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THE CONCISE GUIDE TO PHARMACOLOGY 2015/16: Nuclear hormone receptors

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Abstract

The Concise Guide to PHARMACOLOGY 2015/16 provides concise overviews of the key properties of over 1750 human drug targets with their pharmacology, plus links to an open access knowledgebase of drug targets and their ligands (www.guidetopharmacology.org), which provides more detailed views of target and ligand properties. The full contents can be found at <http://onlinelibrary.wiley.com/doi/10.1111/bph.13352/full>. Nuclear hormone receptors are one of the eight major pharmacological targets into which the Guide is divided, with the others being: G protein-coupled receptors, ligand-gated ion channels, voltage-gated ion channels, other ion channels, catalytic receptors, enzymes and transporters. These are presented with nomenclature guidance and summary information on the best available pharmacological tools, alongside key references and suggestions for further reading. The Concise Guide is published in landscape format in order to facilitate comparison of related targets. It is a condensed version of material contemporary to late 2015, which is presented in greater detail and constantly updated on the website www.guidetopharmacology.org, superseding data presented in the previous Guides to Receptors & Channels and the Concise Guide to PHARMACOLOGY 2013/14. It is produced in conjunction with NC-IUPHAR and provides the official IUPHAR classification and nomenclature for human drug targets, where appropriate. It consolidates information previously curated and displayed separately in IUPHAR-DB and GRAC and provides a permanent, citable, point-in-time record that will survive database updates.

Conflict of interest

The authors state that there are no conflicts of interest to declare.

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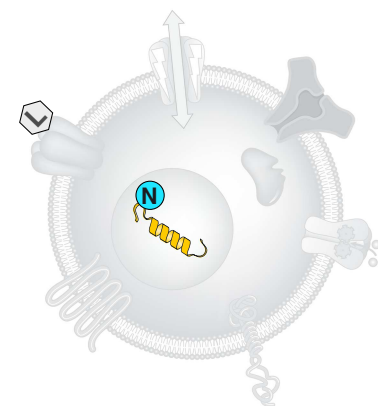
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Overview: Nuclear hormone receptors are specialised transcription factors with commonalities of sequence and structure, which bind as homo- or heterodimers to specific consensus sequences of DNA (response elements) in the promoter region of particular target genes. They regulate (either promoting or repressing) transcription of these target genes in response to a variety of endogenous ligands. Endogenous agonists are hydrophobic entities which, when bound to the receptor promote conformational changes in the receptor to allow recruitment (or dissociation) of protein partners, generating a large multiprotein complex.

Two major subclasses of nuclear receptors with identified endogenous agonists can be identified: steroid and non-steroid hormone receptors. Steroid hormone receptors function typically as dimeric entities and are thought to be resident outside the nucleus in the unliganded state in a complex with chaperone proteins, which are liberated upon agonist binding. Migration to the nucleus and interaction with other regulators of gene transcription, including RNA polymerase, acetyltransferases and deacetylases, allows gene transcription to be regulated. Non-steroid hormone receptors typically exhibit a greater distribution in the nucleus in the

unliganded state and interact with other nuclear receptors to form heterodimers, as well as with other regulators of gene transcription, leading to changes in gene transcription upon agonist binding.

Selectivity of gene regulation is brought about through interaction of nuclear receptors with particular consensus sequences of DNA, which are arranged typically as repeats or inverted palindromes to allow accumulation of multiple transcription factors in the promoter regions of genes.



Family structure

5958	1A. Thyroid hormone receptors	5965	2A. Hepatocyte nuclear factor-4 receptors	5972	5A. Fushi tarazu F1-like receptors
5959	1B. Retinoