency on both targets. Amongst these two dual modulators, **57** revealed significantly higher aqueous solubility (1.5 µg/mL) than **56** (< 0.1 µg/mL (LLOQ)) and was, therefore, selected for further *in vitro* evaluation. Isothermal titration calorimetry (ITC, supporting figure S7) revealed a Kd of 0.13 µM for **57** and indicated enthalpic binding (ΔH = -19.5 kcal/mol, ΔS = - 34.0 cal/mol · K). The discrepancy between cellular EC_{50} value and Kd seems due to absence of coactivators in the ITC experiment that might significantly affect the binding equilibrium. The high binding energy might partly arise from potentially marked conformational changes in the FXR-LBD upon binding.

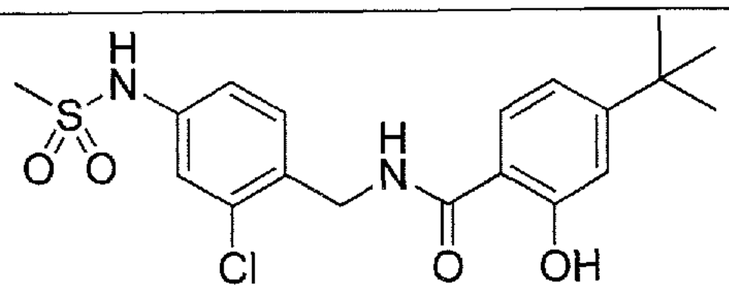
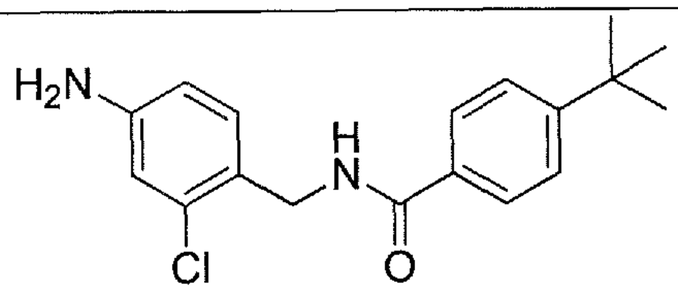
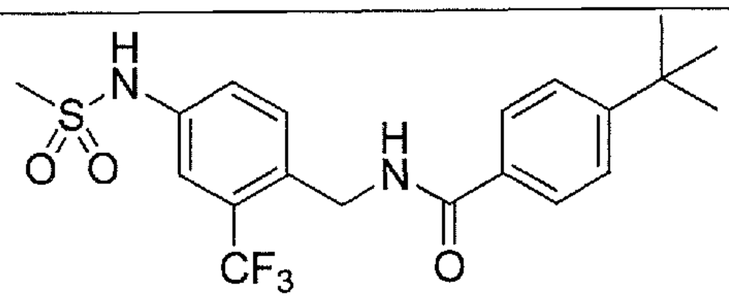
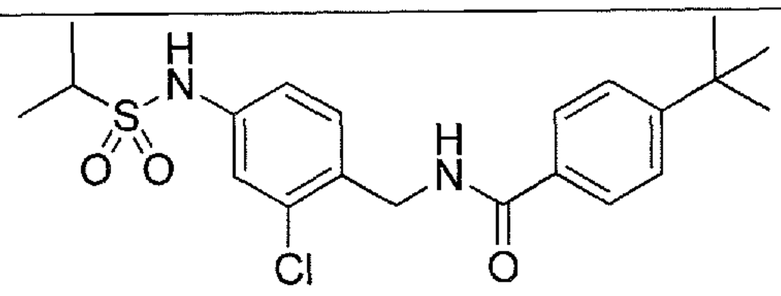
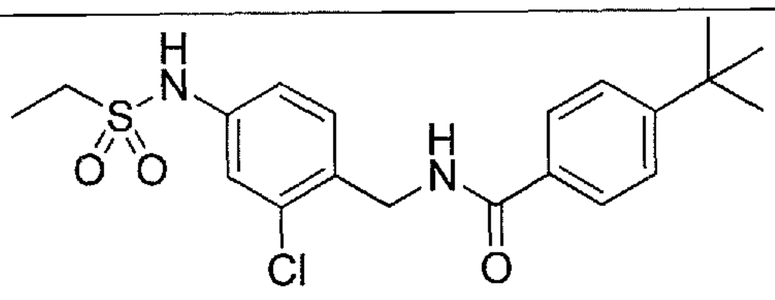
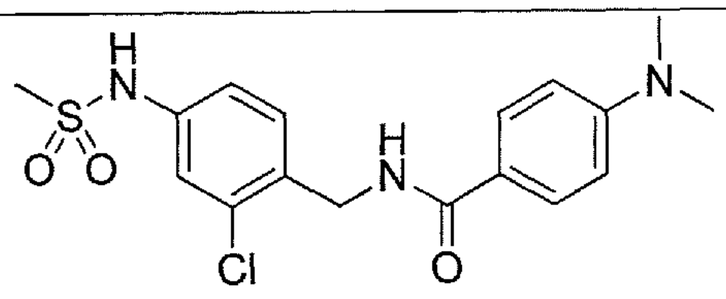
Table 7: *In vitro* activity of **55-57** on FXR and sEH (data represents mean±SEM, n=3-6)

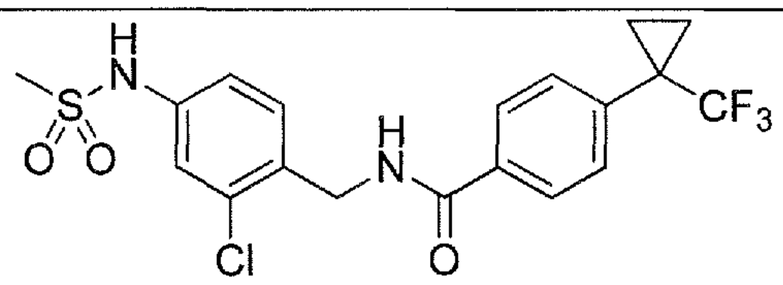
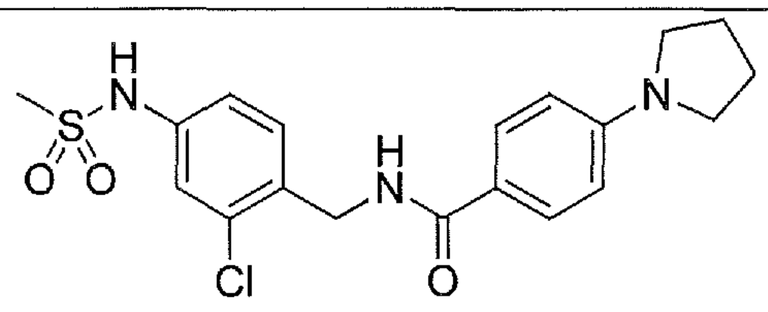
#	**R =**	***FXR activation*** EC_{50} (max. rel. activation) or % activation at indicated conc.	***sEH inhibition*** IC_{50} or % inhibition at indicated conc.
55		0.97±0.11 µM (34±1%)	0.137±0.018 µM
56		0.014±0.001 µM (21±1%)	0.0089±0.0016 µM
57		0.0204±0.0042 µM (35±1%)	0.0041±0.0004 µM

Further, the following additional compounds were produced and tested for their activity towards FXR activation and she inhibition (see table 8).

Table 8: *In vitro* activity of additional compounds on FXR and sEH (data represents mean±SEM, n=3-6)

		FXR activation EC50 (max. rel. activation) or % activation at indicated conc.	sEH inhibition IC50 or % inhibition at indicated conc.
78	 Chemical Formula: $C_{19}H_{23}ClN_2O_4S$ Exact Mass: 410,11 Molecular Weight: 410,91	0.003±0.000001 µM (24±1%)	0.0160±0.0006 µM

77	 Chemical Formula: $C_{19}H_{23}ClN_2O_4S$ Exact Mass: 410,11 Molecular Weight: 410,91	antagonistic	0.38±0.05 μM
69a	 Chemical Formula: $C_{18}H_{21}ClN_2O$ Exact Mass: 316,13 Molecular Weight: 316,83	0.045±0.011 μM (29±1%)	0.040±0.006 μM
80	 Chemical Formula: $C_{20}H_{23}F_3N_2O_3S$ Exact Mass: 428,14 Molecular Weight: 428,47	1.2±0.18 μM (19±1%)	0.002±0.00008 μM
81	 Chemical Formula: $C_{21}H_{27}ClN_2O_3S$ Exact Mass: 422,14 Molecular Weight: 422,97	0.42±0.02 μM (11±1%)	0.011±0.0003 μM
82	 Chemical Formula: $C_{20}H_{25}ClN_2O_3S$ Exact Mass: 408,13 Molecular Weight: 408,94	0.49±0.05 μM (23±1%)	0.006±0.0005 μM
83	 Chemical Formula: $C_{17}H_{20}ClN_3O_3S$ Exact Mass: 381,09 Molecular Weight: 381,88	1.46±0.023 μM (23±1%)	0.045±0.002 μM

84	 Chemical Formula: $C_{19}H_{18}ClF_3N_2O_3S$ Exact Mass: 446,07 Molecular Weight: 446,87	0.54±0.02 µM (31±1%)	0.004±0.0004 µM
85	 Chemical Formula: $C_{19}H_{22}ClN_3O_3S$ Exact Mass: 407,11 Molecular Weight: 407,91	0.25±0.012 µM (27±1%)	0.041±0.004 µM

The following procedures were used to synthesize the compounds:

1-(4-Amino-2-chlorophenyl)methanamine (**58k**): $LiAlH_4$ (1 M in THF, 16.4 mL, 16.4 mmol, 2.5 eq) was cooled to 0 °C. 4-Amino-2-chlorobenzonitrile **62** (1.0 g, 6.6 mmol, 1.0 eq) in 3 mL THF was slowly added to the mixture. After evolution of H_2 had ceased, the mixture was allowed to warm to room temperature and then refluxed for 16 h. After cooling to room temperature, the mixture was diluted with 10 mL THF and then cooled to 0 °C. 1 mL 10% NaOH solution and 1.8 mL water were added dropwise. The colorless precipitate was filtered through celite and washed with 15 mL diethyl ether. Evaporation of the organic solvents from the filtrate yielded **58k** as yellow oil (0.77 g, 75%). ^{1}H NMR (500 MHz, DMSO-d_6) δ= 7.11 (d, *J*= 8.2 Hz, 1H), 6.58 (d, *J*= 2.2 Hz, 1H), 6.48 (dd, *J*= 8.2, 2.2 Hz, 1H), 5.19 (s, 2H), 3.59 (s, 2H). ^{13}C NMR (126 MHz, DMSO-d_6) δ= 148.56, 132.33, 129.67, 127.74, 113.63, 112.72, 42.88.

N-(4-Amino-2-chlorobenzyl)-4-(tert-butyl)benzamide (**69a**): 1-(4-Amino-2-chlorophenyl)methanamine **58k** (0.31 g, 2.0 mmol, 1.1 eq) was dissolved in 10 mL $CHCl_3$, 5 mL NEt_3 were added and the mixture was cooled to 0 °C. 4-*tert*-Butylbenzoyl chloride **630** (0.35 mL, 1.8 mmol, 1.0 eq) was slowly added over 10 min and the mixture was stirred for two hours at room temperature. Then, 50 mL 10% aqueous hydrochloric acid were added, phases were separated and the aqueous layer was washed with 30 mL EtOAc. The aqueous layer was brought to pH 10 with Na_2CO_3 solution and extracted three times with 80 mL EtOAc at a time. The combined organic layers were dried over Na_2SO_4 and the solvent was evaporated in vacuum. Further purification was performed by column chromatography with petrolether/EtOAc (90:10) as mobile phase to obtain **69a** as yellow solid (0.57 g, 97%). R_f(petrolether/EtOAc = 67:33) = 0.26. ^{1}H NMR (500 MHz, MeOH-d_4) δ= 7.81 (dt, *J*= 8.6, 2.3 Hz, 2H), 7.53 (dt, *J*= 8.6, 2.3 Hz, 2H), 7.45 (d, *J*= 8.3 Hz, 1H), 7.31 (d, *J*= 2.2 Hz, 1H), 7.15 (dd, *J*= 8.3, 2.2 Hz, 1H), 4.64 (s, 2H),

1.36 (s, 9H).^{13}C NMR (126 MHz, MeOH-d_4) δ= 170.32, 156.67, 140.89, 135.23, 132.33, 131.39, 128.29, 126.59, 122.96, 120.82, 119.16, 42.13, 35.36, 31.54. HRMS (MALDI): m/z calculated 317.14152 for $C_{18}H_{21}ClN_2O$, found 317.14130 $[M+H]^+$.

N-(4-Amino-2-chlorobenzyl)-4-(tert-butyl-2-methoxy)benzamide (**69b**): 4-Amino-2-chlorobenzamine (**58k**, 0.23 g, 0.15 mmol, 1.3 eq) was dissolved in 30 mL dry $CHCl_3$. 4-DMAP (0.12 g, 1.15 mmol, 1.00 eq), 1-Ethyl-3-(3-dimethylaminopropyl)carbodiimid (0.24 g, 1.27 mmol, 1.10 eq) and 4-*tert*-butyl-2-methoxy benzoic acid (**64b**, 0.24 g, 1.15 mmol, 1.0 eq) were added. The mixture was stirred for 16 h at room temperature. Then 25 mL 5% aqueous hydrochloric acid was added and the aqueous layer was extracted three times with 15 mL EtOAc. The combined organic layers were dried over Na_2SO_4 and the solvent was removed in vacuo. Further purification was performed by crystallization from hexane/ethyl acetate to obtain **69b** as pale yellow solid (0.324 g, 81%). ^{1}H NMR (250 MHz, DMSO-d_6): δ= 8.62 (t, *J*= 6.0 Hz, 1H), 7.73 (d, *J*= 8.0 Hz, 1H), 7.27 (d, *J*= 8.3 Hz, 1H), 7.07 (dd, *J*= 10.1, 2.0 Hz, 3H), 6.97 (t, *J*= 7.2 Hz, 1H), 4.47 (d, *J*= 6.0 Hz, 2H), 3.94 (s, 3H), 1.31 (s, 9H). ^{13}C NMR (75 MHz, DMSO-d_6) δ= 164.89, 156.98, 155.90, 150.38, 150.31, 132.32, 130.41, 129.61, 119.72, 117.52, 109.08, 106.97, 55.89, 34.91, 30.90.

4-(tert-Butyl-3-methoxy)-N-(2-chloro-4-(methylsulfonamido)benzyl)benzamide (**76a**): *N*-(4-Amino-2-chlorobenzyl)-4-(*tert*-butyl-2-methoxy)benzamide **69b** (0.32 g, 0.93 mmol, 1.00 eq) was dissolved in 20 mL $CHCl_3$ and 5 mL pyridine were added. Mesyl chloride (**70**, 0.09 mL, 1.12 mmol, 1.20 eq) was carefully added. The mixture was stirred for two hours at room temperature. Then 15 mL 10% aqueous hydrochloric acid was added and extracted three times by 30 mL ethyl acetate. The combined organic layers were dried over Na_2SO_4 and the solvent was removed in vacuo. Further purification was performed by crystallization from hexane/ethyl acetate to obtain **76a** as pale brown solid (0.172 g, 35%). ^{1}H NMR (250 MHz, DMSO-d_6) δ= 9.97 (s, 1H), 8.72 (t, *J*= 6.0 Hz, 1H), 7.79 (d, *J*= 8.0 Hz, 1H), 7.36 (dd, *J*= 14.9, 5.2 Hz, 2H), 7.25-7.13 (m, 3H), 4.56 (d, *J*= 6.0 Hz, 2H), 4.00 (s, 3H), 3.08 (s, 3H), 1.37 (s, 9H). ^{13}C NMR (126 MHz, DMSO-d_6) δ= 165.47, 157.45, 156.36, 138.79, 132.71, 132.32, 130.85, 129.87, 120.27, 117.99, 109.54, 60.22, 56.36, 35.39, 31.37, 21.24, 14.56.

4-(tert-Butyl-2-hydroxy)-N-(2-chloro-4-(methylsulfonamido)benzyl)benzamide (**77**): 4-(*tert*-Butyl-2-methoxy)-*N*-(2-chloro-4-(methylsulfonamido)benzyl)benzamide (**76a**, 0.17 g, 0.40 mmol, 1.0 eq) was dissolved in 30 mL DCM and BBr_3 (4.05 mL, 4.05 mmol in DCM, 10.0 eq) was added at 0 °C. The mixture was stirred for 16 hours at room temperature and then diluted in 30 mL iced water. The pH was adjusted to 6 with $NaHCO_3$ and the mixture was extracted three times with 30 mL ethyl acetate at a time. The combined organic layers were concentrated in vacuo. Further purification was performed by crystallization from hexane/ethyl

acetate to obtain 77 as colorless solid (0.098 g, 60%).^{1}H NMR (500 MHz, DMSO-d_6) δ= 12.30 (s, 1H), 9.95 (s, 1H), 9.21 (t, *J*= 5.5 Hz, 1H), 7.84 (d, *J*= 8.4 Hz, 1H), 7.35-7.24 (m, 2H), 7.15 (d, *J*= 8.5 Hz, 1H), 6.98-6.93 (m, 1H), 6.89 (s, 1H), 4.51 (d, *J*= 5.6 Hz, 2H), 3.02 (s, 3H), 1.26 (s, 9H). ^{13}C NMR (126 MHz, DMSO-d_6) δ= 168.84, 159.78, 157.29, 138.57, 132.42, 131.05, 129.75, 127.69, 119.71, 118.24, 116.17, 113.95, 112.50, 34.65, 30.71, 30.49. HRMS (MALDI): m/z calculated 411.11398 for $C_{19}H_{24}ClN_2O_4S$, found 411.11373 $[M+H]^+$.

N-(4-Amino-2-chlorobenzyl)-4-(tert-butyl-3-methoxy)benzamide **(69c)**: 4-Amino-2-chlorobenzamine (**58k**, 0.23 g, 0.15 mmol, 1.3 eq) was dissolved in 30 mL dry $CHCl_3$. 4-DMAP (0.12 g, 1.15 mmol, 1.00 eq), 1-Ethyl-3-(3-dimethylaminopropyl)carbodiimid (0.24 g, 1.27 mmol, 1.10 eq) and 4-*tert*-butyl-3-methoxy benzoic acid (**64a**, 0.24 g, 1.15 mmol, 1.0 eq) were added. The mixture was stirred for 16 h at room temperature. Then 25 mL 5% aqueous hydrochloric acid was added and the aqueous layer was extracted three times with 15 mL EtOAc at a time. The combined organic layers were dried over Na_2SO_4 and the solvent was removed in vacuo. Further purification was performed by crystallization from hexane/ethyl acetate to obtain **69c** as pale yellow solid (0.312 g, 78%). ^{1}H NMR (250 MHz, DMSO-d_6): δ= 8.84 (t, *J*= 5.7 Hz, 1H), 7.45 (d, *J*= 9.7 Hz, 2H), 7.29 (d, *J*= 7.9 Hz, 1H), 7.13 (d, *J*= 8.4 Hz, 1H), 6.86 (s, 1H), 6.72 (d, *J*= 8.1 Hz, 1H), 4.42 (d, *J*= 5.7 Hz, 2H), 3.86 (s, 3H), 1.34 (s, 9H). MS (ESI+): m/z 369.10 ($[M+Na]^+$, 100)

4-(tert-Butyl-3-methoxy)-N-(2-chloro-4-(methylsulfonamido)benzyl)benzamide **(76b)**: *N*-(4-Amino-2-chlorobenzyl)-4-(*tert*-Butyl-3-methoxy)benzamide **69c** (0.31 g, 0.89 mmol, 1.00 eq) was dissolved in 20 mL $CHCl_3$ and 5 mL pyridine were added. Mesyl chloride **70** (0.07 mL, 1.07 mmol, 1.20 eq) was carefully added. The mixture was stirred for two hours at room temperature. Then 15 mL 10% aqueous hydrochloric acid was added and extracted three times by 30 mL ethyl acetate. The combined organic layers were dried over Na_2SO_4 and the solvent was removed in vacuo. Further purification was performed by crystallization from hexane/ethyl acetate to obtain **76b** as pale brown solid (0.315 g, 83%). ^{1}H NMR (250 MHz, DMSO-d_6) δ= 9.92 (s, 1H), 8.95 (t, *J*= 5.8 Hz, 1H), 7.46 (dd, *J*= 9.6, 1.6 Hz, 2H), 7.34-7.26 (m, 3H), 7.15 (dd, *J*= 8.4, 2.2 Hz, 1H), 4.49 (d, *J*= 5.7 Hz, 2H), 3.87 (s, 3H), 3.01 (s, 3H), 1.34 (s, 9H). ^{13}C NMR (126 MHz, DMSO-d_6) δ= 172.05, 170.40, 166.16, 158.02, 140.79, 138.38, 133.14, 132.33, 131.72, 129.59, 126.16, 119.82, 119.39, 118.34, 110.73, 59.79, 55.42, 34.68, 29.43.

4-(tert-Butyl-3-hydroxy)-N-(2-chloro-4-(methylsulfonamido)benzyl)benzamide **(78)**: 4-(*tert*-Butyl-3-methoxy)-*N*-(2-chloro-4-(methylsulfonamido)benzyl)benzamide (**76b**, 0.31 g, 0.74 mmol, 1.0 eq) was dissolved in 50 mL DCM and BBr_3 (7.40 mL, 7.40 mmol in DCM, 10.0 eq) was added at 0 °C. The mixture was stirred for 16 hours at room temperature and then diluted in 50 mL iced water. The pH was adjusted to 6 with $NaHCO_3$ and the mixture was ex-

tracted three times with 30 mL ethyl acetate at a time. The combined organic layers were concentrated in vacuo. Further purification was performed by crystallization from hexane/ethyl acetate to obtain **78** as colorless solid (0.145 g, 48%).^{1}H NMR (500 MHz, DMSO-d_6) δ= 9.92 (s, 1H), 9.62 (s, 1H), 8.81 (t, *J*= 5.8 Hz, 1H), 7.31-7.27 (m, 2H), 7.27-7.25 (m, 2H), 7.21 (d, *J*= 8.1 Hz, 1H), 7.15 (dd, *J*= 8.4, 2.2 Hz, 1H), 4.45 (d, *J*= 5.8 Hz, 2H), 3.01 (s, 3H), 1.35 (s, 9H). ^{13}C NMR (126 MHz, DMSO-d_6) δ= 170.82, 166.91, 156.27, 139.24, 138.78, 133.49, 132.72, 132.23, 129.83, 126.61, 120.22, 118.72, 117.77, 115.88, 34.93, 29.61. HRMS (MALDI): m/z calculated 411.11398 for $C_{19}H_{24}ClN_2O_4S$, found 411.11383 $[M+H]^+$.

N-(4-Amino-2-(trifluoromethyl)benzyl)-4-(tert-butyl)benzamide **(69d)**: 1-(4-Amino-2-(trifluoromethyl)phenyl)methanamine **58z** (0.25 g, 1.3 mmol, 1.1 eq) was dissolved in 7 mL $CHCl_3$, 7 mL NEt_3 were added and the mixture was cooled to 0 °C. 4-*tert*-Butylbenzoyl chloride **630** (0.28 mL, 1.4 mmol, 1.1 eq) was slowly added over 10 min and the mixture was stirred for two hours at room temperature. Then, 10 mL 10% aqueous hydrochloric acid were added, phases were separated and the aqueous layer was washed with 10 mL EtOAc. The aqueous layer was brought to pH 10 with Na_2CO_3 solution and extracted three times with 10 mL EtOAc at a time. The combined organic layers were dried over Na_2SO_4 and the solvent was evaporated in vacuum. Further purification was performed by column chromatography with hexane/EtOAc (90:10) as mobile phase to obtain **69d** as yellow solid (0.35 g, 84%). R_f(hexane/EtOAc = 90:10) = 0.27. ^{1}H NMR (250 MHz, DMSO-d_6) δ= 8.77 (t, *J*= 5.7 Hz, 1H), 7.87-7.79 (m, 2H), 7.48 (d, *J*= 8.5 Hz, 2H), 7.13 (d, *J*= 8.4 Hz, 1H), 6.90 (d, *J*= 2.3 Hz, 1H), 6.74 (dd, *J*= 8.3, 2.1 Hz, 1H), 5.44 (s, 2H), 4.47 (d, *J*= 5.3 Hz, 2H), 1.30 (s, 9H).^{13}C NMR (75 MHz, DMSO-d_6) δ = 166.14, 154.04, 147.81, 131.50, 129.71, 127.15, 125.05, 123.08, 116.80, 110.55, 110.47, 34.60, 30.94..

4-(tert-Butyl)-N-(2-trifluoromethyl-4-(methylsulfonamido)benzyl)benzamide**(80)**: *N*-(4-Amino-2-(trifluoromethyl)benzyl)-4-(*tert*-butyl)benzamide **69d** (0.35 g, 1.0 mmol, 1.00 eq) was dissolved in 50 mL THF and 5 mL pyridine were added. Mesyl chloride (**70**, 0.23 mL, 3.0 mmol, 3.0 eq) was carefully added. The mixture was stirred overnight at room temperature. Then 50 mL 10% aqueous hydrochloric acid was added and extracted three times by 20 mL ethyl acetate. The combined organic layers were dried over Na_2SO_4 and the solvent was removed in vacuo. Further purification was performed by column chromatography with hexane/EtOAc (67:33) as mobile phase to obtain **80** as pale pink solid (0.09 g, 22%). R_f(hexane/EtOAc = 67:33) = 0.19. ^{1}H NMR (500 MHz, DMSO-d_6) δ= 10.06 (s, 1H), 9.00 (t, *J*= 5.8 Hz, 1H), 7.89-7.82 (m, 2H), 7.54-7.43 (m, 5H), 4.59 (d, *J*= 5.5 Hz, 2H), 3.03 (s, 3H), 1.30 (s, 9H). ^{13}C NMR (126 MHz, DMSO-d_6) δ= 166.42, 154.33, 137.52, 132.71, 131.25, 129.78, 127.24, 125.20, 123.13, 116.72, 116.67, 34.69, 30.98. HRMS (MALDI): m/z calculated 429.14542 for $C_{20}H_{24}F_3N_2O_3S$, found 429.14523 $[M+H]^+$.

***4-(tert-Butyl)-N-(2-chloro-4-(isopropylsulfonamido)benzyl)-benzamide*(81)**: *N*-(4-Amino-2-chlorobenzyl)-4-(*tert*-butyl)benzamide **69a** (0.154 g, 0.49 mmol, 1.0 eq) was dissolved in 20 mL THF and 2 mL pyridine was added. Isopropylsulfonyl chloride **86a** (0.57 mL, 4.89 mmol, 10 eq.) was carefully added, and the mixture was stirred for 24 h at room temperature. Then 15 mL of 10% aqueous hydrochloric acid was added and the mixture was extracted three times with 30 mL of EtOAc at a time. The combined organic layers were dried over Na_2SO_4 and the solvent was evaporated in vacuo. Further purification was performed by column chromatography using hexane/EtOAc (67:33) as mobile phase to obtain **81** yellow solid (0.041 g, 20%). R_f(hexane/EtOAc = 67:33) = 0.20. ^{1}H NMR (500 MHz, DMSO-d_6) δ= 9.95 (s, 1H), 8.92 (t, *J*= 5.7 Hz, 1H), 7.84 (d, *J*= 8.4 Hz, 2H), 7.49 (d, *J*= 8.4 Hz, 2H), 7.36-7.24 (m, 2H), 7.17 (dd, *J*= 8.5, 2.1 Hz, 1H), 4.46 (d, *J*= 5.7 Hz, 2H), 1.30 (s, 9H). ^{13}C NMR (126 MHz, DMSO-d_6) δ= 166.28, 154.21, 138.65, 132.33, 131.37, 131.34, 129.56, 127.20, 125.13, 119.19, 117.78, 51.59, 34.65, 30.96, 16.10. HRMS (MALDI): m/z calculated 423.15037 for $C_{21}H_{28}ClN_2O_3S$, found 423.14967 $[M+H]^+$.

***4-(tert-Butyl)-N-(2-chloro-4-(ethylsulfonamido)benzyl)-benzamide*(82)**: *N*-(4-Amino-2-chlorobenzyl)-4-(*tert*-butyl)benzamide **69a** (0.16 g, 0.51 mmol, 1.0 eq) was dissolved in 20 mL THF and 2 mL pyridine was added. Ethanesulfonyl chloride **86b** (0.5 mL, 5.1 mmol, 10 eq) was carefully added, and the mixture was stirred for 24 h at room temperature. Then 15 mL of 10% aqueous hydrochloric acid was added and the mixture was extracted three times with 30 mL of EtOAc at a time. The combined organic layers were dried over Na_2SO_4 and the solvent was evaporated in vacuo. Further purification was performed by column chromatography using hexane/EtOAc (50:50) as mobile phase to obtain **82** as yellow solid (0.125 g, 60%). R_f(hexane/EtOAc = 50:50) = 0.51. ^{1}H NMR (500 MHz, DMSO-d_6) δ= 9.98 (s, 1H), 8.93 (t, *J*= 5.8 Hz, 1H), 7.84 (d, *J*= 8.4 Hz, 2H), 7.49 (d, *J*= 8.4 Hz, 2H), 7.29 (d, *J*= 8.4 Hz, 1H), 7.27 (d, *J*= 2.1 Hz, 1H), 7.15 (dd, *J*= 8.4, 2.1 Hz, 1H), 4.47 (d, *J*= 5.7 Hz, 2H), 3.11 (q, *J*= 7.3 Hz, 2H), 1.30 (s, 9H), 1.18 (t, *J*= 3.6 Hz, 3H). ^{13}C NMR (126 MHz, DMSO-d_6) δ= 166.27, 154.20, 138.42, 132.34, 131.51, 131.34, 129.57, 127.19, 125.13, 119.35, 117.89, 59.78, 45.29, 39.52, 34.65, 30.96, 8.02. HRMS (MALDI): m/z calculated 409.13472 for $C_{20}H_{26}ClN_2O_3S$, found 409.13444 $[M+H]^+$.

***N-(4-Amino-2-chlorobenzyl)-4-(dimethylamino)benzamide*(69e)**: 1-(4-Amino-1-chlorophenyl)methanamine **58k** (0.30 g, 1.92 mmol, 1.1 eq) was dissolved in 10 mL DMF. 10 mL NEt_3 was added and the mixture was cooled to 0 °C. 4-Dimethylaminobenzoyl chloride **63p** (0.32 mL, 1.73 mmol, 1.0 eq) was slowly added over 10 min and the mixture was stirred for 5 h at room temperature. Then 50 mL of 10% aqueous hydrochloric acid was added, phases were separated and the aqueous layer was brought to pH 10 with Na_2CO_3 solution and extracted three times with 80 mL of EtOAc at a time. The combined organic layers were dried over Na_2SO_4 and

the solvent was evaporated in vaccuo. Further purification was performed by column chromatography with EtOAc/hexane/NEt_3 (65:33:2) to obtain **69e** as a yellow solid (0.205 g, 39%). R_f(EtOAc/hexane/NEt_3 = 65:33:2) = 0.47. ^{1}H NMR (250 MHz, DMSO-d_6) δ= 8.42 (t, *J*= 5.7 Hz, 1H), 7.76 (d, *J*= 9.0 Hz, 2H), 6.98 (d, *J*= 8.3 Hz, 1H), 6.70 (d, *J*= 9.0 Hz, 2H), 6.61 (d, *J*= 2.2 Hz, 1H), 6.47 (dd, *J*= 8.3, 2.3 Hz, 1H), 5.24 (s, 2H), 4.34 (d, *J*= 5.7 Hz, 2H). ^{13}C NMR (75 MHz, DMSO-d_6) δ= 166.25, 152.23, 148.96, 132.34, 129.62, 128.71, 123.13, 121.02, 113.65, 112.70, 110.88, 39.87.

***4-(Dimethylamino)-N-(2-chloro-4-(methylsulfonamido)benzyl)benzamide*(83)**: *N*-(4-Amino-2-chlorobenzyl)-4-(dimethylamino)benzamide **69e** (0.204 g, 0.67 mmol, 1.0 eq) was dissolved in 30 mL THF and 3 mL pyridine was added. Mesyl chloride **70** (0.27 mL, 3.36 mmol, 5,0 eq) was carefully added, and the mixture was stirred for 2 h at room temperature. Then 15 mL of 10% aqueous hydrochloric acid was added and the mixture was extracted three times with 30 mL EtOAc at a time. The combined organic layers were dried over Na_2SO_4 and the solvent was evaporated in vacuo. Further purification was performed by column chromatography using EtOAc as mobile phase. Further crystallization was performed in DCM/hexane and acetone/water to obtain **83** as a yellow solid (0.064 g, 25%). R_f(EtOAc) = 0.64. ^{1}H NMR (500 MHz, MeOD-d_4) δ= 7.76 (d, *J*= 9.0 Hz, 2H), 7.33 (t, *J*= 5.5 Hz, 2H), 7.14 (dd, *J*= 8.4, 2.2 Hz, 1H), 6.73 (d, *J*= 9.0 Hz, 2H), 5.49 (s, 1H), 4.59 (s, 2H), 3.02 (s, 6H), 2.96 (s, 3H). ^{13}C NMR (126 MHz, MeOD-d_4) δ= 170.50, 154.38, 139.71, 134.72, 133.51, 130.77, 129.89, 121.74, 121.54, 119.63, 112.13, 41.90, 40.22, 39.32. HRMS (MALDI): m/z calculated 380.08302 for $C_{17}H_{19}ClN_3O_3S$, found 380.08274 $[M-H]^-$.

***4-((1-Trifluoromethyl)cycloprop-1-yl)benzoic acid*(64i)**: $Pd(OAc)_2$ (0.045 mmol, 0.01 g, 3 mol%), Xantphos (0.045 mmol, 0.01 g, 3 mol%) were dissolved in 10 mL DMF. Afterwards formic acid (10.6 mmol, 0.4 mL, 7,0 eq) and 1-Bromo-4-(1-(trifluoromethyl)cycloprop-1-yl)benzene **87** (1.5 mmol, 0.4 g, 1,0 eq) were added dropwise. Then 1-Ethyl-3-(3-dimethylaminopropyl)carbodiimide and Triethylamine were added to the mixture. The mixture was stirred at 50 °C for 20 h. After cooling the mixture down to room temperature 10 ml of 10% aqueous hydrochloric acid was added and the mixture was extracted three times with 30 mL of EtOAc at a time. The combined organic layers were extracted with 30 ml of a saturated aqueous solution of Na_2CO_3 at a time. Then the combined aqueous layers were brought to pH 1 with concentrated hydrochloric acid and extracted three times with 30 ml of EtOAc at a time. The combined organic layers were dried over Na_2SO_4 and the solvent was evaporated in vacuo to obtain **64i** without further purifications as a beige solid (0.177 g, 51%). ^{1}H NMR (300 MHz, DMSO-d_6) δ= 13.04 (s, 1H), 8.00-7.93 (m, 2H), 7.60 (d, *J*= 8.1 Hz, 2H), 1.40 (dd, *J*= 7.0, 5.0 Hz, 2H), 1.23-1.11 (m, 2H). ^{13}C NMR (75 MHz, DMSO-d_6) δ= 166.85, 140.01, 131.17, 130.85, 129.40, 128.15, 27.75-27.32, 9.78-9.75.

***N-(4-Amino-2-chlorobenzyl)-4-((1-trifluouromethyl)cycloprop-1-yl)-benzamide*(69f)**: 1-(4-Amino-1-chlorophenyl)methanamine **58k** (0.31 g, 2.0 mmol, 3,0 eq), 1-Ethyl-3-(3-dimethylaminopropyl)carbodiimide (0.31 g, 2.0 mmol, 3,0 eq) and 4-(Dimethylamino)pyridine (0.66 mmol, 0.08 g, 1,0 eq) were dissolved in 10 mL $CHCl_3$ and 1 mL DMF. Then 4-((1-Trifluoromethyl)cycloprop-1-yl)benzoic acid **64i** (0.15 g, 0.66 mmol, 1.0 eq) dissolved in 5 mL $CHCl_3$ and 0.5 mL DMF was slowly added over 10 min and the mixture was stirred for 5 h at 60 °C. After cooling the mixture to room temperature 10 mL of 10% aqueous hydrochloric acid was added, phases were separated and the aqueous layer was brought to pH 10 with Na_2CO_3 solution and extracted three times with 20 mL of EtOAc at a time. The combined organic layers were dried over Na_2SO_4 and the solvent was evaporated in vaccuo. Further purification was performed by column chromatography with hexane/EtOAC (57:43) as a mobile phase to obtain **69f** as a yellow solid (0.123 g, 50%). R_f(hexane/EtOAc = 57:43) = 0.45. ^{1}H NMR (300 MHz, acetone-d_6) δ= 7.95-7.90 (m, 2H), 7.57 (d, *J*= 8.1 Hz, 2H), 7.15 (d, *J*= 8.3 Hz, 1H), 6.72 (d, *J*= 2.3 Hz, 1H), 6.58 (dd, *J*= 8.3, 2.3 Hz, 1H), 4.85 (s, 1H), 4.54 (d, *J*= 5.6 Hz, 2H), 1.39 (dd, *J*= 6.9, 5.0 Hz, 2H), 1.18-1.12 (m, 2H). ^{13}C NMR (75 MHz, MeOD-d_4) δ= 169.60, 149.99, 140.91, 135.73, 134.95, 132.42, 131.42, 128.50, 124.97, 116.42, 114.75, 42.29, 29.28, 28.83, 10.41

***4-((1-Trifluoromethyl)cycloprop-1-yl)-N-(2-chloro-4-(methylsulfonamido)benzyl)benzamide*(84)**: *N*-(4-Amino-2-chlorobenzyl)-4-((1-trifluouromethyl)cycloprop-1-yl)-benzamide **69f** (0.1 g, 0.028 mmol, 1.0 eq) was dissolved in 15 mL THF and 1.5 mL pyridine was added. Mesyl chloride **70** (0.22 mL, 2.8 mmol, 10.0 equiv.) was carefully added, and the mixture was stirred for 24 h at room temperature. Then 15 mL of 10% aqueous hydrochloric acid was added and the mixture was extracted three times with 30 mL EtOAc at a time. The combined organic layers were dried over Na_2SO_4 and the solvent was evaporated in vacuo. Further purification was performed by column chromatography using hexane/EtOAc (50:50) as mobile phase to obtain **84** as white solid (0.052 g, 41%). R_f(hexane/EtOAc = 50:50) = 0.36. ^{1}H NMR (500 MHz, DMSO-d_6) δ= 9.93 (s, 1H), 9.04 (s, 1H), 7.91 (d, *J*= 8.3 Hz, 2H), 7.57 (d, *J*= 8.1 Hz, 2H), 7.32 (d, *J*= 8.4 Hz, 1H), 7.26 (d, *J*= 2.1 Hz, 1H), 7.15 (dd, *J*= 8.4, 2.1 Hz, 1H), 4.48 (d, *J*= 5.7 Hz, 2H), 3.02 (s, 3H), 1.38 (s, 2H), 1.17 (s, 2H). ^{13}C NMR (126 MHz, MeOD-d_4) δ= 169.74, 141.13, 139.98, 135.45, 134.93, 132.85, 132.52, 131.10, 128.53, 121.72, 119.59, 42.16, 39.37, 29.21-28.95, 10.44-10.43. HRMS (MALDI): m/z calculated 447.07515 for $C_{19}H_{19}ClF_3N_2O_3S$, found 447.07455 $[M+H]^+$.

***N-(4-Amino-2-chlorobenzyl)-4-(pyrrolidine)-benzamide*(69g)** 1-(4-Amino-1-chlorophenyl)methanamine **58k** (0.49 g, 3.1 mmol, 3.0 eq), 1-Ethyl-3-(3-dimethylaminopropyl)carbodiimide (0.49 g, 3.1 mmol, 3.0 eq) and 4-(Dimethylamino)pyridine (1.1 mmol, 0.13 g, 1.0 eq) were dissolved in 20 mL $CHCl_3$ and 2 mL DMF. Then 4-

pyrrolidinebenzoic acid (0.2 g, 1.1 mmol, 1.0 eq) dissolved in 5 ml $CHCl_3$ and 0.5 mL DMF was slowly added over 10 min and the mixture was stirred for 5 h at 60 °C. After cooling the mixture down to room temperature 10 mL of 10% aqueous hydrochloric acid was added, phases were separated and the aqueous layer was brought to pH 10 with Na_2CO_3 solution and extracted three times with 20 mL EtOAc at a time. The combined organic layers were dried over Na_2SO_4 and the solvent was evaporated in vaccuo. Further purification was performed by column chromatography with EtOAc/hexane (86:14) as mobile phase to obtain **69g** as yellow solid (0.100 g, 29%). R_f(EtOAc/hexane = 86:14) = 0.45. ^{1}H NMR (250 MHz, DMSO-d_6) δ= 8.39 (s, 1H), 7.76 (d, *J*= 8.8 Hz, 2H), 6.98 (d, *J*= 8.3 Hz, 1H), 6.61 (d, *J*= 2.2 Hz, 1H), 6.53 (d, *J*= 8.9 Hz, 2H), 6.47 (dd, *J*= 8.3, 2.3 Hz, 1H), 5.24 (s, 2H), 4.35 (d, *J*= 5.7 Hz, 2H), 3.27 (d, *J*= 7.2 Hz, 4H), 1.96 (t, *J*= 4.8 Hz, 4H). ^{13}C NMR (75 MHz, DMSO-d_6) δ= 162.32, 149.50, 148.89, 132.23, 129.53, 128.75, 123.11, 120.31, 113.53, 112.59, 110.54, 47.21, 35.78, 24.96.

***4-(Pyrrolidine)-N-(2-chloro-4-(methylsulfonamido)benzyl)benzamide*(85)**: *N*-(4-Amino-2-chlorobenzyl)-4-(pyrrolidine)-benzamide **69g** (0.1 g, 0.03 mmol, 1.0 eq) was dissolved in 15 mL THF and 2 mL pyridine was added. Mesyl chloride **70** (0.12 mL, 1.55 mmol, 5,0 eq) was carefully added, and the mixture was stirred for 2 h at room temperature. Then 15 mL of 10% aqueous hydrochloric acid was added and the mixture was extracted three times with 30 mL of EtOAc at a time. The combined organic layers were dried over Na_2SO_4 and the solvent was evaporated in vacuo. Further purification was performed by column chromatography using EtOAc/hexane (67:33) yielding **85** a white solid (0.033 g, 26%). R_f(EtOAc/hexane = 67:33) = 0.37. ^{1}H NMR (500 MHz, DMSO-d_6) δ= 9.91 (s, 1H), 8.60 (s, 1H), 7.77 (d, *J*= 8.8 Hz, 2H), 7.28 (d, *J*= 8.4 Hz, 1H), 7.25 (d, *J*= 2.1 Hz, 1H), 7.14 (dd, *J*= 8.4, 2.2 Hz, 1H), 6.54 (d, *J* = 8.9 Hz, 2H), 4.44 (d, *J*= 5.5 Hz, 2H), 3.28 (s, 4H), 3.01 (s, 3H), 1.98-1.94 (m, 4H). ^{13}C NMR (126 MHz, DMSO-d_6) δ= 166.38, 149.61, 138.20, 132.30, 132.19, 129.43, 128.81, 119.97, 119.76, 118.29, 110.59, 47.23, 42.98, 36.56, 24.98. HRMS (MALDI): m/z calculated 408.11432 for $C_{19}H_{23}ClN_3O_3S$, found 408.11361 $[M+H]^+$.

Example 4: Virtual Inspection

Binding of compound **57** was analyzed *in silico* by molecular docking using the X-ray structures of sEH and FXR containing the ligands from which lead compound **5** was constructed (compound **3**/PDB-ID: 4QE8 for FXR and compound **2**/PDB-ID: 3I28 for sEH). The resulting binding modes (shown in figure 2) are in congruence with the SAR of *N*-benzylbenzamides **5-57** on both targets. In the binding mode of **57** in FXR (figure 2A), the *tert*-butyl moiety tightly fits into the binding pocket and mediates receptor activation through stabilization of helix 12. The adjacent phenyl ring is well positioned into the lipophilic pocket that does not allow variations in 2-

or 3-position. The sulfonamide occupies a hydrophilic region and does not exhibit specific interactions, which explains the wide tolerability of hydrophilic moieties in this position of the benzyl moiety. The amide moiety forms no directed H-bonds which is also the case for the reference ligand **3** in the FXR X-ray structure 4QE8. The methylene bridge is bound in proximity to Leu287 explaining the enhanced potency of compound **32** which carries an additional methyl group in this position. The chlorine atom points towards a tight subpocket defined by Ile352 and the phenolic moiety of Tyr369 (supporting figure S1) that tolerates chlorine or fluorine (**30**) but no purely lipophilic residues as the methyl substituent in **29**.

The proposed binding mode of **57** to sEH (figure 2B) reveals that its amide group interacts with the catalytic residues Tyr383, Tyr466, and Asp335. The methylene bridge is located in a narrow tunnel which does not allow any structural modifications. The chlorine substituent of the benzyl moiety points towards a lipophilic pocket and is crucial for binding. Similar to the FXR binding mode, the sulfonamide moiety binds in a more hydrophilic subpocket does not form specific interactions. The 4-*tert*-butyl phenyl residue is located in a tight hydrophobic pocket offering space for substituents in position 4 or 3, but not in 2-position of the aromatic ring.

To study the selectivity profile of **57** amongst related nuclear receptors, the inventors determined its activity on PPARs, LXRs, RXRs, RARs, PXR and VDR at 10 µM concentration in Gal4-hybrid reporter gene assays for the respective receptors (figure 3A). **57** was inactive on PPARα and PPARδ, both LXR subtypes as well as RXRα. Only on PPARγ **57** exhibited weak partial agonism with an EC_{50} value of 14.7±0.9 µM and, therefore, is highly selective for FXR amongst nuclear receptors (selectivity ≥ 720). Moreover, **57** displayed no cytotoxic activity up to a concentration of 100 µM in a water soluble tetrazolium (WST-1) assay (figure 3B). To estimate metabolic stability, **57** was incubated with liver microsomes of *Wistar* rats which revealed an acceptable stability with > 50% of the compound remaining after 60 minutes (figure 3C). Still, the inventors studied metabolic conversion of **57** more in detail *in vitro* and identified its metabolites (figure 6, scheme 10). According to LC-MS-MS analysis (supporting figures S2-S6), **57** is metabolized by hydrolysis of the sulfonamide moiety resulting in aniline **69a**, by hydroxylation on the *tert*-butylbenzamide moiety which can lead to the three isomers **77**, **78** and **79** (figure 6, scheme 10) and by hydroxylation on the aromatic ring of the benzylsubstituent. The inventors synthesized **77** and **78** carrying a hydroxyl group on the benzamide aromatic ring but both isomers were not detectable in the metabolized residue confirming **79** as metabolite of **57**. Metabolite **69a** retains considerable potency activating FXR with an EC_{50} value of 0.046±0.006 µM and inhibiting sEH with an IC_{50} value of 0.040±0.006 µM. Hence, metabolite **69a** may contribute to the pharmacodynamic activity of dual modulation *in vivo* and prolong the pharmacologic effect of the original compound **57**.

To evaluate the FXR agonistic effect of **57** under less artificial conditions than in a reporter gene assay, the inventors also quantified the effect of the compound on FXR target gene expression in HepG2 hepatoma cells (figure 4A). For this purpose, the cells were incubated with the endogenous FXR agonist CDCA (**1b**) at 50 µM, the partial agonist **57** at 0.1 µM and 1 µM or with DMSO (0.1%) as control for 8 or 16 hours and then FXR target gene mRNA was quantified. Data was analyzed according to the $2^{\Delta\Delta Ct}$ method and all results were normalized to the values of the house-keeping gene glycerinaldehyde 3-phosphate dehydrogenase (GAPDH). Gene expression of vehicle treated control cells was defined as 100%. **57** revealed a partial FXR agonistic profile and modulated all nine studied genes similar to the endogenous agonist CDCA (**1b**) but with smaller amplitude. Expression of the bile salt export protein (BSEP) was only moderately increased by **57** while induction of small hetero-dimer partner (SHP), peroxisome proliferator-activated receptor α (PPARα), fibroblast growth factor 19 (FGF 19), pyruvate dehydrogenase kinase 4 (PDK4) and liver-type fatty acid binding protein (fatty acid binding protein 1, FABP1) reached amplitudes of 50-80% of CDCA (**1b**). Moreover, **57** repressed cholesterol 7α-hydroxylase (CYP7A1), sterol regulatory element-binding protein 1c (SREBP1c) and fatty acid synthase (FAS) which are indirectly regulated by FXR via induction of SHP. Concerning CYP7A1, **57** behaved as partial agonist and caused less repression than **1b** while repression of SREBP1c and FAS by **57** and **1b** reached equal amplitudes. For all the genes, **57** caused an equal effect at 0.1 µM and 1 µM confirming saturation at these concentrations. In contrast, PPARγ target genes scavenger receptor 3B (CD36) and cytokine-like protein 2-19 (FAM3A) were not markedly modulated by **57** even at a higher concentration of 10 µM further confirming the compound's selectivity (figure 4B).

Inhibition of soluble epoxide hydrolase was also studied in a less artificial context in HepG2 cell homogenates by quantifying conversion of the deuterated sEH substrate 14.15-EET-d11 in presence of varying concentrations of inhibitor **57** (figure 4C). The compound exerted robust inhibition of cellular sEH with a statistically significant increase in the EET/DHET ratio even at 1 nM concentration. In the cellular context, **57** revealed an IC_{50} value for sEH inhibition of approximately 10 nM.

Example 5: In-Vivo Characterization

Encouraged by the high potency and very favorable *in vitro* characteristics of **57**, the inventors conducted a pilot *in vivo* study of the compound in male wild-type C57BL6/J mice (figure 5). To record a pharmacokinetic profile and to evaluate pharmacodynamic data concerning FXR activation and sEH inhibition *in vivo*, six mice received a single dose of **57** (p.o., 10 mg/kg body weight). Three additional animals served as vehicle control.

The dual modulator **57** displayed favorable oral bioavailability (c_{max}=1182 ng/mL) and rapid uptake (t_{max}=0.5 h) accompanied by a moderate half-life ($t_{1/2}$=0.7 h). Altogether, the single dose of **57** produced effective concentrations above the EC_{50} (FXR) and IC_{50} (sEH) values over approximately three to four hours (figure 5A). To evaluate pharmacodynamic effects of **57**, mouse plasma was analyzed for EET/DHET ratio, and FXR target gene expression was determined in mouse livers 8 hours post application (figure 5B). The EET/DHET ratios for the 8.9- and 11.12-isomers were increased by approximately a factor 2 upon treatment with **57** indicating that sEH activity was inhibited by the dual modulator *in vivo*. Moreover, FXR target gene expression was altered in livers of mice receiving **57** with increased expression of BSEP (approx. 3-fold), SHP (approx. 4-fold) and FGF15 (approx. 2.5-fold) and reduced SREBP1c (approx. 5-fold) levels which also suggested FXR activation *in vivo* (figure 5C). CYP7A1 mRNA levels showed a slight trend to repression. Expression of the PPARγ target gene fatty acid transport protein (FATP) was not affected by **57** *in vivo*. Hence, the pilot animal study revealed acceptable pharmacokinetics and clearly indicated dual target engagement of **57** *in vivo*.

The growing incidence of NASH with hepatocellular carcinoma and liver cirrhosis as their most serious potential consequences represents a rapidly growing global health concern. While liver transplantation is the only effective therapy available to date, research on pharmacological options is very intensive. The FXR agonist OCA (**1a**) is leading the pipeline and holds much promise to be the first effective drug to counter NASH. It exhibited anti-steatotic and anti-fibrotic effects accompanied by several metabolic improvements in clinical trials.[6,12] The dual PPARα/δ agonist elafibranor has successfully completed phase II trials and might succeed OCA as therapeutic option.[38] Still, the multifactorial nature of NASH involving steatosis, fibrosis and - importantly - inflammation might require a broader therapeutic strategy that addresses all participating factors. In light of the impressive efficacy of FXR activation on steatosis[6,12] and promising reports on hepatic anti-steatotic as well as anti-inflammatory effects of sEH inhibition[23,39], the inventors assumed that combination of these strategies might be synergistic. Therefore, the inventors have developed a highly potent dual modulator of FXR and sEH with well-balanced activity.

The inventors successfully merged known pharmacophores of partial FXR agonists and sEH inhibitors to generate the lead structure **5** that displayed weak but statistically significant activity on both targets. The low fragment-like properties and structural flexibility of this lead compound allowed considerable structural variation to achieve optimization and, therefore, the moderate activity seemed sufficient. In four consecutive steps, the inventors systematically investigated the SAR of the compound class on FXR and sEH and reached strong optimization of dual potency. However, although the inventors identified several highly potent modulators of the single targets, no compound with low nanomolar potency on both targets was discovered in

the systematic SAR study. For the final decisive optimization step we, therefore, combined structural elements of the most active agents on the single targets which led to the development of **57** as highly potent dual modulator with an EC_{50} value of 20.4±4.2 nM for partial FXR activation and an IC_{50} value of 4.1±0.4 nM for sEH inhibition. Broader *in vitro* characterization of **57** revealed a very favorable selectivity profile over related nuclear receptors and no cytotoxic activity up to a concentration of 100 µM. In evaluation of *in vitro* metabolism **57** turned out moderately stable which was confirmed by a moderate half-life *in vivo*. However, closer evaluation and characterization of the main metabolites indicates that aniline **69a** formed by hydrolysis of the sulfonamide moiety of **57** possesses almost equal potency and is likely to be pharmacologically active prolonging the dual modulatory effect of **57**.

In HepG2 cells, **57** exerted a partial induction of FXR target genes compared to the endogenous agonist CDCA (**1b**). This observation in non-transfected liver cells and the fact that the partial agonistic modulation was equal at 1 µM and 0.1 µM concentration confirmed the true partial FXR agonistic nature of the dual modulator **57**. The clinical development of obeticholic acid (**1a**)[6] has reported disturbed cholesterol homeostasis upon treatment with the full FXR agonist which seems due to strong repression of the FXR target gene cholesterol 7α hydroxylase (CYP7A1). This enzyme constitutes the first and rate-limiting enzyme in metabolic conversion of cholesterol to bile acids and, therefore, full FXR activation blocks one of the main pathways of cholesterol elimination. To avoid this side effect, partial FXR activation seems preferable.

The FXR target gene expression profile of HepG2 cells after stimulation with **57** suggests beneficial effects on NAFLD and NASH. Recent studies reported reduced serum levels of fibroblast factor 19 (FGF19) in NAFLD and NASH patients[40] and treatment with FGF19 improved insulin sensitivity, lowered body weight and decreased hepatic fat content in mice. Increased levels of FGF19 were observed under treatment with OCA (**1a**) and considered as important beneficial pharmacodynamic effect.[12] Induction of PPARα which is considered as major regulator of hepatic fatty acid degradation by β-oxidation[41] combined with a repression of hepatic FAS causing reduced fatty acid *de-novo* synthesis is favorable for reducing hepatic steatosis. Notably, hepatic fat content in NAFLD and NASH is dominated by free fatty acids.[4] This effect may be further enhanced by induction of PDK4 leading to reduced glycolysis and, consequently, to fatty acid utilization for energy generation.[42] Liver-type fatty acid binding protein (FABP1) is involved in numerous physiological processes and globally affects lipid homeostasis. In liver, FABP1 has a cytoprotective role and counters oxidative cell damage.[43] Since oxidative stress in hepatocytes is a major factor in NAFLD/NASH development and manifestation, enhanced expression of FABP1 as exerted by **57** seems favorable in NASH.

Inhibitory potency of **57** on soluble epoxide hydrolase was also studied in a less artificial setting by quantifying the conversion of the deuterated sEH substrate 14.15-EET-d11 in HepG2 cell lysates. In this system, **57** possessed an IC_{50} value of 1.6±0.5 nM which is in perfect agreement with the results obtained in the cell-free fluorescence-based assay on recombinant protein. Hence, the dual modulator **57** is equally potent in inhibiting the human sEH in presence of other proteins and cellular components from liver cells.

Encouraged by the promising *in vitro* profile the inventors applied **57** to a pilot *in vivo* study in male wild-type C57BL6/J mice to evaluate pharmacokinetics and pharmacodynamic effects of the dual modulator. **57** displayed favorably rapid uptake and oral bioavailability and although the molecule possessed a rather short half-life, the inventors observed active concentrations over a period of around 3.5-4 hours after a single oral dose of 10 mg/kg body weight. The quantification of FXR target gene mRNA in mouse livers 8 hours after application of **57** revealed a clear trend to upregulation of SHP and BSEP that only curtly failed to reach statistical significance and marked effects on the expression of FGF15 and SREBP1c. CYP7A1 displayed a slight trend to down-regulation. Particularly the induction of BSEP points to activation of FXR by **57** *in vivo* since this gene is almost exclusively regulated by FXR.[44-46] Moreover, as discussed above, repression of SREBP1c and induction of FGF15 suggest favorable effects in NAFLD/NASH treatment. Concerning sEH inhibition *in vivo*, the inventors evaluated the effect of **57** on the ratios of sEH substrates (EETs) to sEH products (DHETs) in plasma which were significantly shifted to EETs in mice receiving the dual modulator. This accumulation of EETs indicates that **57** inhibited sEH *in vivo* as well and might exhibit anti-inflammatory activity which would highly contribute to beneficial effects in NASH.

The here reported dual modulator **57** that partially activates FXR and inhibits sEH with low nanomolar potency is the first compound with such activity. Its pharmacodynamic effects with modulation of FXR target gene expression and EET/DHET ratios indicates that **57** hit both targets *in vivo*. For this unique activity, the dual modulator perfectly qualifies for larger animal models to study its therapeutic efficacy and the concept of dual FXR/sEH modulation in NASH and related metabolic or cardiovascular disorders.

Materials and Methods

Chemistry

General. All chemicals and solvents were of reagent grade and used without further purification unless otherwise specified. All reactions were conducted in oven-dried glassware under argon-atmosphere and in absolute solvents. NMR spectra were recorded on a Bruker AV 400, Bruker

AV 300, Bruker am250xp or a Bruker AV 500 spectrometer (Bruker Corporation, Billerica, MA, USA). Chemical shifts (δ) are reported in ppm relative to tetramethylsilane (TMS) as reference; multiplicity: s, singlet; d, doublet; dd, doublet of doublets; t, triplet; dt, doublet of triplets; m, multiplet; approximate coupling constants (J) are shown in hertz (Hz). Mass spectra were obtained on a VG Platform II (Thermo Fischer Scientific, Inc., Waltham, MA, USA) using electrospray ionization (ESI). High resolution mass spectra were recorded on a MALDI LTQ ORBITRAP XL instrument (Thermo Fisher Scientific). Compound purity was analyzed on a Varian ProStar HPLC (SpectraLab Scientific Inc., Markham, ON, Canada) equipped with a MultoHigh100 Phenyl-5 µ 240+4 mm column (CS-Chromatographie Service GmbH, Langerwehe, Germany) using a gradient (H_2O/MeOH 80:20+0.1% formic acid isocratic for 5 min to MeOH+0.1% formic acid after additional 45 min and MeOH+0.1% formic acid for additional 10 min) at a flow rate of 1 mL/min and UV-detection at 245 nm and 280 nm. Compound **16** was analyzed by elemental analysis because no molecular ion was found in MS. All final compounds for biological evaluation had a purity ≥ 95%.

*Preparation of dual modulator **57**:*

***1-(4-Amino-1-chlorophenyl)methanamine* (58k)**: $LiAlH_4$ (1 M in THF, 16.4 mL, 16.4 mmol, 2.5 eq) was cooled to 0 °C. 4-Amino-2-chlorobenzonitrile **62** (1.0 g, 6.6 mmol, 1.0 eq) in 3 mL THF was slowly added to the mixture. After evolution of H_2 had ceased, the mixture was allowed to warm to room temperature and then refluxed for 16 h. After cooling to room temperature, the mixture was diluted with 10 mL THF and then cooled to 0 °C. 1 mL 10% NaOH solution and 1.8 mL water were added dropwise. The colorless precipitate was filtered through celite and washed with 15 mL diethyl ether. Evaporation of the organic solvents from the filtrate yielded **58k** as yellow oil (0.77 g, 75%). ^{1}H NMR (500 MHz, DMSO-d_6) δ = 7.11 (d, J = 8.2 Hz, 1H), 6.58 (d, J = 2.2 Hz, 1H), 6.48 (dd, J = 8.2, 2.2 Hz, 1H), 5.19 (s, 2H), 3.59 (s, 2H). ^{13}C NMR (126 MHz, DMSO-d_6) δ = 148.56, 132.33, 129.67, 127.74, 113.63, 112.72, 42.88.

***N-(4-Amino-2-chlorobenzyl)-4-(tert-butyl)benzamide* (69a)**: 1-(4-Amino-1-chlorophenyl)methanamine **58k** (0.31 g, 2.0 mmol, 1.1 eq) was dissolved in 10 mL $CHCl_3$, 5 mL NEt_3 were added and the mixture was cooled to 0 °C. 4-*tert*-Butylbenzoyl chloride **630** (0.35 mL, 1.8 mmol, 1.0 eq) was slowly added over 10 min and the mixture was stirred for two hours at room temperature. Then, 50 mL 10% aqueous hydrochloric acid were added, phases were separated and the aqueous layer was washed with 30 mL EtOAc. The aqueous layer was brought to pH 10 with Na_2CO_3 solution and extracted three times with 80 mL EtOAc at a time. The combined organic layers were dried over Na_2SO_4 and the solvent was evaporated in vacuum. Further purification was performed by column chromatography with petrolether/EtOAc (9:1) as mobile phase to obtain **69a** as yellow solid (0.57 g, 97%). R_f(petrolether/EtOAc = 2:1) = 0.26. ^{1}H NMR (500 MHz, MeOH-d_4) δ = 7.81 (dt, J = 8.6, 2.3 Hz, 2H), 7.53 (dt, J = 8.6, 2.3 Hz, 2H),

7.45 (d, J = 8.3 Hz, 1H), 7.31 (d, J = 2.2 Hz, 1H), 7.15 (dd, J = 8.3, 2.2 Hz, 1H), 4.64 (s, 2H), 1.36 (s, 9H).^{13}C NMR (126 MHz, MeOH-d_4) δ = 170.32, 156.67, 140.89, 135.23, 132.33, 131.39, 128.29, 126.59, 122.96, 120.82, 119.16, 42.13, 35.36, 31.54. HRMS (MALDI): m/z calculated 317.14152 for $C_{18}H_{21}ClN_2O$, found 317.14130 $[M+H]^+$.

4-(tert-Butyl)-N-(2-chloro-4-(methylsulfonamido)benzyl)benzamide (**57**): *N*-(4-Amino-2-chlorobenzyl)-4-(*tert*-butyl)benzamide **69a** (0.04 g, 0.12 mmol, 1.0 eq) was dissolved in 5 mL $CHCl_3$ and 0.5 mL pyridine were added. Mesyl chloride **70** (0.02 mL, 0.14 mmol, 1.2 eq) was carefully added and the mixture was stirred for two hours at room temperature. Then, 15 mL 10% aqueous hydrochloric acid were added and the mixture was extracted three times with 30 mL EtOAc at a time. The combined organic layers were dried over Na_2SO_4 and the solvent was evaporated in vacuum. Further purification was performed by column chromatography using petrolether/EtOAc (4:1) as mobile phase to obtain **57** as colorless solid (0.047 g, 66%). R_f(petrolether/EtOAc = 2:1) = 0.13. ^{1}H NMR (500 MHz, MeOH-d_4) δ = 7.80 (dt, J = 8.6, 2.0 Hz, 2H), 7.52 (dt, J = 8.6, 2.0 Hz, 2H), 7.36 (d, J = 8.4 Hz, 1H), 7.33 (d, J = 2.2 Hz, 1H), 7.16 (dd, J = 8.4, 2.3 Hz, 1H), 4.62 (s, 2H), 2.97 (s, 3H), 1.35 (s, 9H). ^{13}C NMR (126 MHz, MeOH-d_4) δ = 170.30, 156.55, 139.90, 134.88, 133.07, 132.46, 130.99, 128.29, 126.56, 121.75, 119.62, 42.06, 39.36, 35.81, 31.55. MS (ESI-): m/z 393.1 (100, $[M-H]^-$). HRMS (MALDI): m/z calculated 395.11907 for $C_{19}H_{24}ClN_2O_3S$, found 395.11892 $[M+H]^+$.

For preparation and characterization of compounds **4-56** and **77-78** as well as the respective intermediates please refer to supporting information.

Biological evaluation

Full length FXR transactivation assay

Plasmids: pcDNA3-hFXR contains the sequence of human FXR and was already published elsewhere.[47] pGL3basic (Promega Corporation, Fitchburg, WI, USA) was used as a reporter plasmid, with a shortened construct of the promotor of the bile salt export protein (BSEP) cloned into the SacI/NheI cleavage site in front of the luciferase gene.[48] pRL-SV40 (Promega) was transfected as a control for normalization of transfection efficiency and cell growth. pSG5-hRXR was already published elsewhere as well.[49]

Assay procedure: HeLa cells were grown in DMEM high glucose supplemented with 10% FCS, sodium pyruvate (1 mM), penicillin (100 U/mL) and streptomycin (100 µg/mL) at 37 °C and 5% CO_2. 24 h before transfection, HeLa cells were seeded in 96-well plates with a density of 8000 cells per well. 3.5 h before transfection, medium was changed to DMEM high glucose, supplemented with sodium pyruvate (1 mM), penicillin (100 U/mL), streptomycin (100 µg/mL)

and 0.5% charcoal-stripped FCS. Transient transfection of HeLa cells with BSEP-pGL3, pRL-SV40 and the expression plasmids pcDNA3-hFXR and pSG5-hRXR was carried out using calcium phosphate transfection method. 16 h after transfection, medium was changed to DMEM high glucose, supplemented with sodium pyruvate (1 mM), penicillin (100 U/mL), streptomycin (100 µg/mL) and 0.5% charcoal-stripped FCS. 24 h after transfection, medium was changed to DMEM without phenol red, supplemented with sodium pyruvate (1 mM), penicillin (100 U/mL), streptomycin (100 µg/mL), L-glutamine (2 mM) and 0.5% charcoal-stripped FCS, now additionally containing 0.1% DMSO and the respective test compound or 0.1% DMSO alone as untreated control. Each concentration was tested in triplicate wells and each experiment was repeated independently at least three times. Following 24 h incubation with the test compounds, cells were assayed for luciferase activity using Dual-Glo™ Luciferase Assay System (Promega) according to the manufacturer's protocol. Luminescence was measured with a Tecan Infinite M200 luminometer (Tecan Deutschland GmbH, Crailsheim, Germany). Normalization of transfection efficiency and cell growth was done by division of firefly luciferase data by renilla luciferase data multiplied by 1000 resulting in relative light units (RLU). Fold activation was obtained by dividing the mean RLU of the tested compound at a respective concentration by the mean RLU of untreated control. Relative activation was obtained by dividing the fold activation of the tested compound at a respective concentration by the fold activation of FXR full agonist GW4064 (**1c**) at 3 µM. EC_{50} and standard error of the mean values were calculated with the mean relative activation values of at least three independent experiments by SigmaPlot 10.0 (Systat Software GmbH, Erkrath, Germany) using a four parameter logistic regression. The assay was validated with FXR agonists **1b** (EC_{50}=18±1 µM, 88±3% rel. max. act.), **1a** (EC_{50}=0.16±0.02 µM, 87±3% rel. max. act.) and **1c** (EC_{50}=0.51±0.16 µM, 3 µM defined as 100%).[15]

sEH activity assay

The sEH inhibitory potency of the compounds were determined in a fluorescence-based 96-well sEH activity assay using recombinant human enzyme[50,51]. Non-fluorescent PHOME (3-phenylcyano-(6-methoxy-2-naphthalenyl)methyl ester 2-oxiraneacetic acid; Cayman Chemicals) which can be hydrolyzed by the sEH to fluorescent 6-methoxynaphthaldehyde served as substrate. Recombinant human sEH (in Bis-Tris buffer, pH 7, with 0.1 mg/mL BSA containing a final concentration of 0.01% Triton-X 100) was pre-incubated with test compounds (in DMSO, final DMSO concentration: 1%) for 30 min at room temperature. Then, substrate was added (final concentration 50 µM) and hydrolysis of the substrate was determined by measuring fluorescent product formation on a Tecan Infinite F200 Pro (λ_{em}=330 nm, λ_{ex}=465 nm) for 30 min (one point every minute). A blank control (no protein and no compound) as well as a positive control (no compound) were executed. All experiments were conducted in triplicate and repeat-

ed in at least three independent experiments. For IC_{50} calculation, dose-response curves of increasing compound concentrations were recorded.

Hybrid reporter gene assays for PPARα/γ/δ, LXRα/β, RXRα/β/γ, RARα/β/γ, VDR and PXR

Plasmids: The Gal4-fusion receptor plasmids pFA-CMV-hPPARα-LBD[52], pFA-CMV-hPPARγ-LBD[52], pFA-CMV-hPPARδ-LBD[52], pFA-CMV-hLXRα-LBD[32] and pFA-CMV-hLXRβ-LBD[32] have been reported previously. The Gal4-fusion receptor plasmids pFA-CMV-hRXRα-LBD, pFA-CMV-hRXRβ-LBD, pFA-CMV-hRXRγ-LBD, pFA-CMV-hRARα-LBD, pFA-CMV-hRARβ-LBD, pFA-CMV-hRARγ-LBD, pFA-CMV-hVDR-LBD and pFA-CMV-hPXR-LBD coding for the hinge region and ligand binding domain (LBD) of the canonical isoform of the respective nuclear receptor (uniprot entries: hRXRα - P19793, residues 225-462; hRXRβ - P28702-1, residues 294-533; hRXRγ - P48443-1, residues 229-463; hRARα - P10276-1, residues 177-462; hRARβ - P10826-1, residues 177-455; hRARγ - P13631-1, residues 179-454; hVDR - P11473-1, residues 119-427; hPXR - O75469-1, residues 138-434) were constructed by integrating cDNA fragments obtained from PCR amplification of commercial cDNA (Source BioSience, Nottingham, UK) into the BamH1 cleavage site of the pFA-CMV vector (Stratagene, La Jolla, CA, USA) and an afore inserted KpnI cleavage site. Frame and sequence of all fusion receptors were verified by sequencing. pFR-Luc (Stratagene) was used as reporter plasmid and pRL-SV40 (Promega) for normalization of transfection efficiency and cell growth.

Assay procedure: HEK293T cells were grown in DMEM high glucose, supplemented with 10% FCS, sodium pyruvate (1 mM), penicillin (100 U/mL) and streptomycin (100 µg/mL) at 37 °C and 5% CO_2. The day before transfection, HEK293T cells were seeded in 96-well plates ($2.5 \cdot 10^4$ cells/well). Before transfection, medium was changed to Opti-MEM without supplements. Transient transfection was carried out using Lipofectamine LTX reagent (Invitrogen) according to the manufacturer's protocol with pFR-Luc (Stratagene), pRL-SV40 (Promega) and pFA-CMV-hRXRα-LBD. 5 h after transfection, medium was changed to Opti-MEM supplemented with penicillin (100 U/mL), streptomycin (100 µg/mL), now additionally containing 0.1% DMSO and the respective test compound or 0.1% DMSO alone as untreated control. Each concentration was tested in triplicates and each experiment was repeated independently at least three times. Following overnight (12-14 h) incubation with the test compounds, cells were assayed for luciferase activity using Dual-Glo™ Luciferase Assay System (Promega) according to the manufacturer's protocol. Luminescence was measured with an Infinite M200 luminometer (Tecan Deutschland GmbH). Normalization of transfection efficiency and cell growth was done by division of firefly luciferase data by renilla luciferase data and multiplying the value by 1000 resulting in relative light units (RLU). Fold activation was obtained by dividing the mean RLU of a test compound at a respective concentration by the mean RLU of untreated control. Relative activation was obtained by dividing the fold activation of a test compound at a respective con-

centration by the fold activation of a respective reference agonist at 1 μM (PPARα: GW7647; PPARγ: pioglitazone; PPARδ: L165,041; LXRα/β: T0901317; RXRs: bexarotene; RARs: tretinoin; VDR: calcitriol; PXR: SR12813). All hybrid assays were validated with the above mentioned reference agonists which yielded EC_{50} values in agreement with literature.

FXR target gene quantification (quantitative real-time PCR)

FXR target gene quantification was performed as described previously.[15] In brief, HepG2 cells were incubated with test compound **57** (0.1 μM and 1 μM) or **1b** (50 μM) or 0.1% DMSO alone as untreated control for 8 or 16 h, harvested, washed with cold phosphate buffered saline (PBS) and then directly used for RNA extraction. Two micrograms of total RNA were extracted from HepG2 cells by the Total RNA Mini Kit (R6834-02, Omega Bio-Tek, Inc., Norcross, GA, USA). RNA was reverse-transcribed into cDNA using the High-Capacity cDNA Reverse Transcription Kit (4368814, Thermo Fischer Scientific, Inc.) according to the manufacturer's protocol. FXR target gene expression was evaluated by quantitative real time PCR analysis with a StepOnePlus™ System (Life Technologies, Carlsbad, CA, USA) using PowerSYBRGreen (Life Technologies; 12.5 μL per well). The primers are listed in the supporting information. Each sample was set up in duplicates and repeated in at least three independent experiments. The expression was quantified by the comparative ΔΔCt method and glycerinaldehyde 3-phosphate dehydrogenase (GAPDH) served as reference gene. Results (expressed as mean±SEM % change in expression compared to vehicle set as 100%; n≥4): BSEP: DMSO: 100; **1b** (50 μM): 557±28; **57** (0.1 μM): 216±18; **57** (1 μM): 222±20. SHP: DMSO: 100; **1b** (50 μM): 368±35; **57** (0.1 μM): 242±61; **57** (1 μM): 317±78. CYP7A1: DMSO: 100; **1b** (50 μM): 34±12; **57** (0.1 μM): 50±7; **57** (1 μM): 52±8. PPARα: DMSO: 100; **1b** (50 μM): 289±59; **57** (0.1 μM): 170±11; **57** (1 μM): 211±10. SREBP1c: DMSO: 100; **1b** (50 μM): 45±7; **57** (0.1 μM): 49±17; **57** (1 μM): 36±12. FAS: DMSO: 100; **1b** (50 μM): 34±14; **57** (0.1 μM): 22±8; **57** (1 μM): 38±15. FGF19: DMSO: 100; **1b** (50 μM): 407±42; **57** (0.1 μM): 309±101; **57** (1 μM): 325±77. PDK4: DMSO: 100; **1b** (50 μM): 284±50; **57** (0.1 μM): 255±54; **57** (1 μM): 226±57. FABP1: DMSO: 100; **1b** (50 μM): 249±17; **57** (0.1 μM): 183±34; **57** (1 μM): 194±42. CD36: DMSO: 100; pioglitazone (1 μM): 353±43; **57** (1 μM): 119±33; **57** (10 μM): 129±42. FAM3A: DMSO: 100; pioglitazone (1 μM): 310±66; **57** (1 μM): 112±12; **57** (10 μM): 142±7.

Cellular sEH assay

Quantification of cellular sEH metabolic activity was performed as described by Zha et al.[53] Accordingly, 1 μg of total cell homogenate from HepG2 cells (diluted in 100 μl of PBS containing 0.1 mg/ml BSA) was incubated with varying concentrations of **57**, *N*-cyclohexyl-*N'*-(4-iodophenyl)urea (CIU, 10 μM)[36] as positive control or vehicle (DMSO in a final concentration of 1%) as negative control for 15 min at 37 °C. 25 ng (±)14(15)-EET-d11 (Cayman Chemical, Ann Arbor, USA) was added and incubation was continued for additional 10 min at 37 °C. A blank

test was performed with PBS (containing 0.1 mg/ml BSA) treated likewise. The reactions were stopped by adding 100 µl of ice cold methanol. After centrifugation (2000 rpm, 4 °C, 5 min), supernatants were analyzed by LC-MS/MS and the amounts of (±)14(15)-EET-d11 and the corresponding (±)14(15)-DHET-d11 were determined. Quantification of (±)14(15)-EET-d11 and (±)14(15)-DHET-d11 from supernatants was performed by LC-MS according to the procedure reported for quantification of EETs and DHETs from mouse plasma (see below). Results (expressed as mean (±)14(15)-EET-d11/(±)14(15)-DHET-d11 ratio±SEM; n=3): blank (w/o cells): 499±123; DMSO (1%): 63±16; CIU (10 µM): 519±55; **57**: 0.001 µM: 191±7; 0.01 µM: 396±65; 0.1 µM: 442±7; 1 µM: 602±56; 10 µM: 614±96.

Animal study

Animals and compound application: 9 male C57BL/6JRj mice (23-26 g body weight, purchased from Janvier Labs, France) were used in the present study. The animals were housed in a temperature-controlled room (20-24 °C) and maintained in a 12 h light/12 h dark cycle. Food and water were available *ad libitum*. The in life phase was performed by the contract research organization Pharmacelsus (Saarbrücken, Germany). All experimental procedures were approved by and conducted in accordance with the regulations of the local Animal Welfare authorities (Landesamt für Gesundheit und Verbraucherschutz, Abteilung Lebensmittel- und Veterinärwesen, Saarbrücken). Six animals received a single oral dose of 10 mg/kg body weight of dual modulator **57** in water containing 1% HPMC/Tween 80 (99:1). Three animals received the vehicle (water containing 1% HPMC/Tween 80 (99:1)). All animals behaved normal throughout the study and showed no adverse effects.

Blood and liver sampling: At six time points (15 min, 30 min, 60 min, 120 min, 240 min and 480 min after application of **57**), blood (20 µl) of the six restrained and conscious mice was obtained from the lateral tail vein. For the last time-point (480 min), mice were anesthetized under isoflurane and blood (~500 µl) was obtained by retro-orbital puncture. A part of the blood was centrifuged (6000 rpm, 10 min, +4 °C) to obtain plasma for quantification of EET/DHET ratio and stored at -80 °C until further evaluation. For liver collection, mice were sacrificed by cervical dislocation after the last blood sampling (8 h post dose). Complete liver was immediately snap-frozen and stored at -80 °C until further evaluation. Plasma and liver were equally obtained from three control mice which received oral application of the vehicle (1% HPMC/Tween 80 (99:1)).

*Quantification of **57** from blood samples*: Calibration samples: Stock solutions of the test items (1 mg/ml in DMSO) were diluted in DMSO to a final concentration of 200 µg/ml (start solution). Further working solutions were prepared by dilution of the working solutions in DMSO.

Individual stock solutions were used for preparation of calibration standards and QCs. Calibration standards and QCs were prepared by spiking 20 µl of drug free blank blood with 2.4 µl working solution. Accordingly, unknown samples, zero samples and blanks were spiked with 2.4 µl DMSO. The calibration standards and quality controls were prepared in duplicates. A volume of 40 µl acetonitrile containing the internal standard (Griseofulvin, 600 ng/ml) was added to 22.4 µl of unknown sample, zero sample, calibration standard and QC sample. Acetonitrile without internal standard was added to blank samples. All samples were vigorously shaken and centrifuged for 10 minutes at 6000 g and room temperature. The particle free supernatant (50 µl) was diluted with an equal volume water. An aliquot was transferred to 200 µl sampler vials and subsequently subjected to LC MS with an injection volume of 15 µl. LC-MS analysis: The HPLC pump flow rate was set to 600 µl/min and the compounds were separated on a Kinetex Phenyl-Hexyl, 2.6 µm, 50x2.1 mm (Phenomenex, Aschaffenburg, Germany) analytical column with a pre-column (Kinetex Phenyl-Hexyl, SecurityGuard Ultra, 2.1 mm). Gradient elution with water and 0.1% formic acid as aqueous phase (A) and acetonitrile with 0.1% formic acid as organic phase (B) was used: % B (t (min)), 0(0-0.1)-97(0.4-1.7)-0(1.8-3.0). Full scan mass spectra were acquired in the positive ion mode using syringe pump infusion to identify the protonated quasi-molecular ions $[M+H]^+$. Auto-tuning was carried out for maximizing ion abundance followed by the identification of characteristic fragment ions using a generic parameter set: ion-transfer-capillary temperature 350 °C, capillary voltage 3.8 kV, collision gas 0.8 mbar argon, sheath gas, ion sweep gas and auxiliary gas pressure were 20, 2 and 8 (arbitrary units), respectively. Pharmacokinetic analysis was performed applying a non-compartment model using the Kinetica 5.0 software (Thermo Scientific, Waltham, USA).

Quantification of FXR target gene mRNA from mouse livers: *Hepatocyte isolation of mouse liver tissue for RT-qPCR:* To homogenize the liver samples, one third of each liver was placed on one Falcon™ Cell Strainer with 40 µm pore size (BD Bioscience, Erembodegem, Belgium) in a 50 mL Falcon tube. Every tissue was rinsed with PBS buffer containing 10% FCS and 1% Pen-Strep and pressed through the cell strainer until 5 mL cell suspension had been collected. The samples were centrifuged at 1200 rpm for 10 min at 4 °C. The supernatant was discarded and the pellets were washed with 5 mL cold PBS buffer and again centrifuged at 1200 rpm for 10 min at 4 °C. After discarding the supernatant, the cell pellets were re-suspended in 1 mL PBS and total RNA was extracted using the E. Z. A. Total RNA Kit I (Omega bio-tek Inc., Narcoss, Georgia, USA) following the Animal Tissue Protocol. The extracted RNA was used for qRT-PCR and equally treated as described for mRNA quantification from HepG2 cells (see above). PCR primers for the murine genes are listed in the supporting information. Results (expressed as mean±SEM % change in expression compared to vehicle set as 100%; n=6 for **57**, n=3 for vehicle): BSEP: vehicle: 105±24; **57** (10 mg/kg): 312±103. SHP: vehicle: 108±29; **57** (10 mg/kg): 410±147. CYP7A1: vehicle: 106±25; **57** (10 mg/kg): 70±11. SREBP1c: vehicle: 82±14; **57** (10

mg/kg): 17±10. FGF15: vehicle: 119±15; **57** (10 mg/kg): 254±9. FATP: vehicle: 101±1; **57** (10 mg/kg): 105±5.

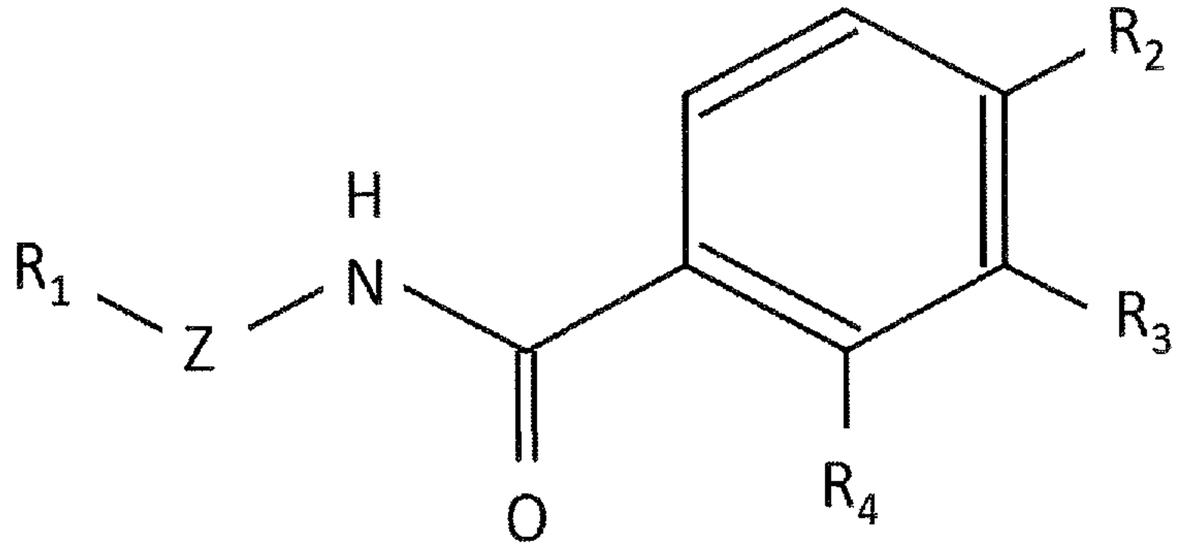
EET/DHET ratio analysis from mouse plasma samples (Determination of Epoxyeicosatrienoicacids (EETs) and their metabolites Dihydroxyepoxyeicosatrienoicacids (DHETs) by LC-MS/MS): 8.9-EET, 11.12-EET and their dehydro-metabolites content of the extracted samples were analyzed employing liquid chromatography tandem mass spectroscopy (LC-MS/MS). The LC-MS/MS system comprised an API 5500 QTrap (AB Sciex, Darmstadt, Germany), equipped with a Turbo-V-source operating in negative ESI mode, an Agilent 1200 binary HPLC pump and degasser (Agilent, Waldbronn, Germany) and an HTC Pal autosampler (Chromtech, Idstein, Germany) fitted with a 25 µL LEAP syringe (Axel Semrau GmbH, Sprockhövel, Germany). High purity nitrogen for the mass spectrometer was produced by a NGM 22-LC/MS nitrogen generator (cmc Instruments, Eschborn, Germany). All compounds were obtained from Cayman Chemical (Ann Arbor, MI, USA). Stock solutions with 2500 ng/ml of all analytes were prepared in methanol. Working standards with a concentration range of 0.1-250 ng/ml were obtained by further dilution for epoxyeicosatrienoic acids and their dehydro-metabolites. Extraction of mouse plasma samples was performed by liquid-liquid-extraction. 150 µl of sample/matrix homogenate were gently mixed with 20 µl of internal standard (8.9-EET-d8 and 11.12-EET-d8 with a concentration of 200 ng/ml in methanol), and were extracted twice with 600 µL of ethyl acetate. To prepare samples for standard curve and quality control, 150 µL PBS were added further 20 µL methanol 20 µL working standard and 20 µL internal standard were added instead of 150 µl of matrix homogenates. The organic solvent was evaporated at a temperature of 45 °C under a gentle stream of nitrogen. The residues were reconstituted with 50 µL of methanol/water (50:50, v/v), centrifuged for 2 minutes at 10000 g and then transferred to glass vials (Macherey-Nagel, Düren, Germany) prior to injection into the LC-MS/MS system. For the chromatographic separation a Gemini NX C18 column and precolumn were used (150 mm ×2 mm i. d., 5 µm particle size and 110 Å pore size from Phenomenex, Aschaffenburg, Germany). A linear gradient was employed at a flow rate of 0.5 ml/min mobile phase with a total run time of 17.5 minutes. Mobile phase was A water/ammonia (100:0.05, v/v) and B acetonitrile/ammonia (100:0.05, v/v). The gradient started from 85% A to 10% within 12 min this was held for 1 min at 10% A. Within 0.5 min the mobile phase shifted back to 85% A and was held for 3.5 min to equilibrate the column for the next sample. The injection volume of samples was 20 µL. Quantification was performed with Analyst Software V 1.5.1 (Applied Biosystems, Darmstadt, Germany) employing the internal standard method (isotope-dilution mass spectrometry). Ratios of analyte peak area and internal standard area (y-axis) were plotted against concentration (x-axis) and calibration curves were calculated by least square regression with $1/c^2$ weighting. Results (expressed as mean ratio±SEM; n=6 for **57**, n=3 for vehicle): 8,9-

EET/8,9-DHET: vehicle: 0.40±0.03; **57** (10 mg/kg): 0.63±0.03. 11,12-EET/11,12-DHET: vehicle: 0.15±0.01; **57** (10 mg/kg): 0.25±0.03.

U30787WO01

Claims

1. A compound having the formula I:



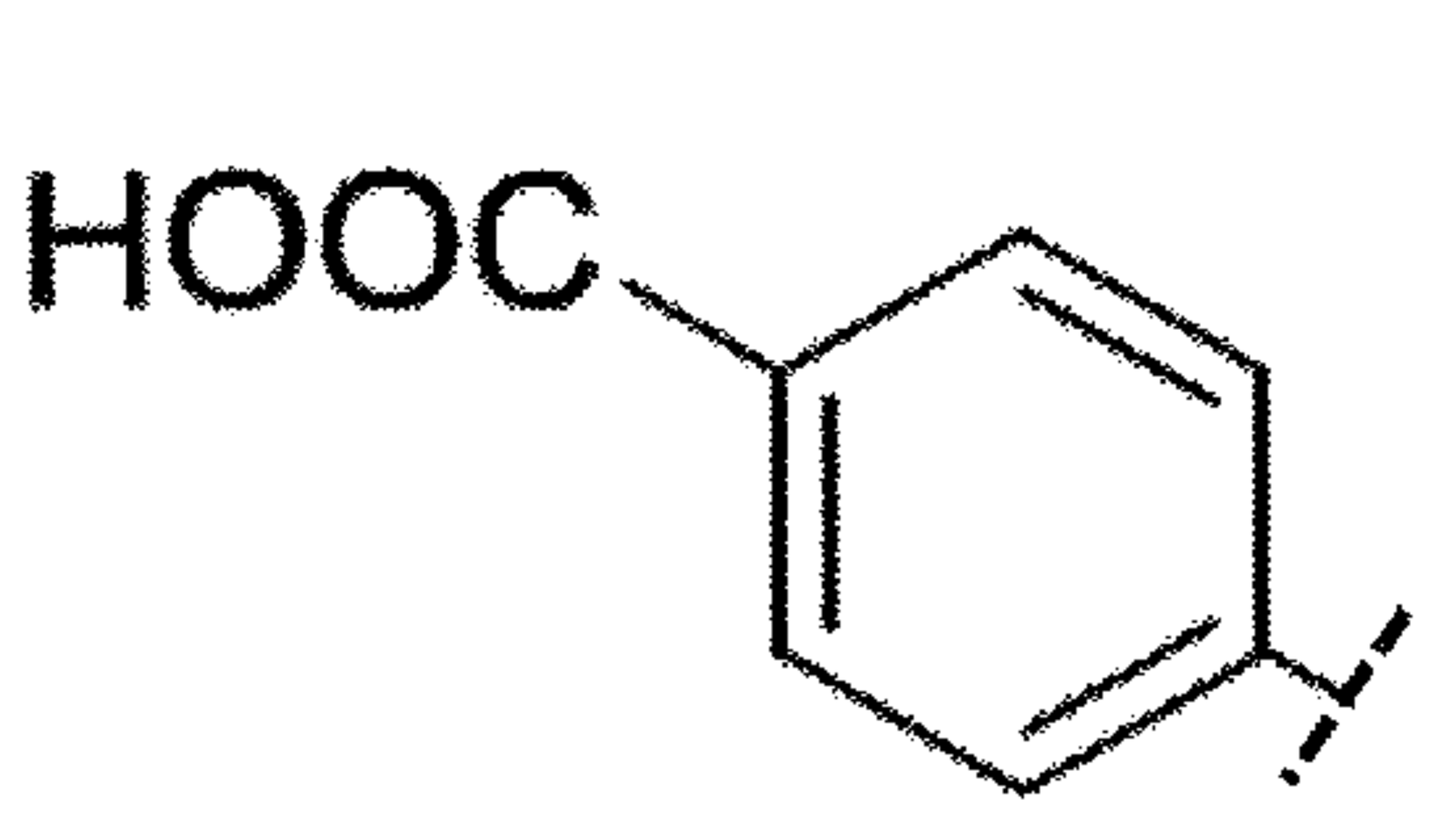
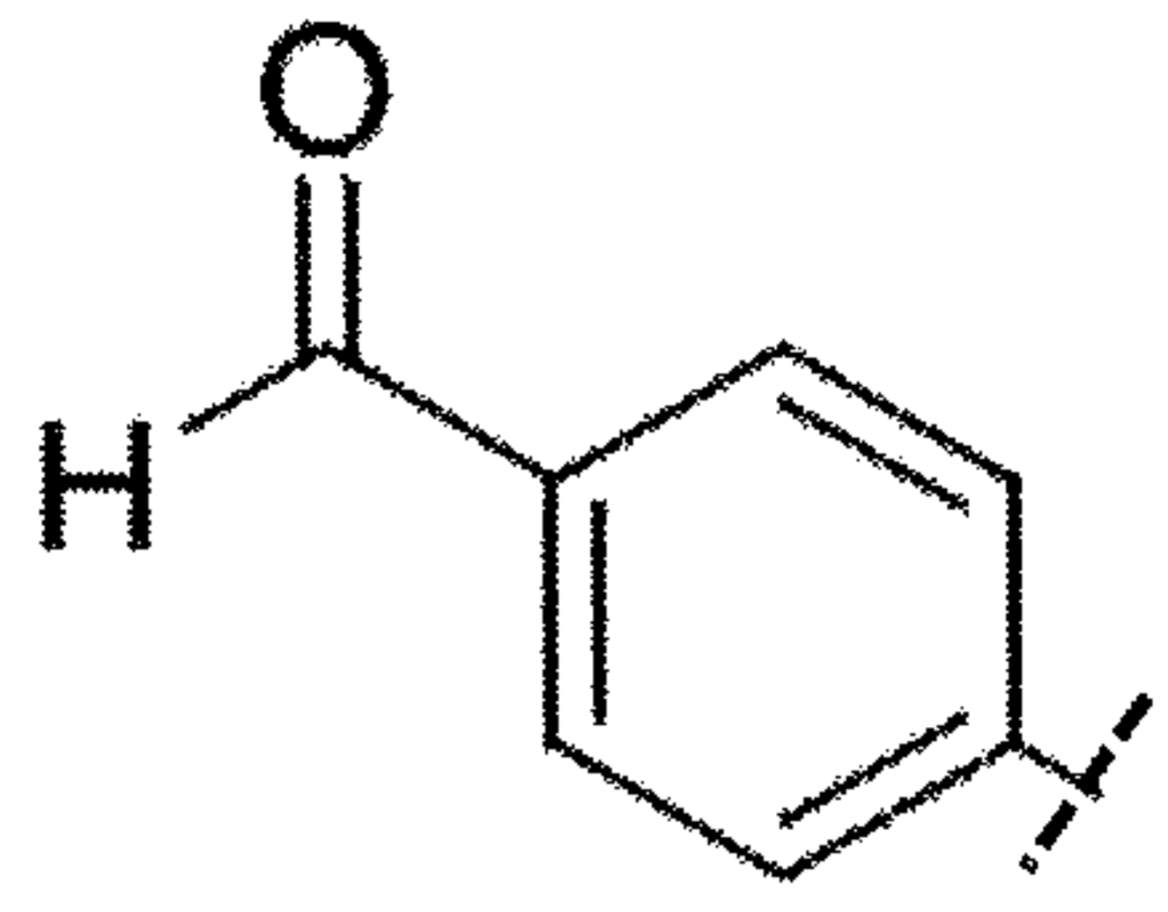
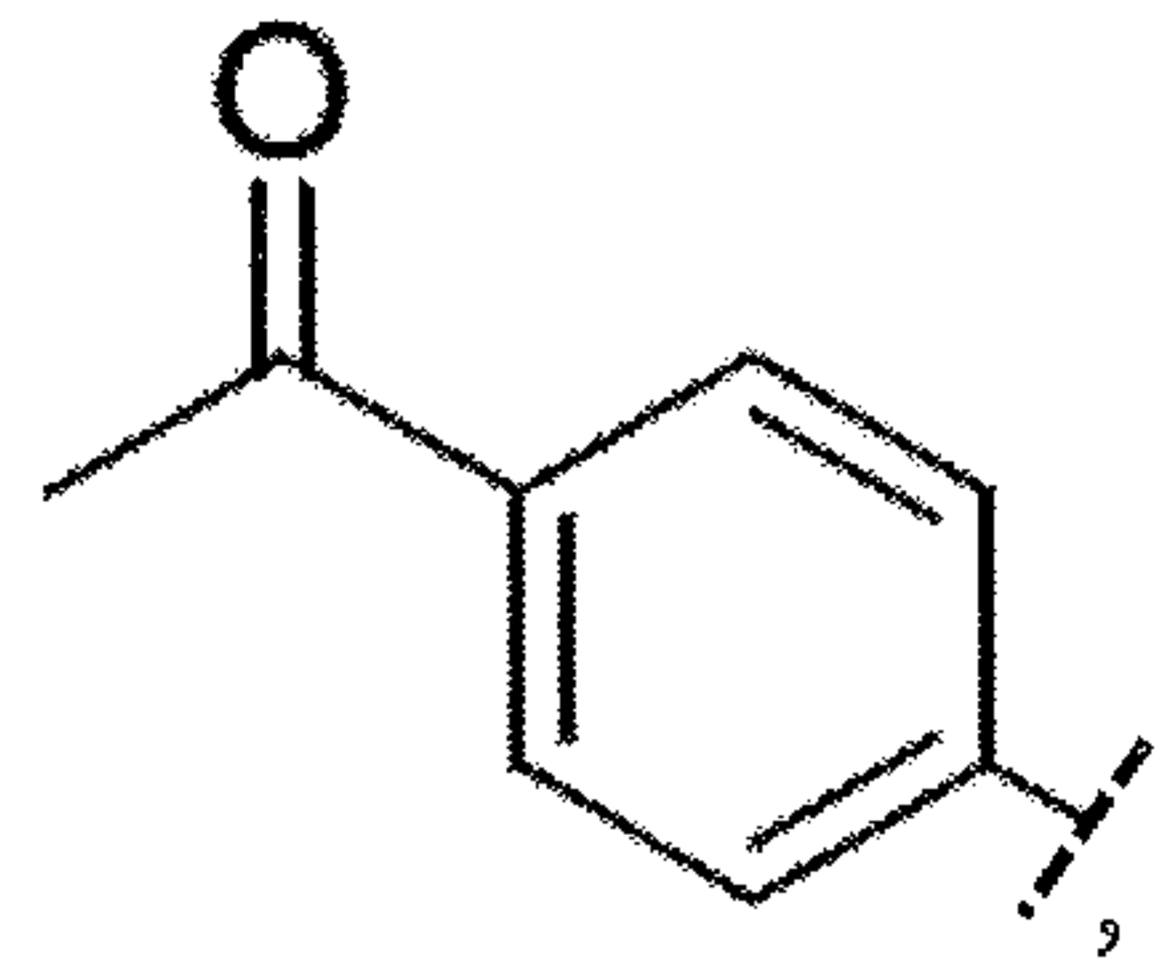
(I),

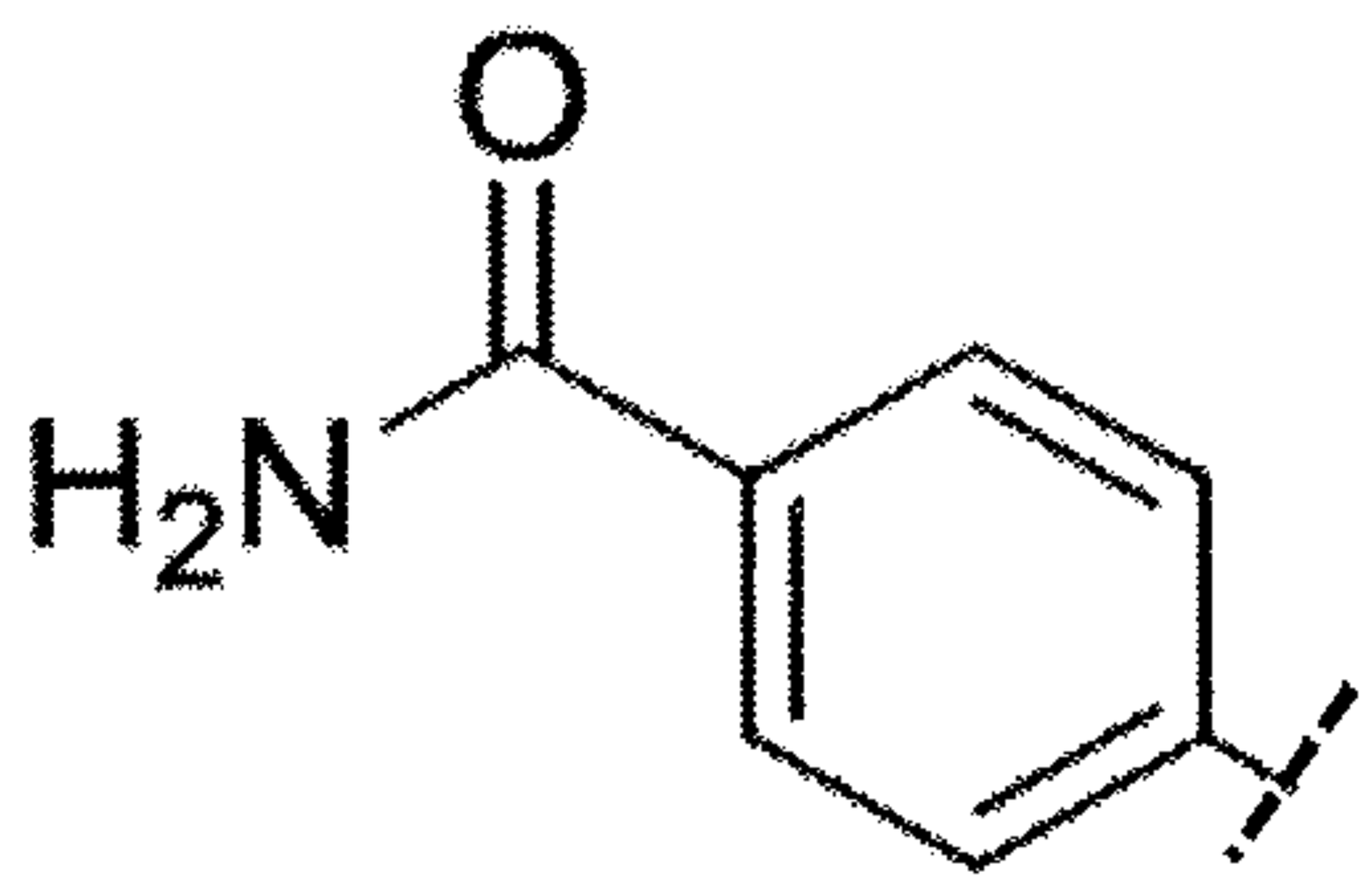
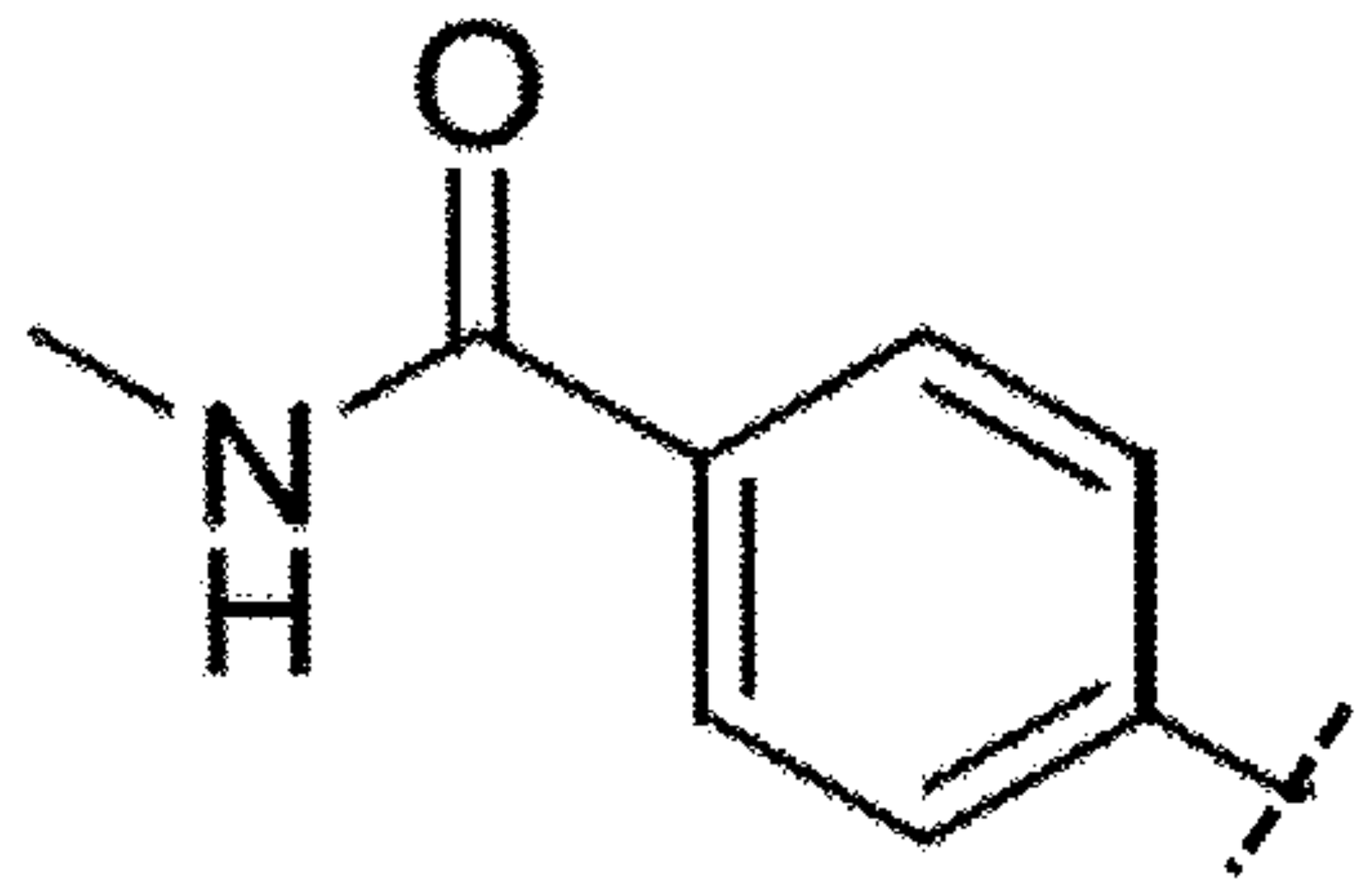
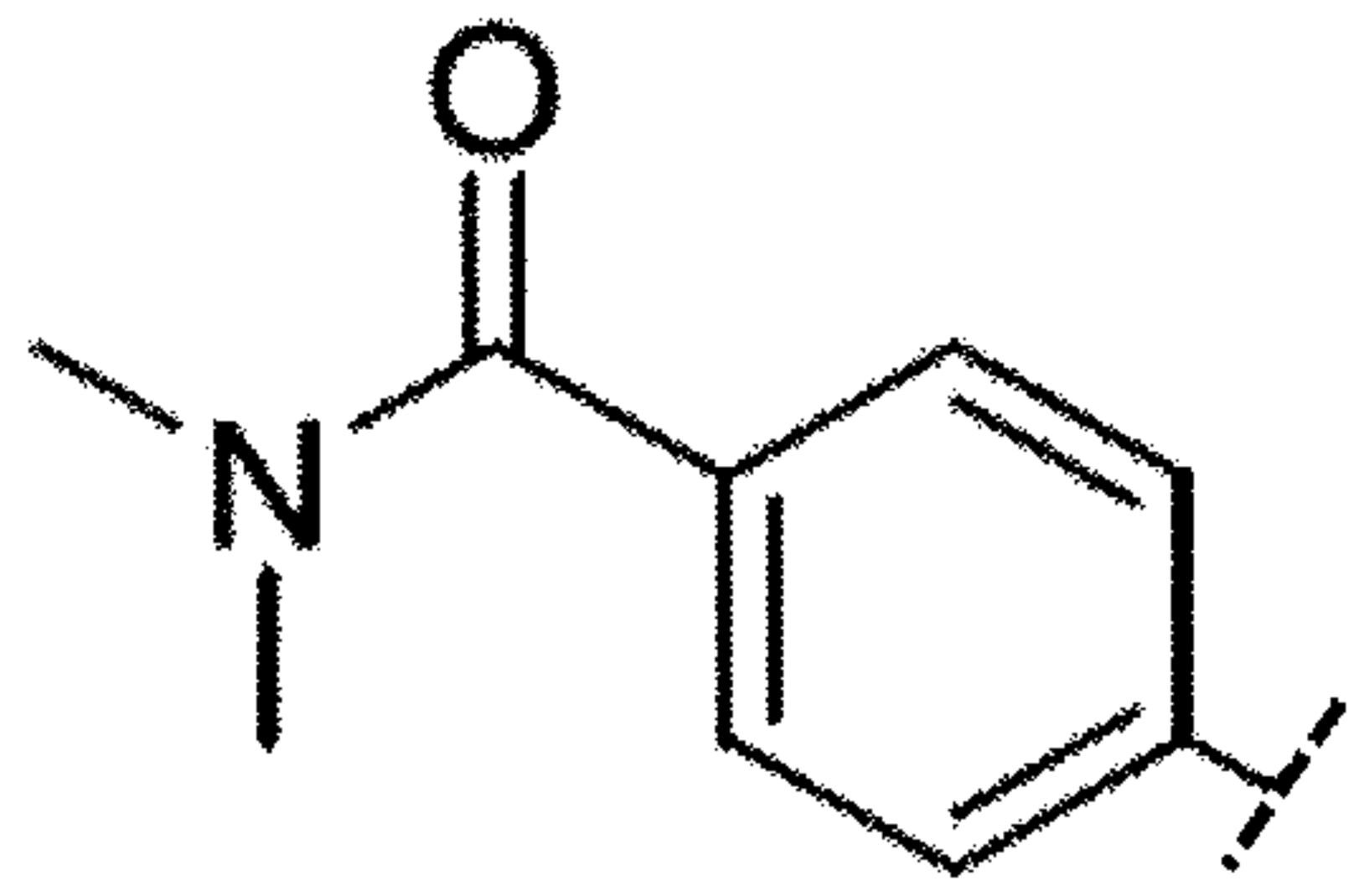
wherein R_1, R_2, R_3 and R_4 are independently selected from H, an unsubstituted, monosubstituted, or polysubstituted C_1-C_{18} alkyl or heteroalkyl, wherein said alkyl is straight, branched or cyclic, a unsubstituted, monosubstituted or polysubstituted C_1-C_{18} alkenyl or heteroalkenyl, wherein said alkenyl is straight, branched or cyclic, an unsubstituted, monosubstituted, or polysubstituted aryl or heteroaryl, an unsubstituted, monosubstituted, or polysubstituted benzyl group, an acyl group, such as formyl, acetyl, trichloroacetyl, fumaryl, maleyl, succinyl, benzoyl, or acyl groups being branched, heteroatom-substituted or aryl-substituted, a sugar or another acetal, and a sulfonyl group, and/or R_2, R_3 and/or R_4 form together a nonsubstituted, monosubstituted, or polysubstituted ring, preferably an aromatic ring;
Z is C with or without any substitution;
or an isomer, prodrug, or derivative thereof, or a pharmaceutically acceptable salt or solvate of these compounds.

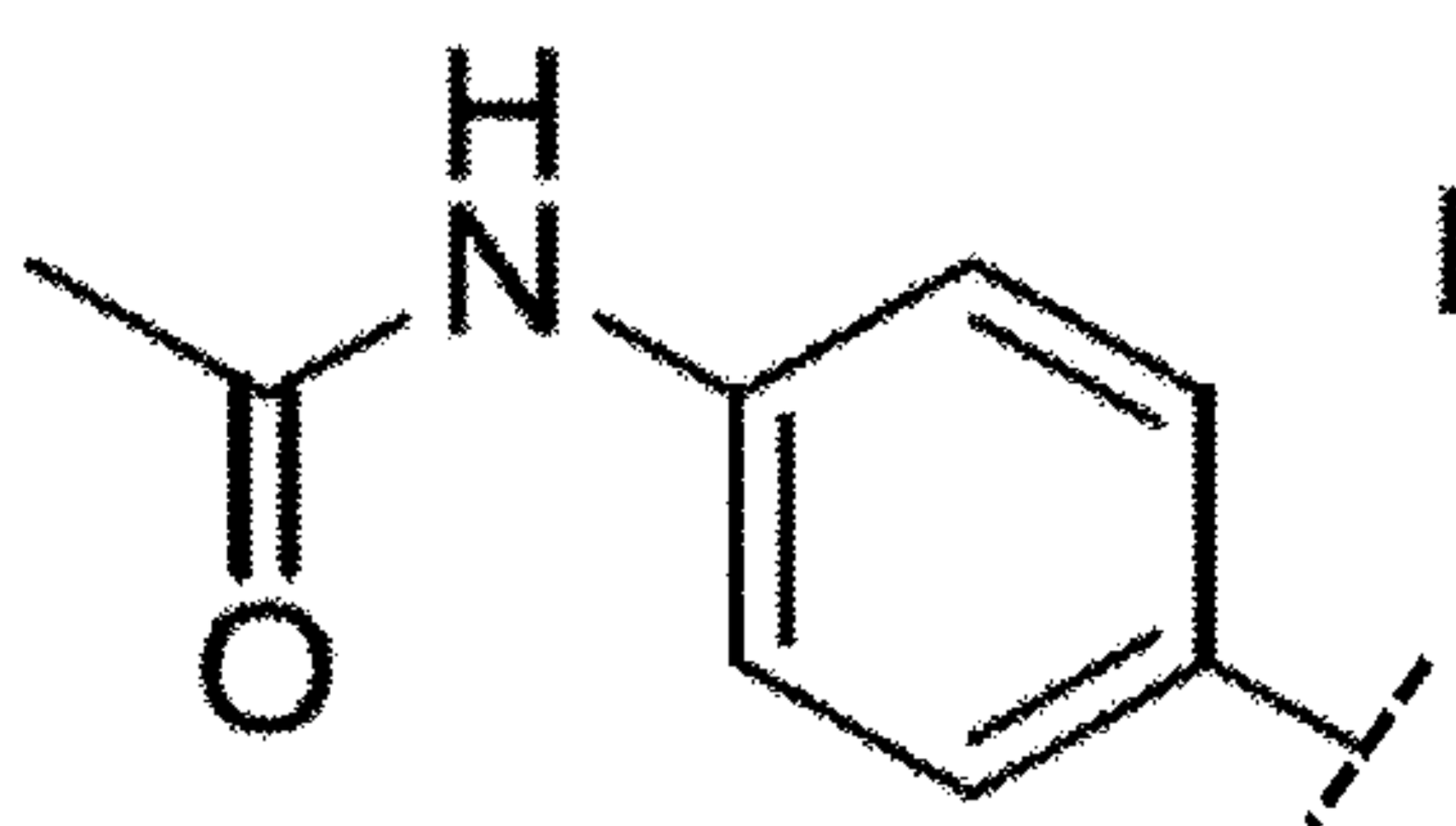
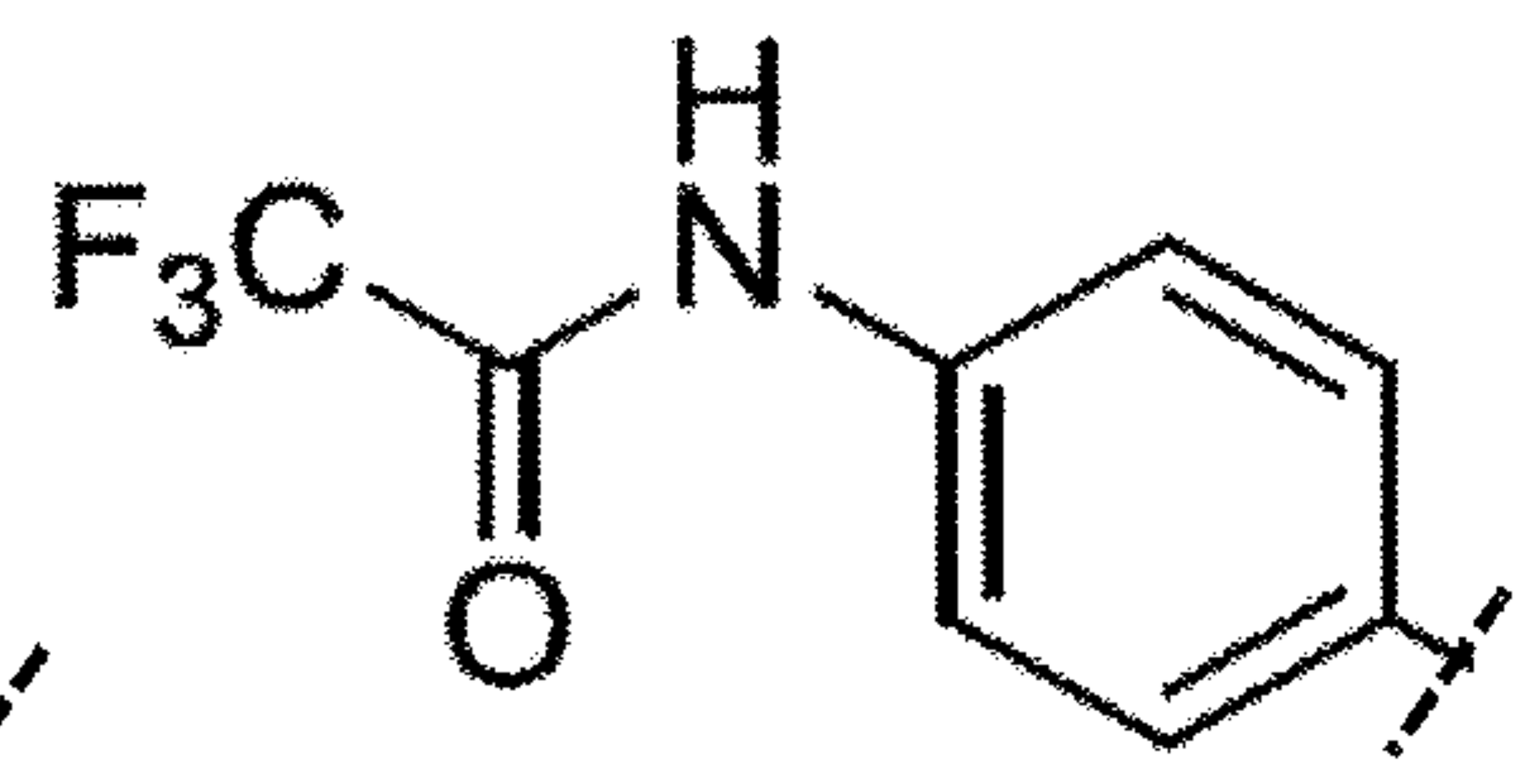
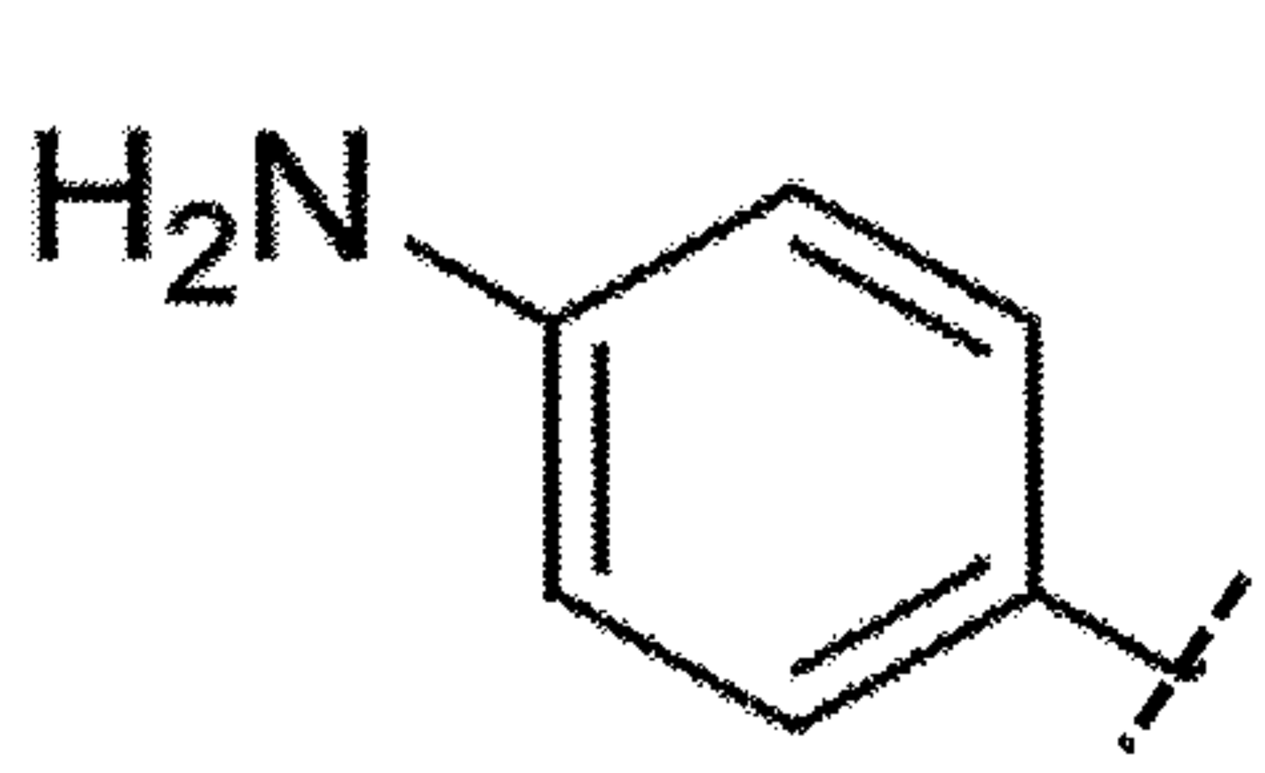
2. The compound according to claim 1, wherein R_2 is C_1-C_{10} alkyl, preferably a branched alky, more preferably $-C(CH_3)_3$, preferably R_3 is H, -OH or –OMe, and preferably R_4 is H, -OH or -OMe.

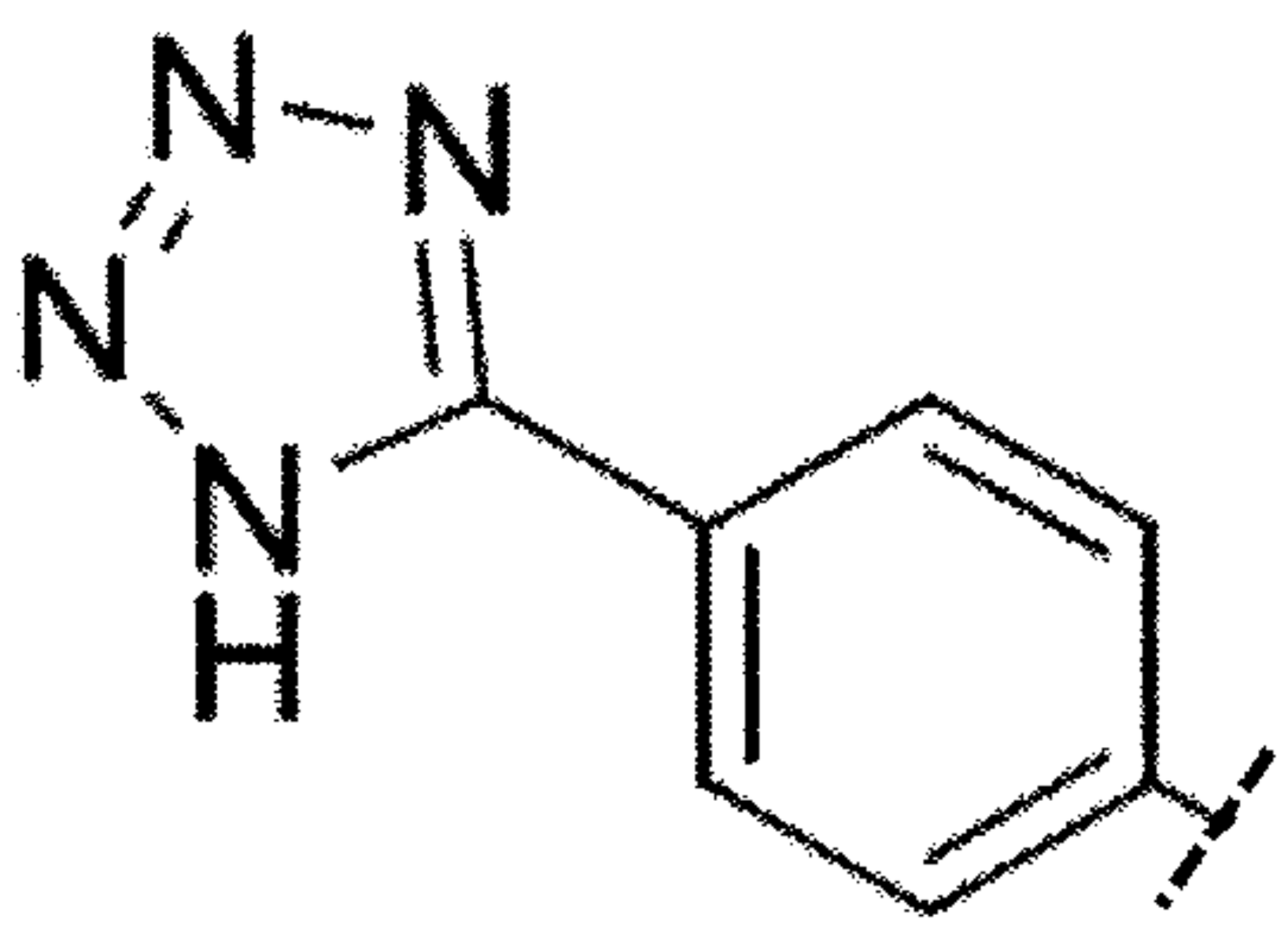
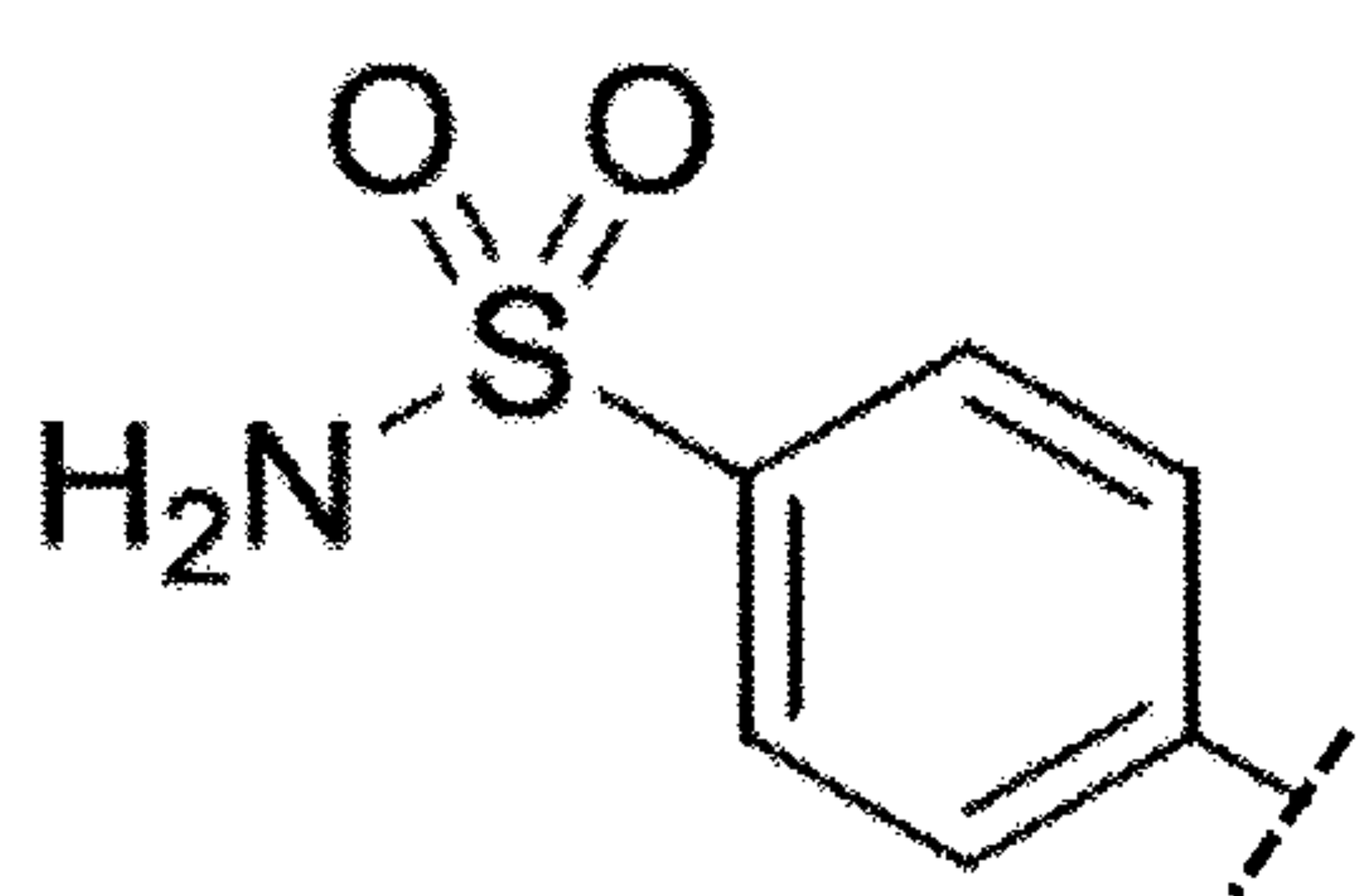
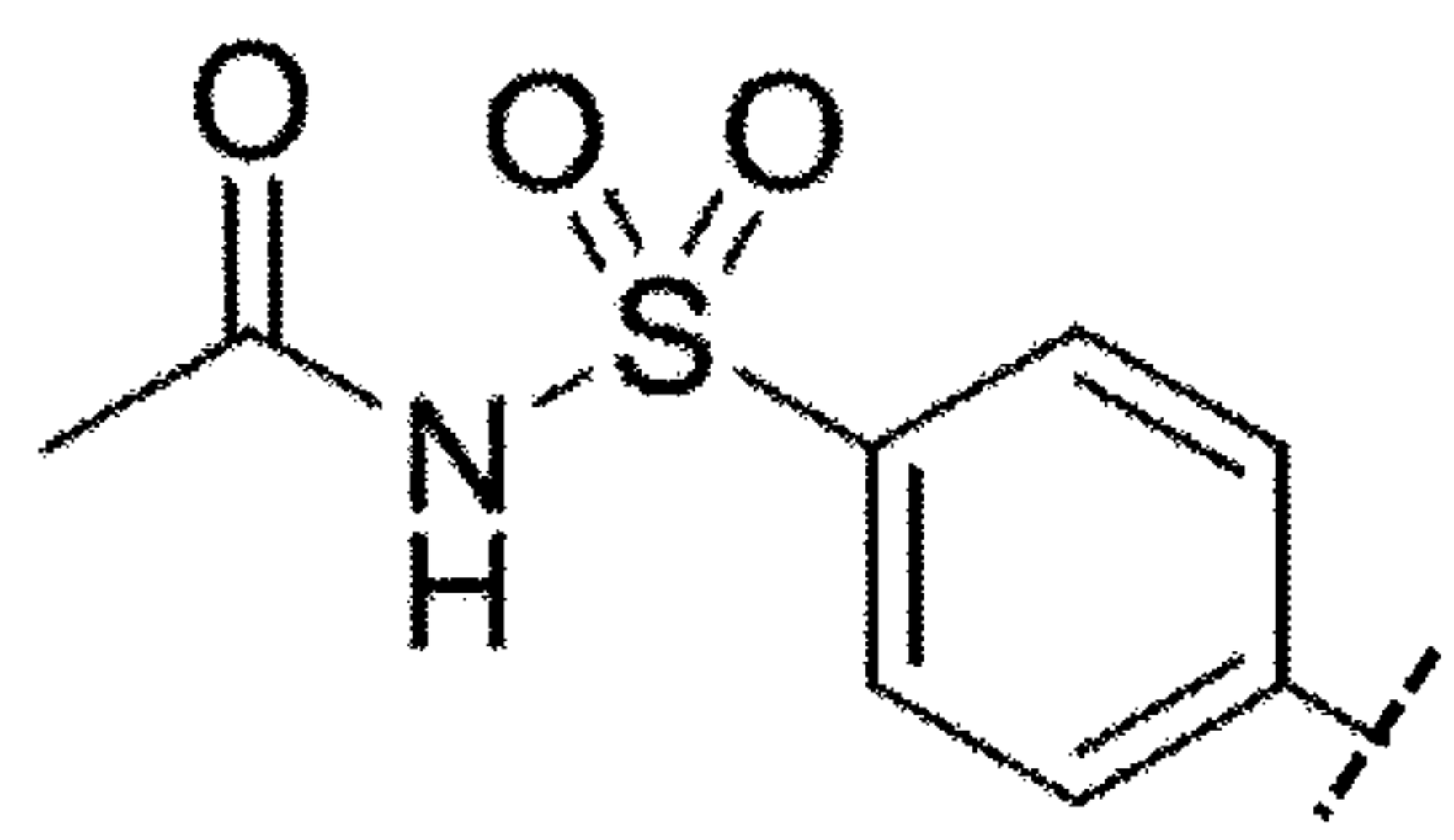
3. The compound according to claim 1 or 2, wherein R_1 is a mono or polysubstituted aryl.

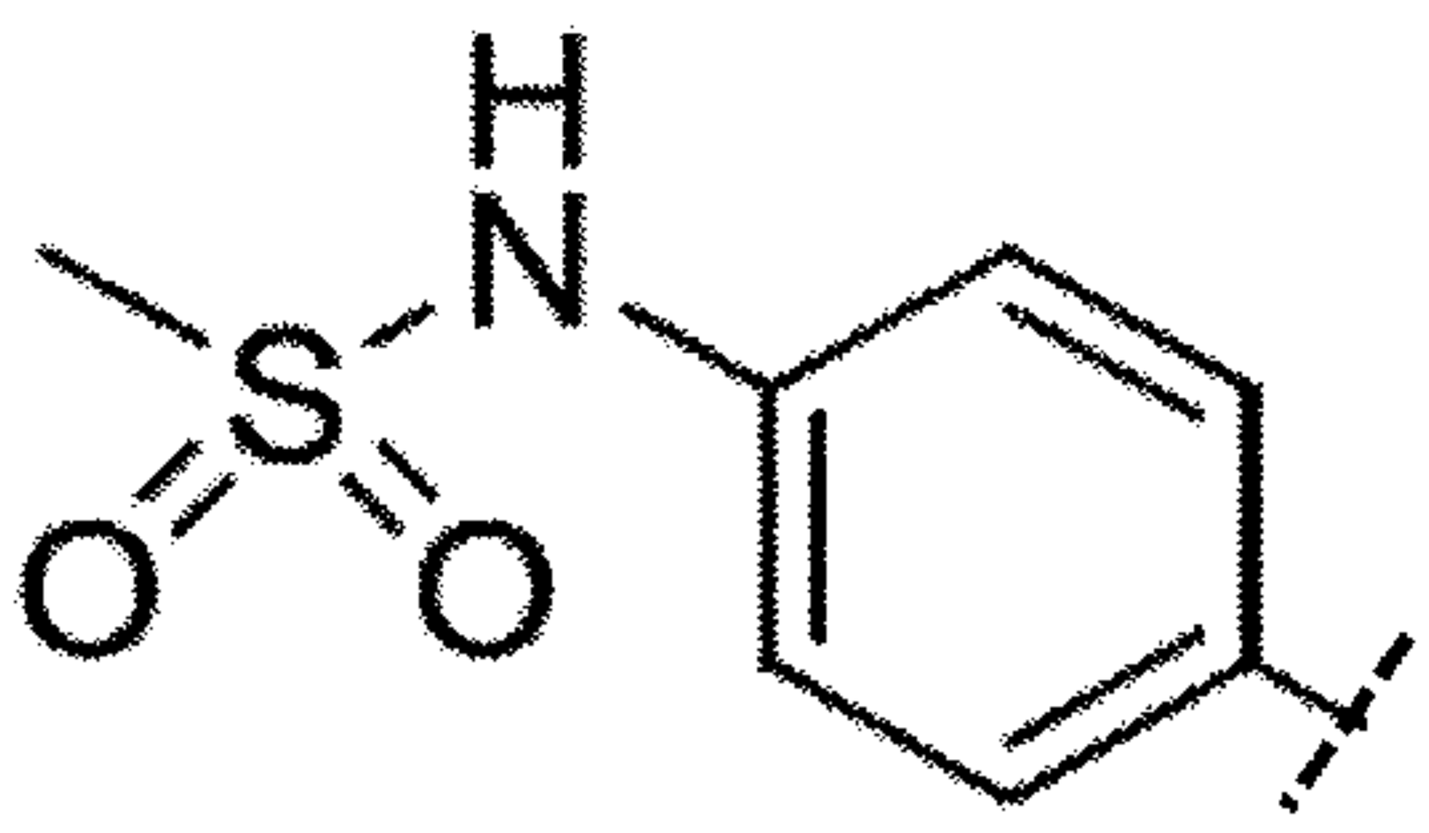
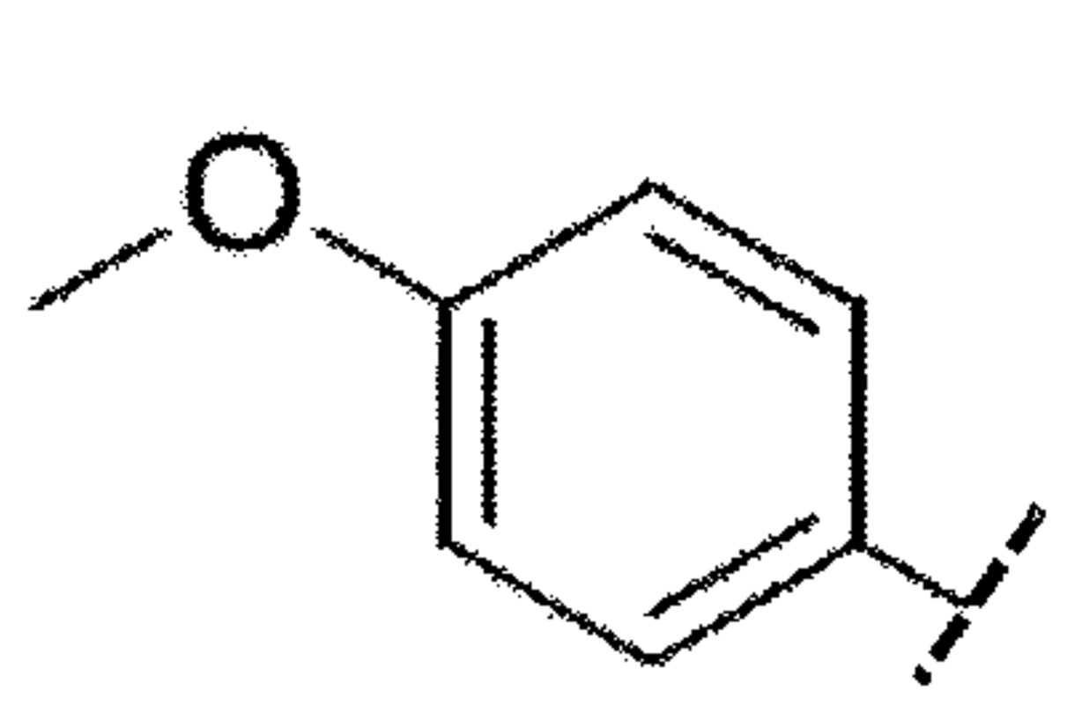
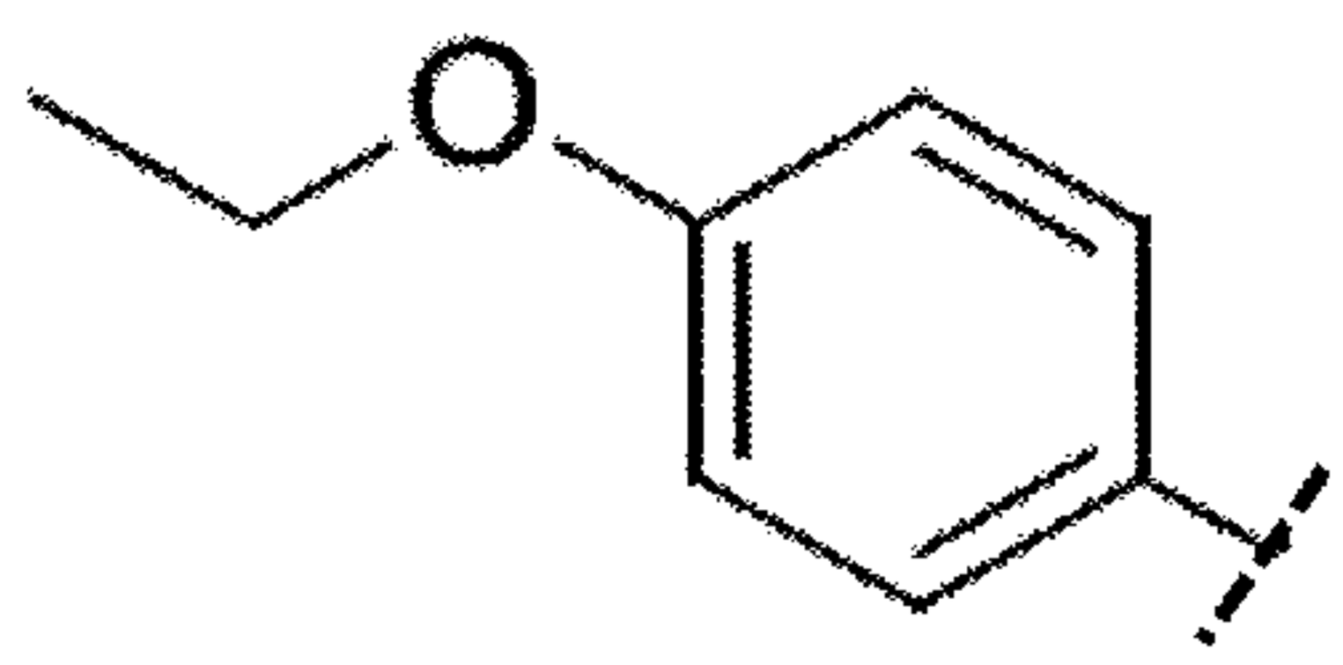
4. The compound according to claim 3, wherein R_1 is selected from any of the following groups:

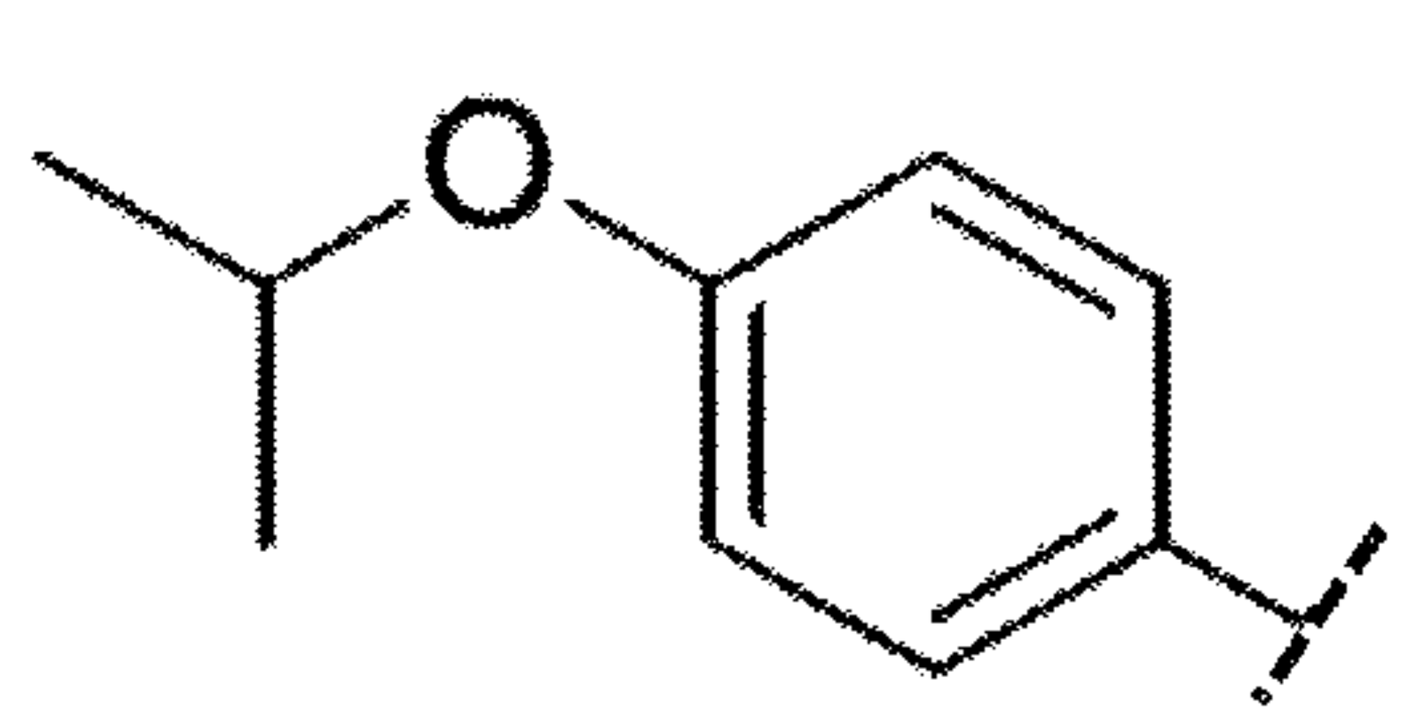
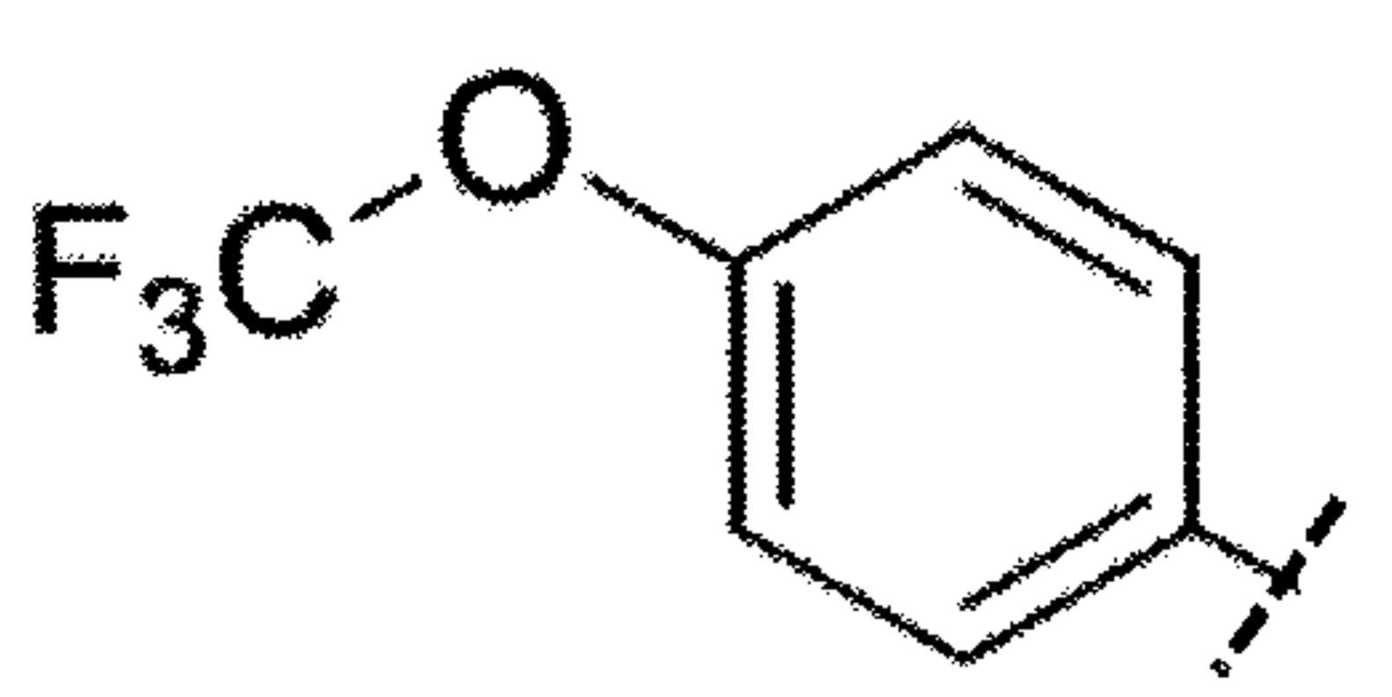
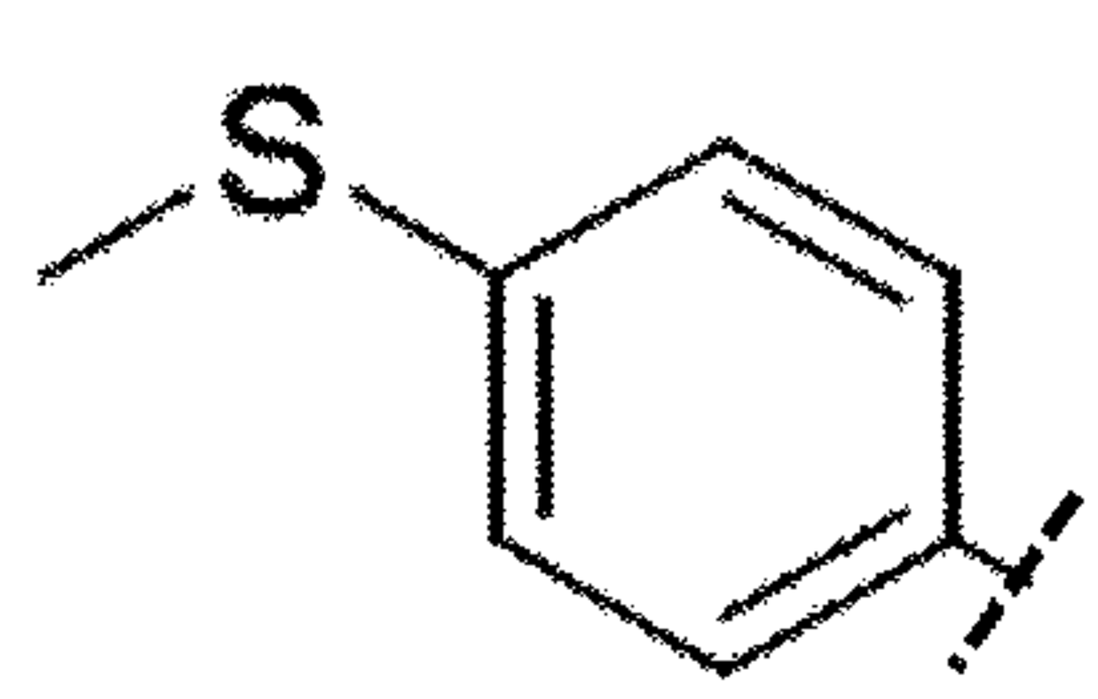
 ,
 ,
 ,

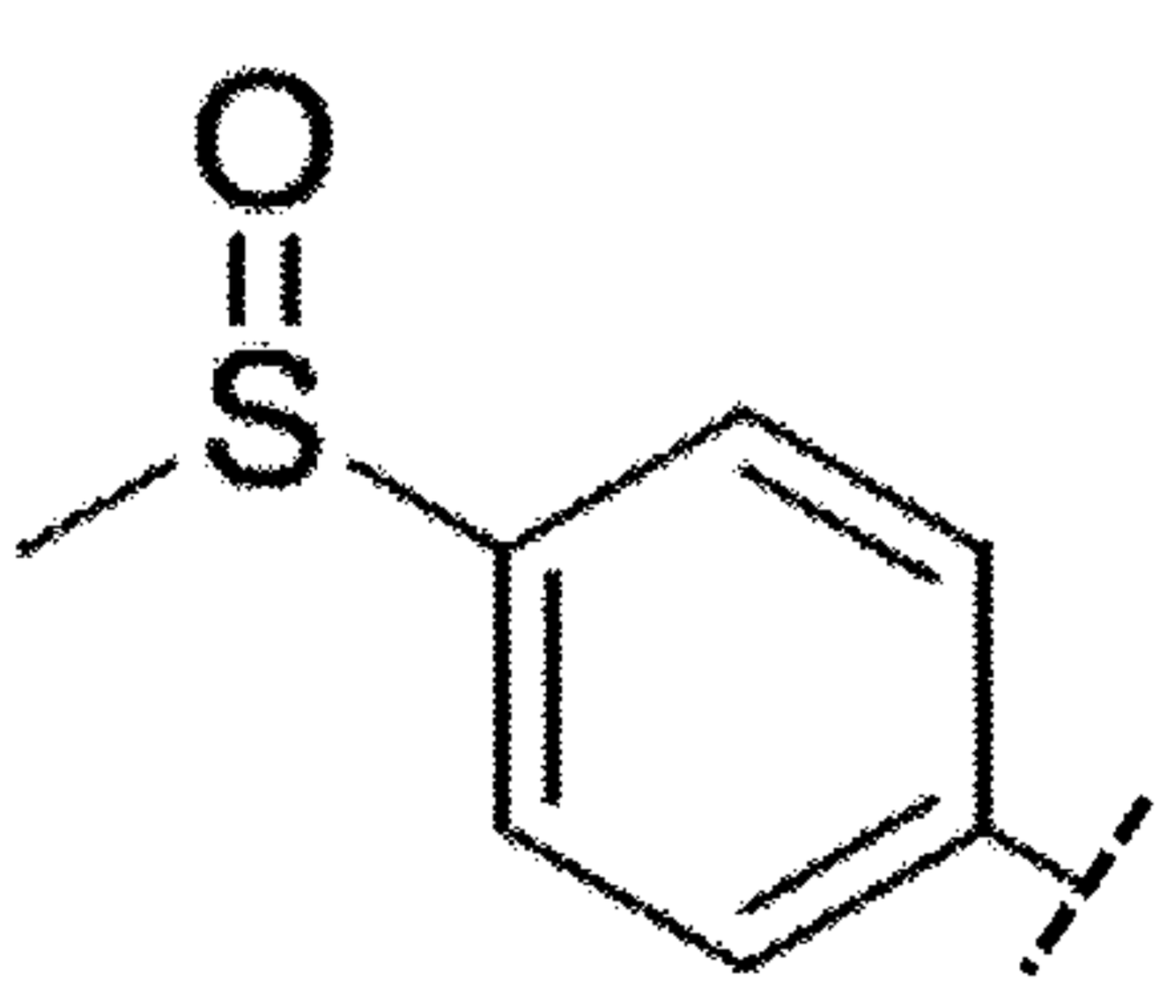
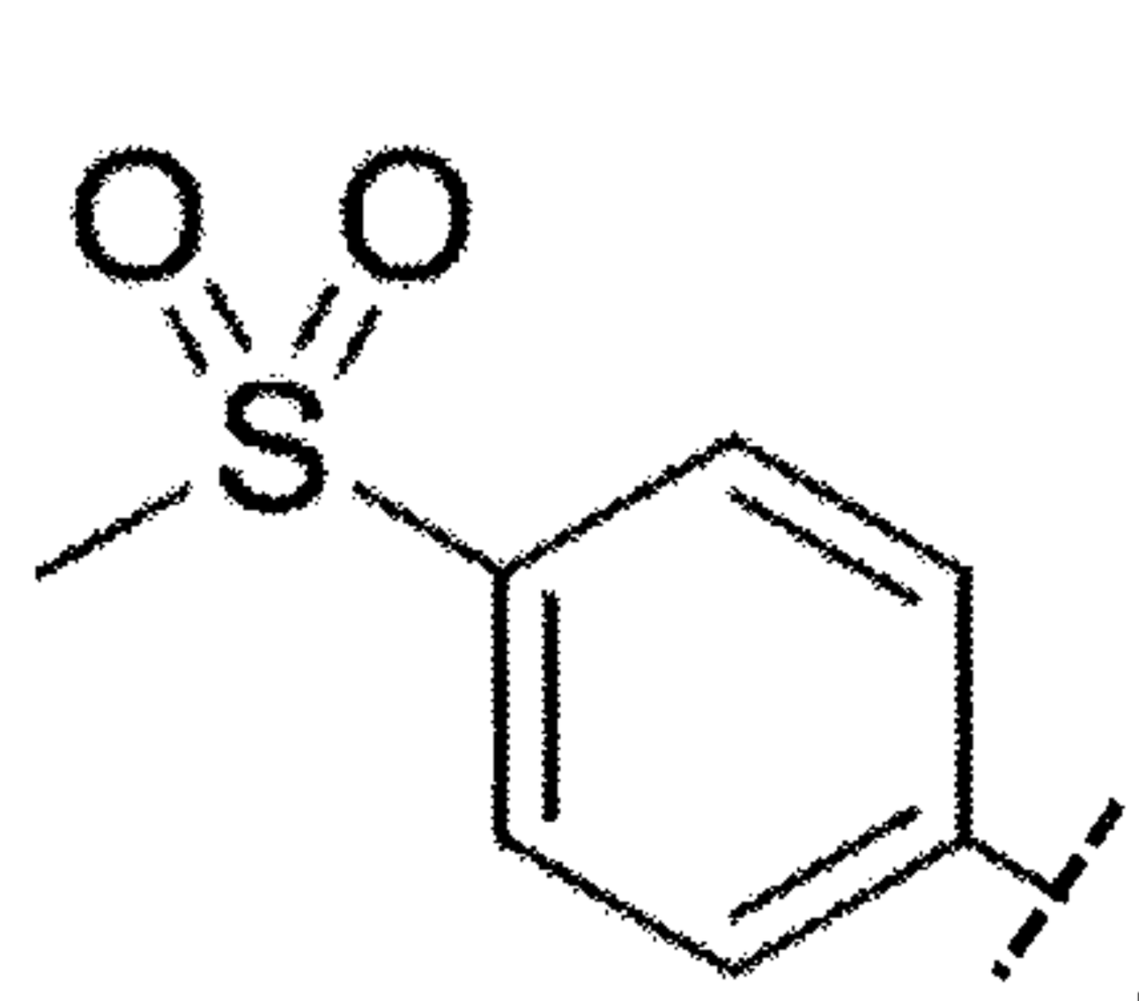
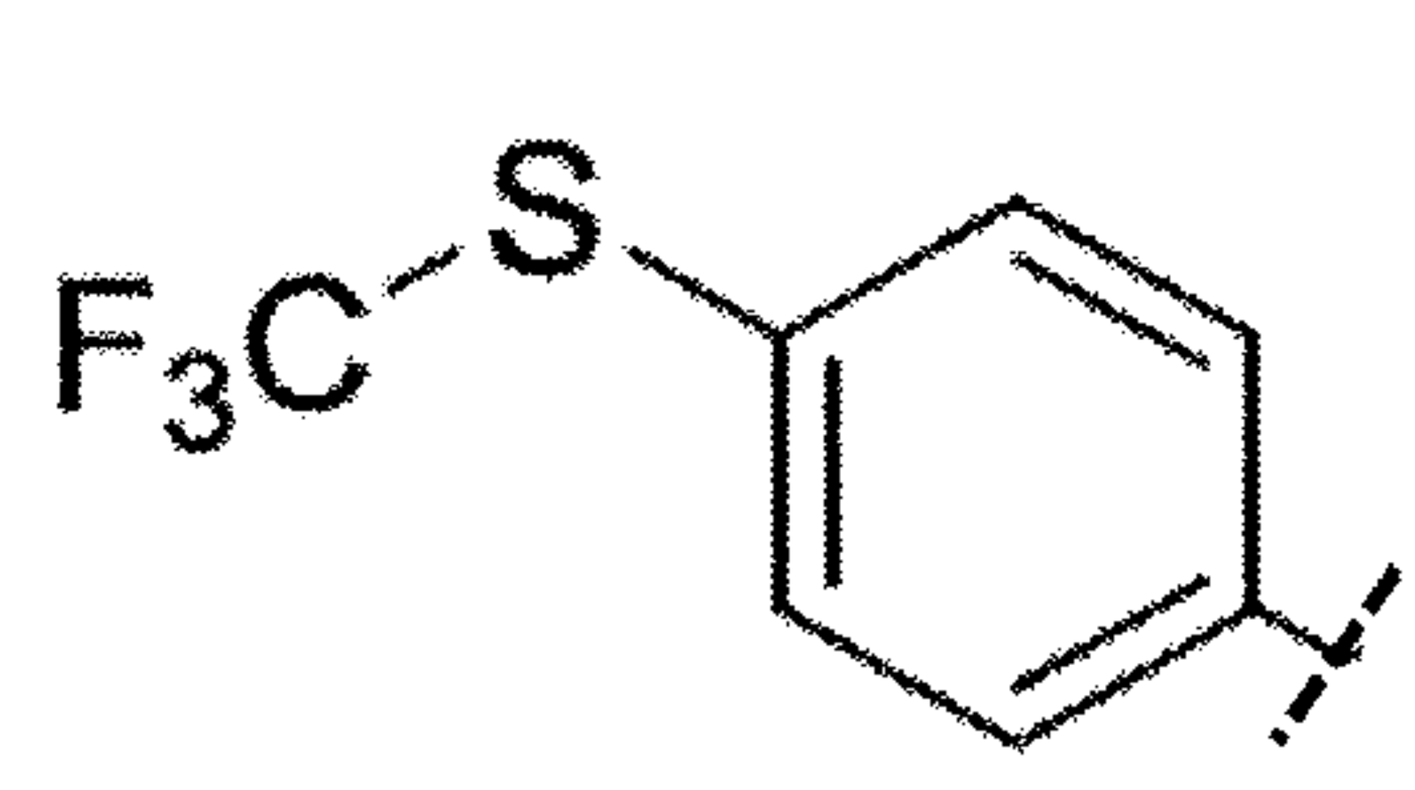
 ,
 ,
 ,

 ,
 ,
 ,

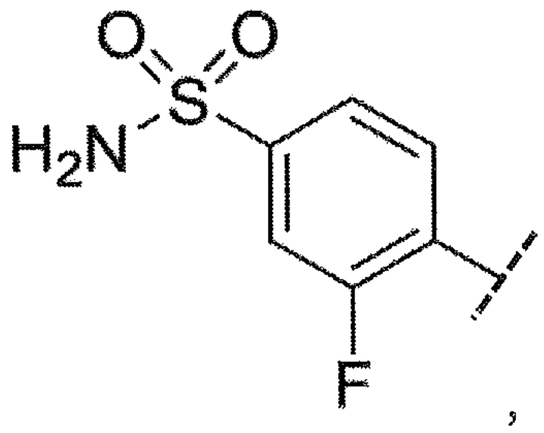
 ,
 ,
 ,

 ,
 ,
 ,

 ,
 ,
 ,

 ,
 , or
 .

5. The compound according to any of claims 1 to 3, wherein R_1 is selected from the group consisting of: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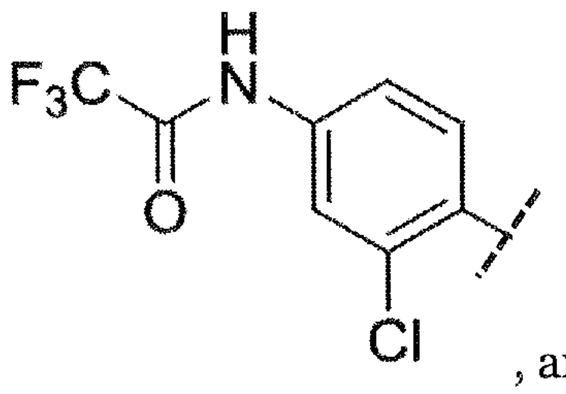
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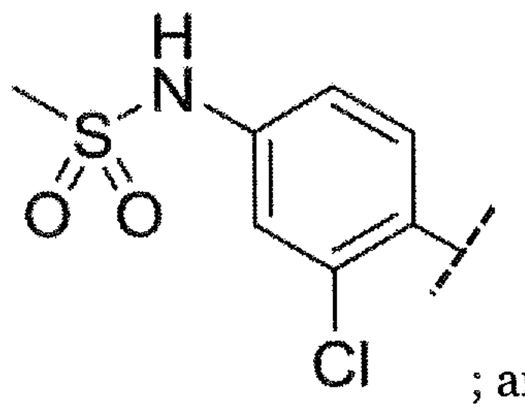
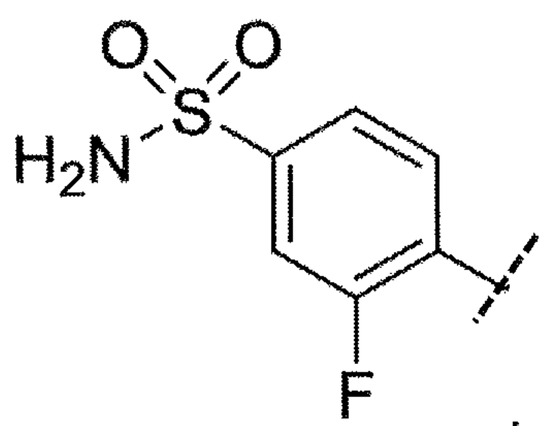

; and

wherein Z is C, R_2 is $-C(CH_3)_3$, and R_3 is H.

6. The compound according to any of claims 1 to 3, wherein R_1 is selected from the group consisting of: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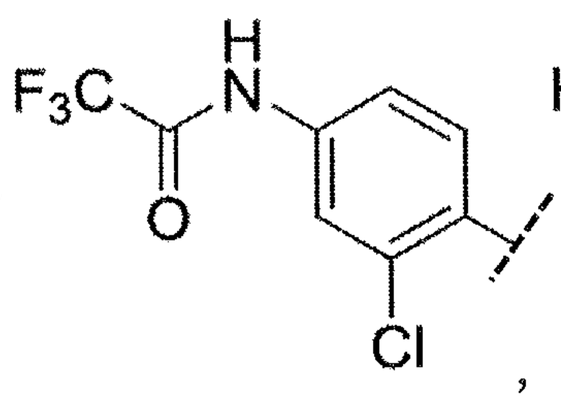
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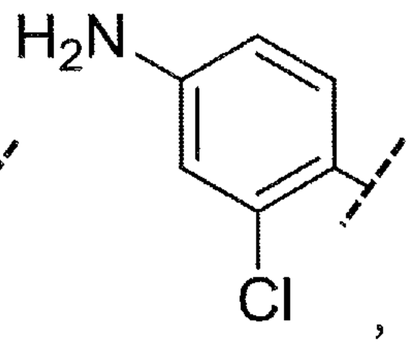
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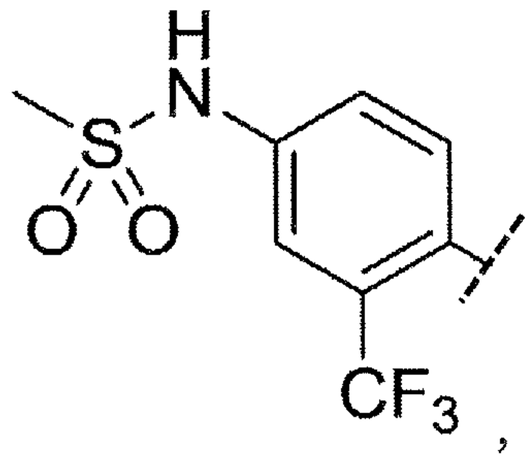
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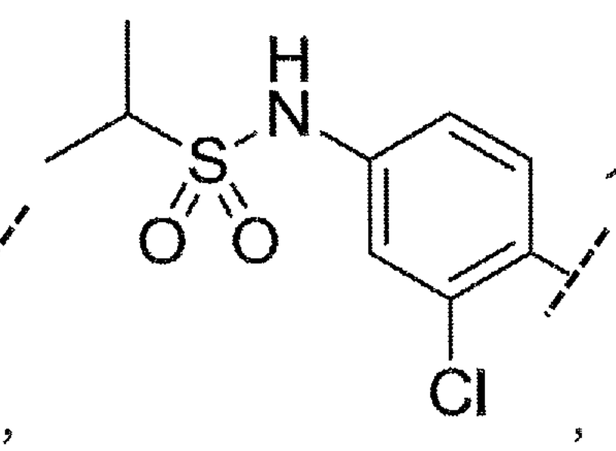
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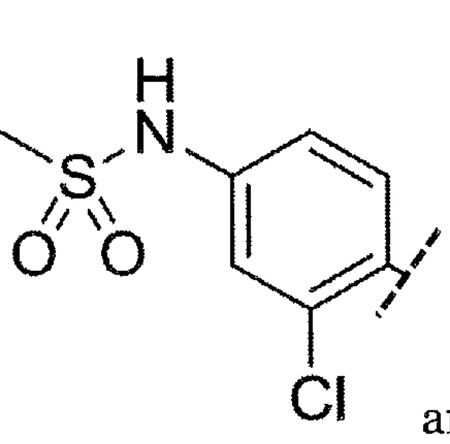
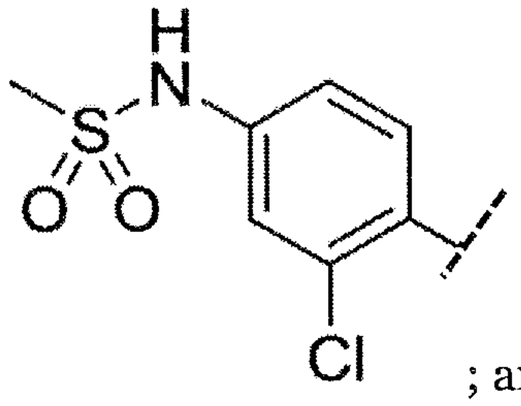
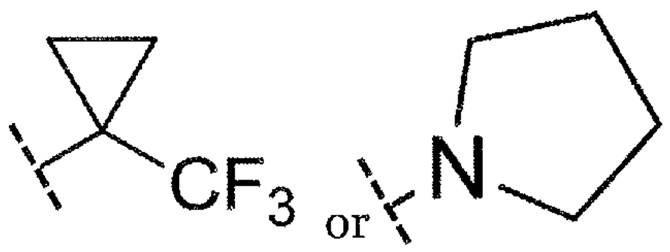

and


; and

wherein Z is C, R_3 is H or OH, and R_4 is H or OH, in particular R_3 and R_4 are not both OH; and wherein R_2 is selected from $-C(CH_3)_3$, $-N(CH_3)_2$, or the R_2 is any of the following structures:


.

7. The compound according to any one of claims 1 to 6, which is a farnesoid X receptor (FXR) agonist and a soluble epoxide hydrolase (sEH) inhibitor.

8. The compound according to any one of claims 1 to 7, for use in the treatment of a disease.

9. The compound for use according to claim 8, wherein the disease is a disorder associated with FXR and sEH.

10. The compound for use according to claim 8, wherein the disease is a metabolic disorder, preferably a metabolic disorder caused by or associated with a high-fat diet.

11. The compound for use according to any one of claims 8to 10, wherein the disease is a liver disease, such as non-alcoholic fatty liver disease or non-alcoholic steatohepatitis (NASH).

12. A method for producing a compound according to any one of claims 1 to 7.

13. A pharmaceutical composition comprising a compound according to any one of claims 1 to 6, together with a pharmaceutical acceptable carrier and/or excipient.

14. A method for concomitant modulation of FXR and sEH, the method comprising the step of administering to a subject a compound according to any one of claims 1 to 7, or of a pharmaceutical composition according to claim 13.

15. The method according to claim 14, wherein the subject is suffering from a disease, preferably a metabolic disease.

16. The method according to claim 15, wherein the method is a method of treating the disease of the subject by administering said compound to the subject.

17. The method according to claim 14, wherein modulation is an activation of FXR and inhibition of sEH.

18. The method according to any one of claims 14 to 17, wherein administering comprising administering the compound in a therapeutically effective amount to the subject.

19. A method of treating a disease in subject, the method comprising a step of administering to the subject a therapeutically effective amount of the compound according to any one of claims 1 to 7, or of the pharmaceutical composition according to claim 13.

20. The method according to any one of claims 14 to 19, wherein the subject is a mammal, preferably a mouse, rat, donkey, horse, cat, dog, guinea pig, monkey, ape, or preferably is a human patient.

21. The method according to any one of claims 16 to 20, wherein the disease is a metabolic disorder, preferably a metabolic disorder caused by or associated with a high-fat diet.

22. The method according to any one of claims 16 to 21, wherein the disease is a liver disease, such as non-alcoholic fatty liver disease or non-alcoholic steatohepatitis (NASH).

FIGURES

Figure 1:

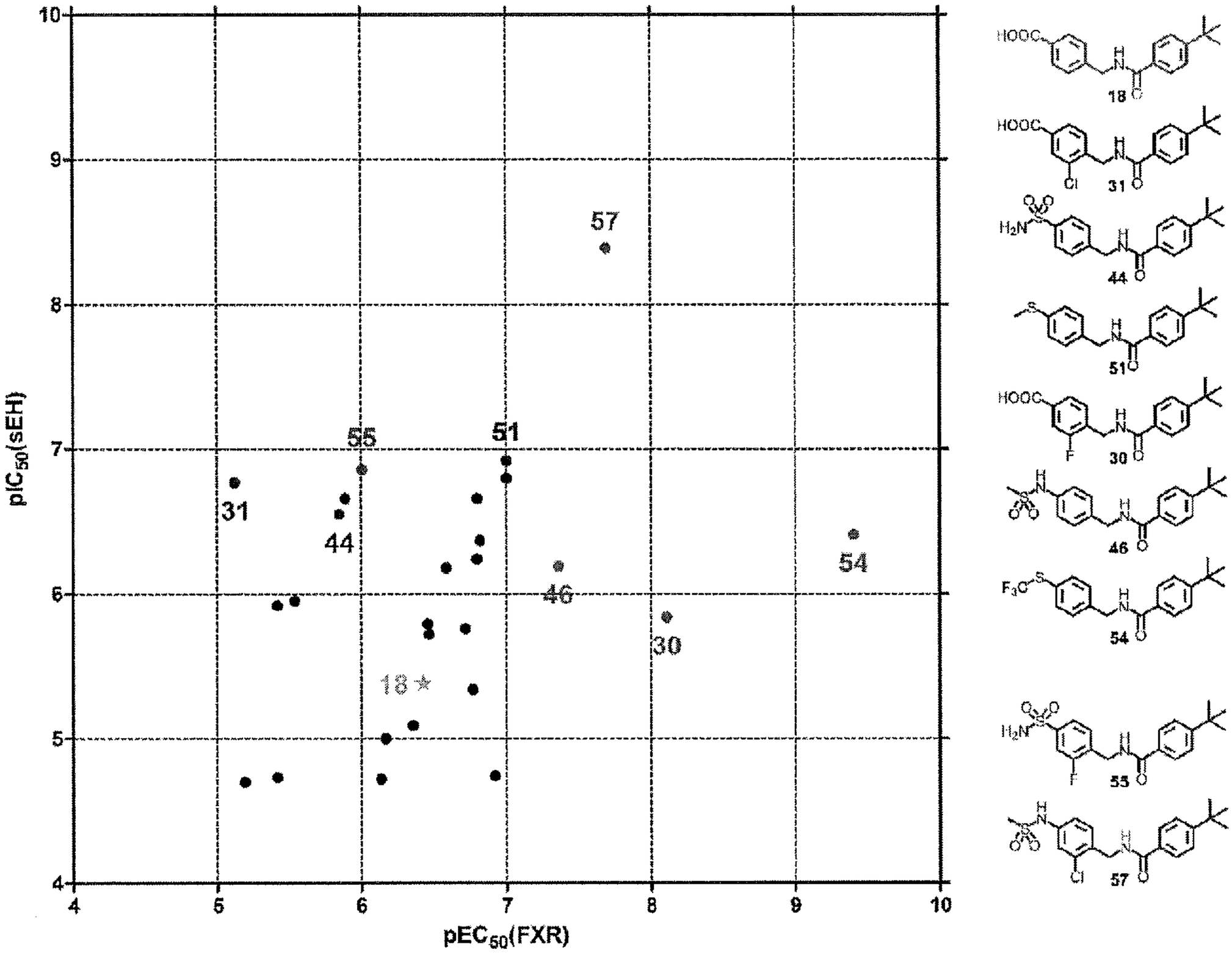


Figure 2:

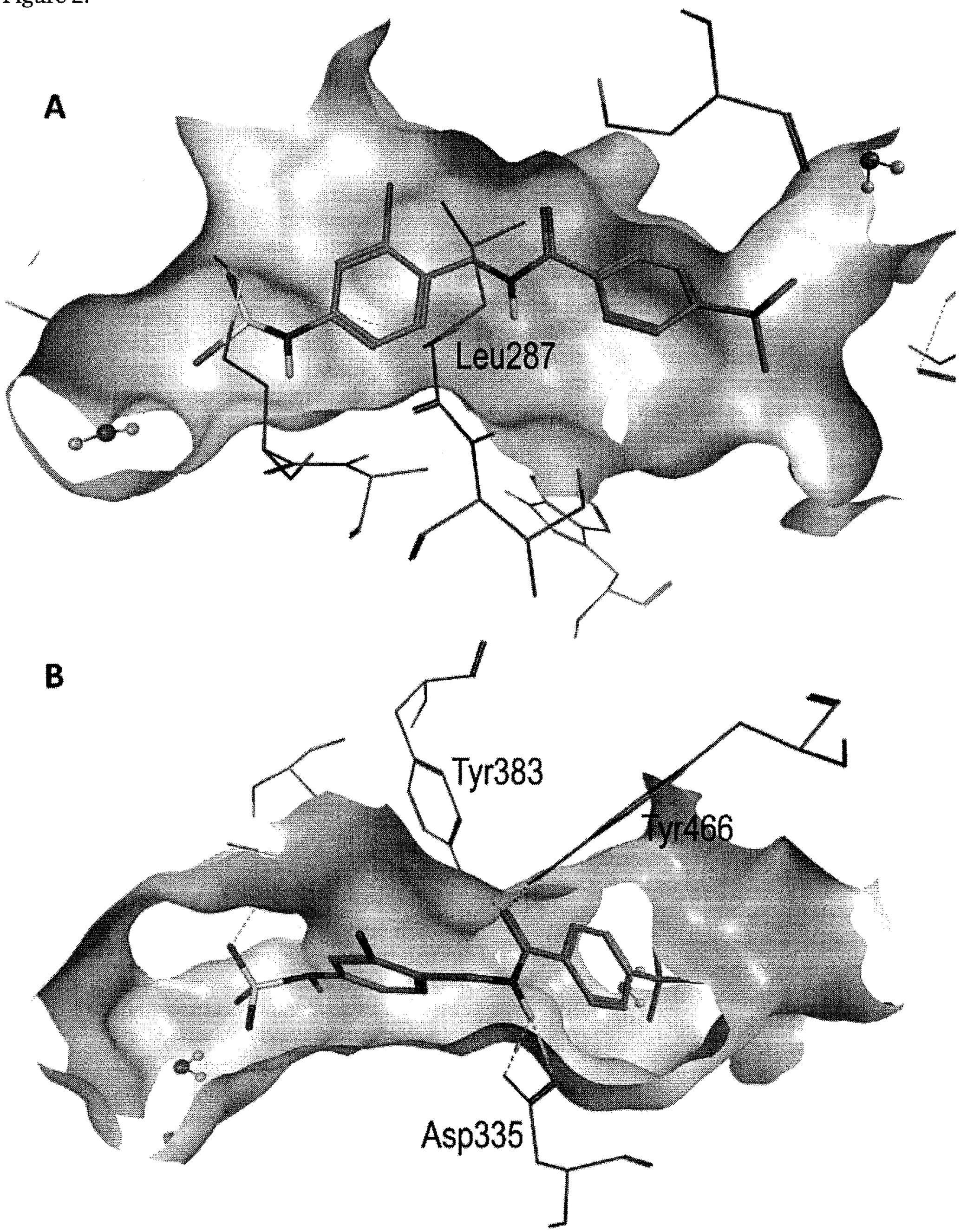


Figure 3:

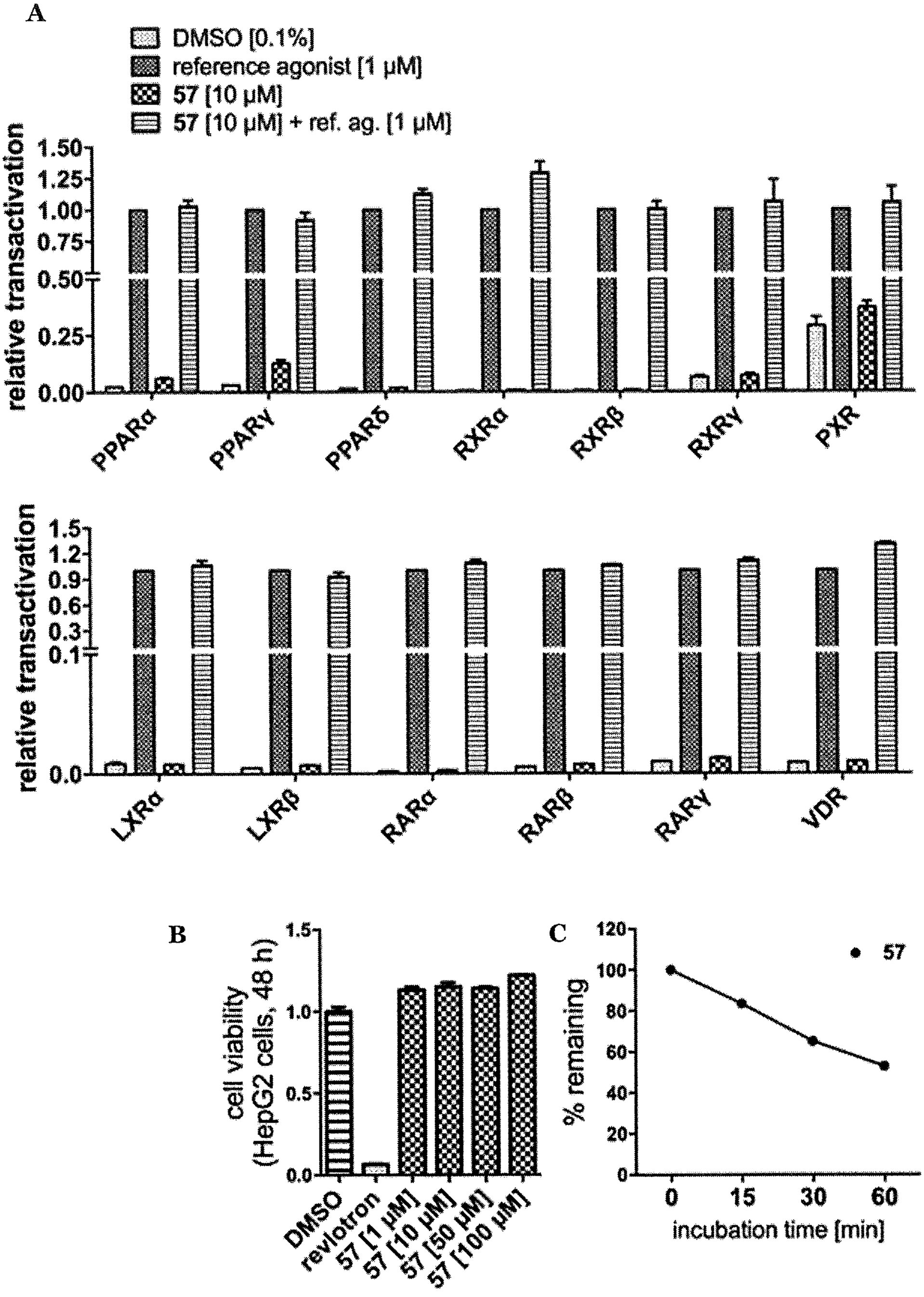

A
DMSO [0.1%]
reference agonist [1 µM]
57 [10 µM]
57 [10 µM] + ref. ag. [1 µM]
relative transactivation
1.50
1.25
1.00
0.75
0.50
0.25
0.00
PPARα
PPARγ
PPARδ
RXRα
RXRβ
RXRγ
PXR
relative transactivation
1.5
1.2
0.9
0.6
0.3
0.1
0.0
LXRα
LXRβ
RARα
RARβ
RARγ
VDR
B
cell viability (HepG2 cells, 48 h)
1.5
1.0
0.5
0.0
DMSO
revlotron
57 [1 µM]
57 [10 µM]
57 [50 µM]
57 [100 µM]
C
% remaining
120
100
80
60
40
20
0
57
0
15
30
60
incubation time [min]

Figure 4:

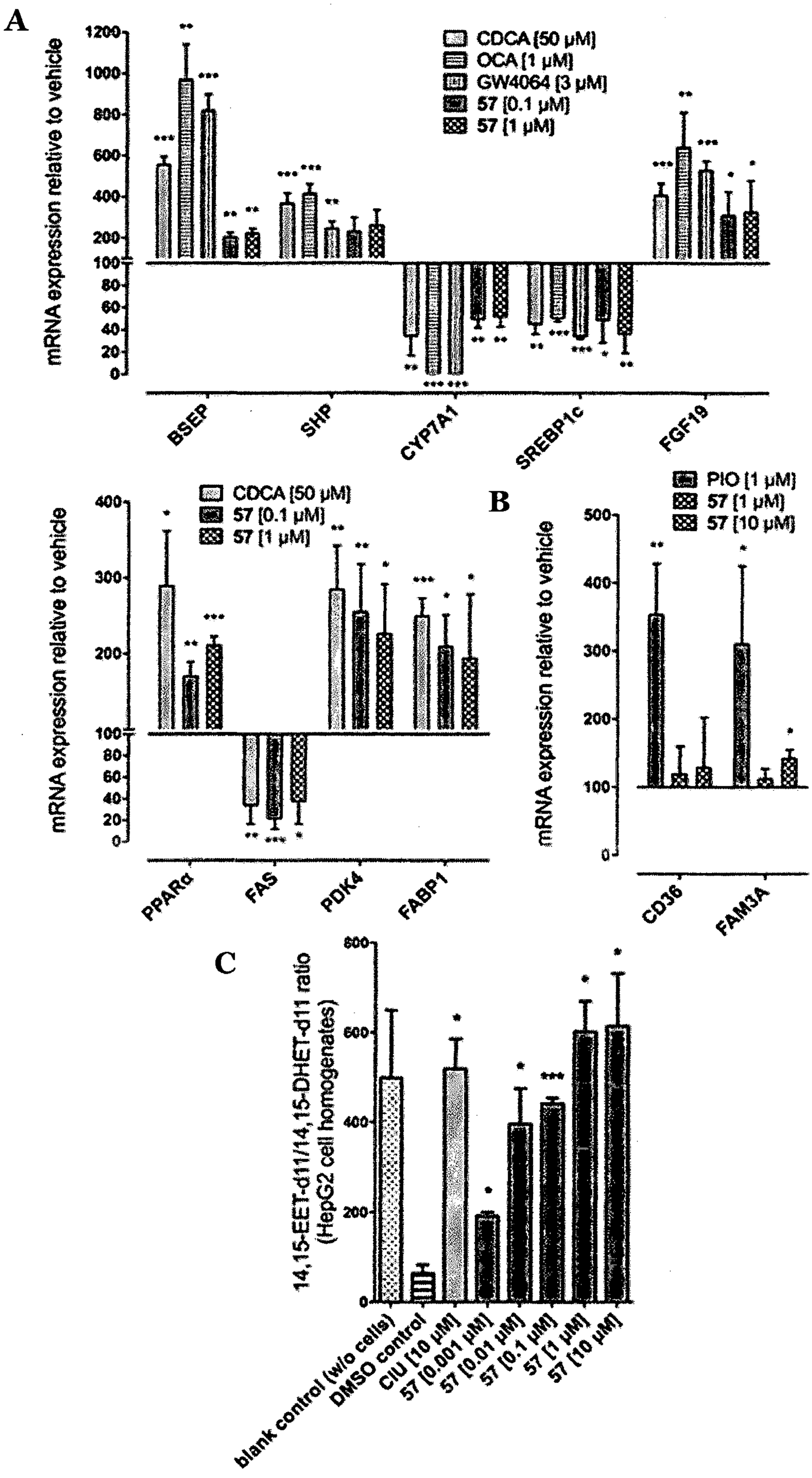

A
CDCA (50 µM)
OCA (1 µM)
GW4064 (3 µM)
57 (0.1 µM)
57 (1 µM)
mRNA expression relative to vehicle
BSEP
SHP
CYP7A1
SREBP1c
FGF19
B
CDCA (50 µM)
57 (0.1 µM)
57 (1 µM)
PIO (1 µM)
57 (1 µM)
57 (10 µM)
mRNA expression relative to vehicle
PPARα
FAS
PDK4
FABP1
CD36
FAM3A
C
14,15-EET-d11/14,15-DHET-d11 ratio (HepG2 cell homogenates)
blank control (w/o cells)
DMSO control
CIU (10 µM)
57 (0.001 µM)
57 (0.01 µM)
57 (0.1 µM)
57 (1 µM)
57 (10 µM)

Figure 5:

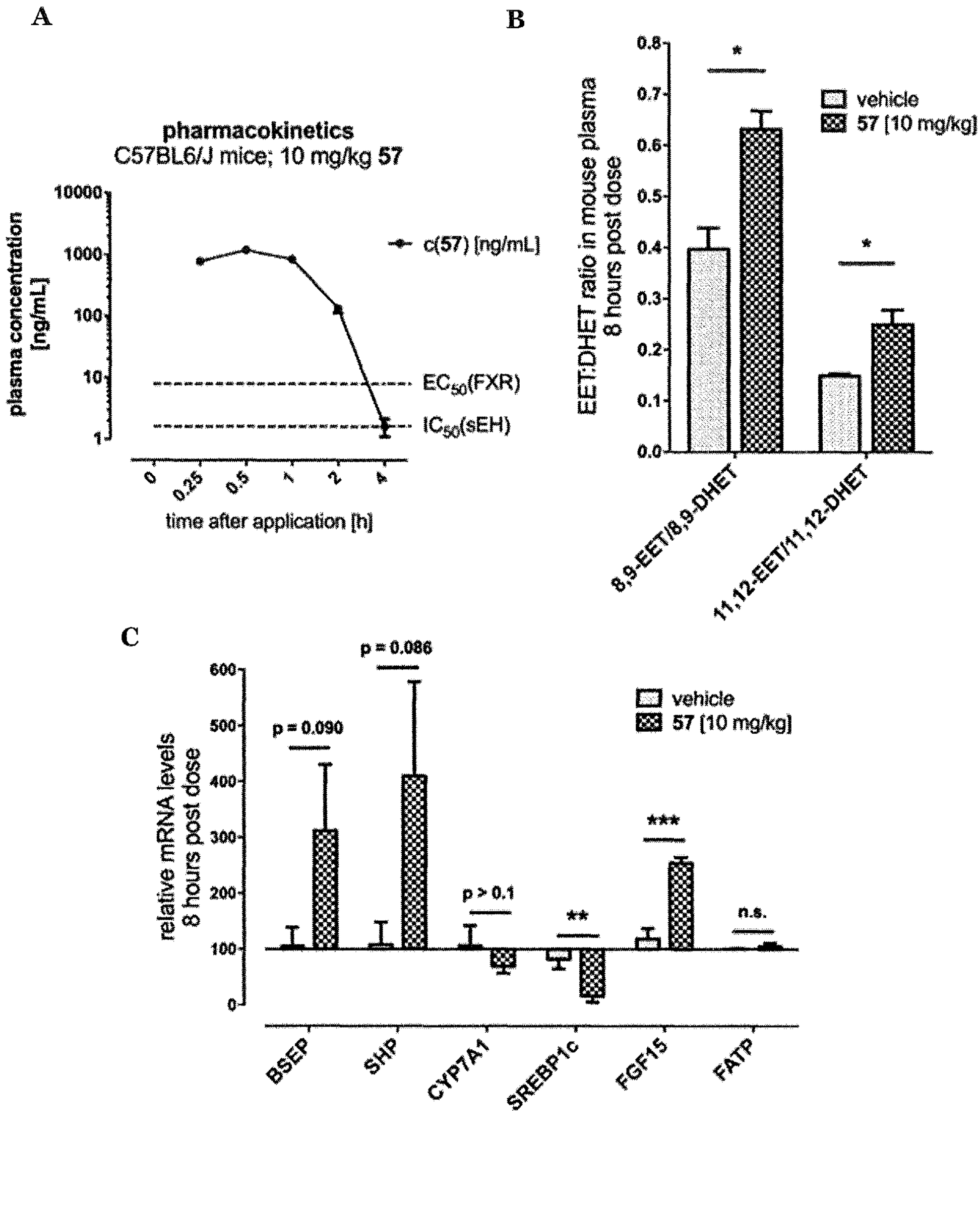

A
pharmacokinetics
C57BL6/J mice; 10 mg/kg 57
plasma concentration [ng/mL]
10000
1000
100
10
1
c(57) [ng/mL]
EC50(FXR)
IC50(sEH)
0
0.25
0.5
1
2
4
time after application [h]
B
EET:DHET ratio in mouse plasma 8 hours post dose
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
*
*
vehicle
57 [10 mg/kg]
8,9-EET/8,9-DHET
11,12-EET/11,12-DHET
C
relative mRNA levels 8 hours post dose
600
500
400
300
200
100
0
p = 0.086
p = 0.090
p > 0.1
**
***
n.s.
vehicle
57 [10 mg/kg]
BSEP
SHP
CYP7A1
SREBP1c
FGF15
FATP

Figure 6:

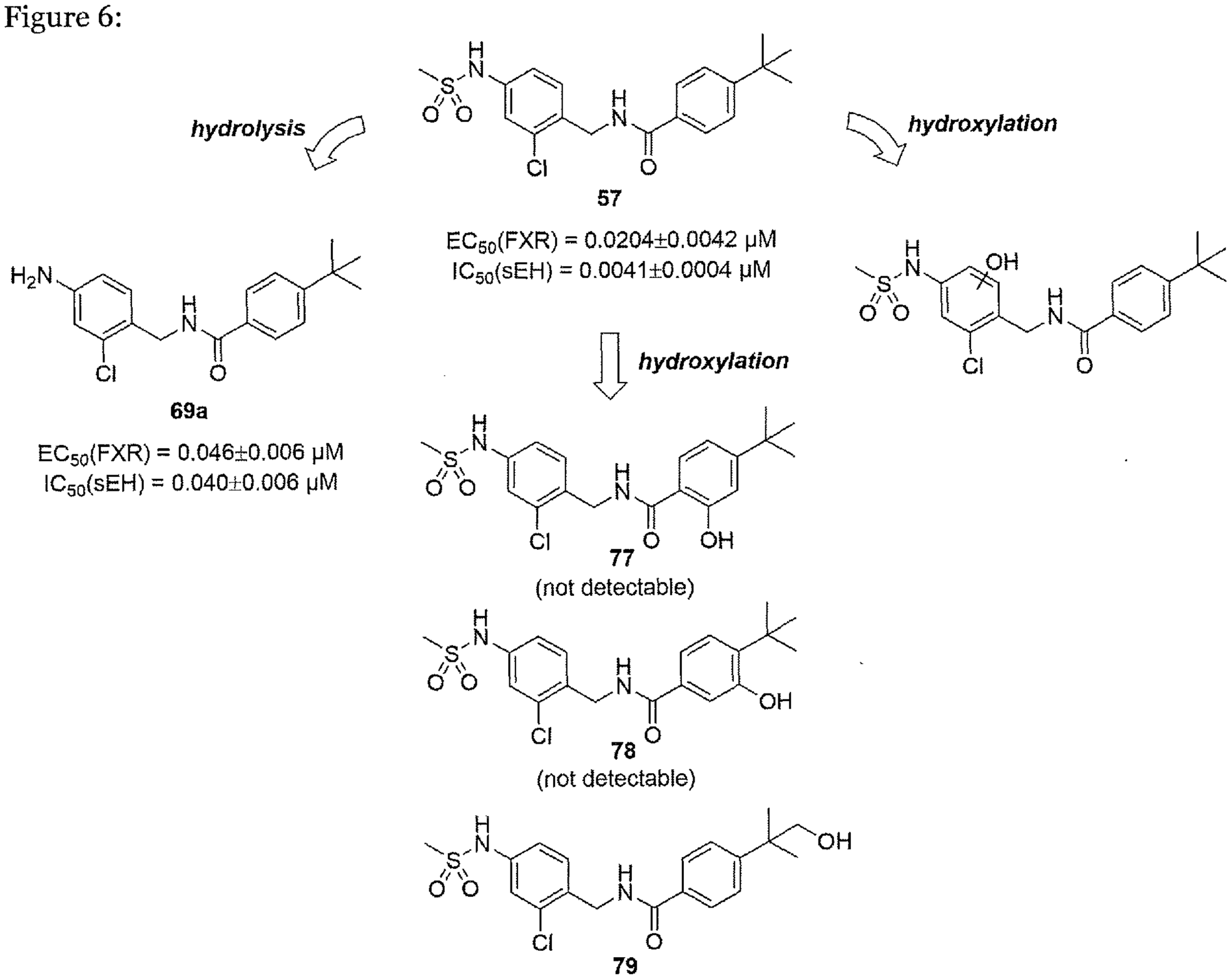
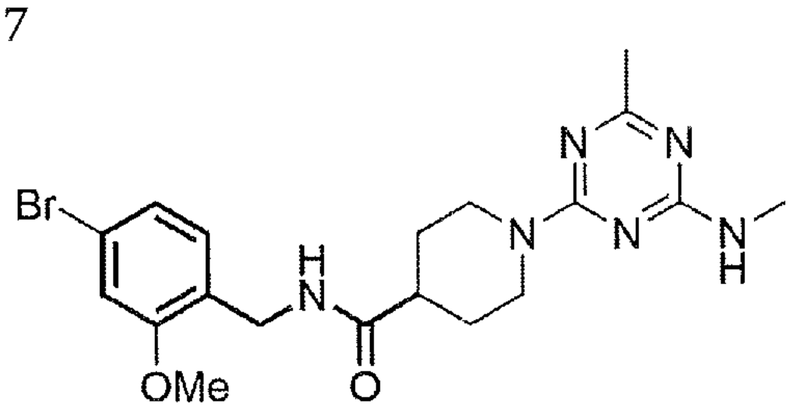
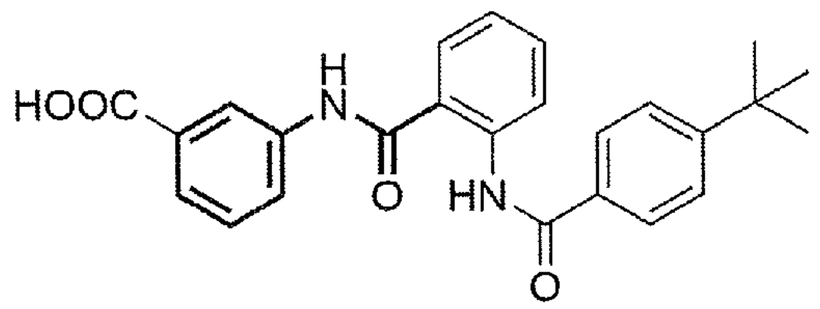

hydrolysis
hydroxylation
57
EC50(FXR) = 0.0204±0.0042 µM
IC50(sEH) = 0.0041±0.0004 µM
69a
EC50(FXR) = 0.046±0.006 µM
IC50(sEH) = 0.040±0.006 µM
hydroxylation
77
(not detectable)
78
(not detectable)
79

Figure 7



2



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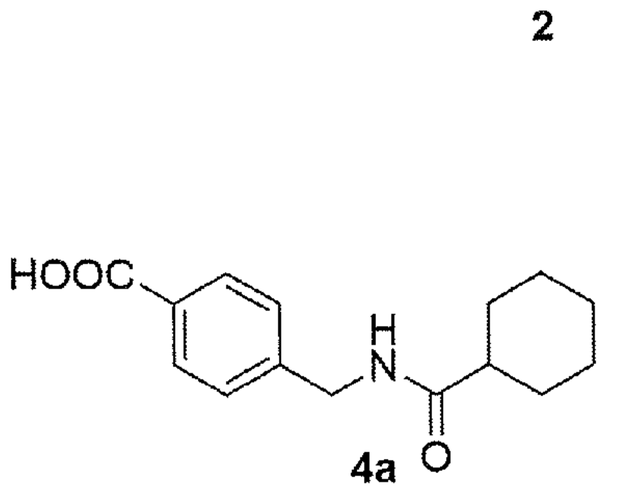
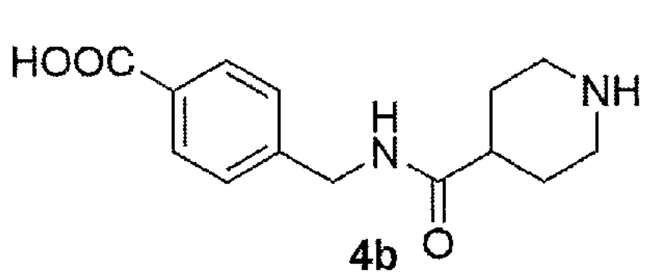


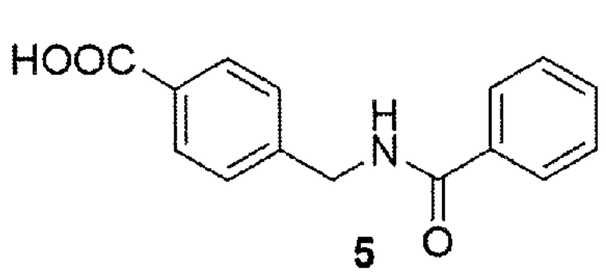
4a

37±1% sEH inhibition (50 µM)
inactive on FXR (50 µM)



4b

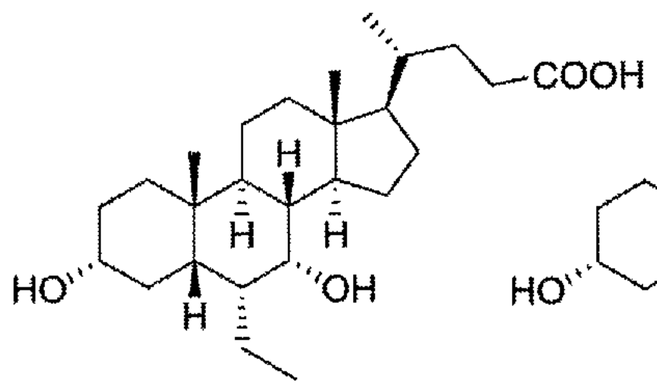
< 3% inhibition (50 µM)
inactive on FXR (50 µM)



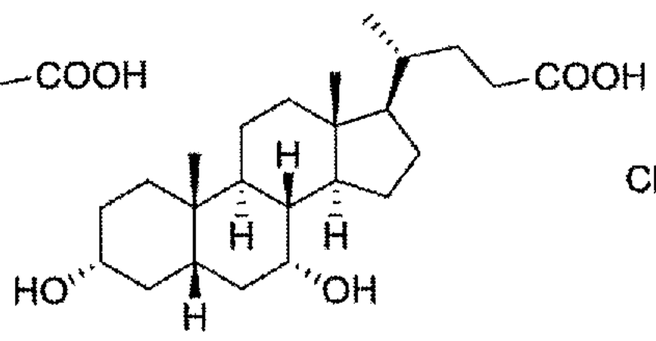
5

16±2% sEH inhibition (50 µM)
12±1% FXR activation (50 µM)

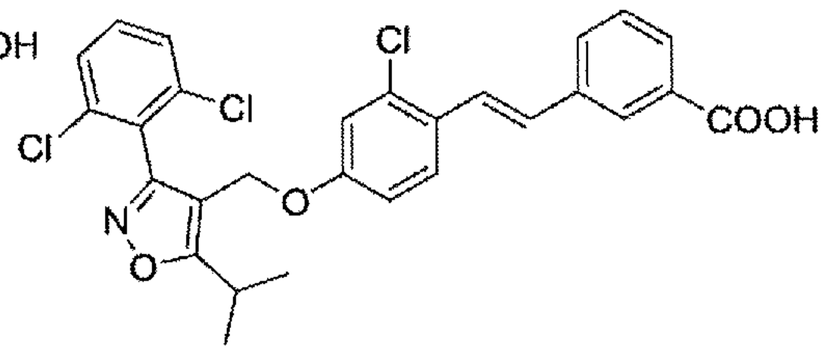
Figure 8:



obeticholic acid (OCA, **1a**)



chenodeoxycholic acid (CDCA, **1b**)



GW4064 (**1c**)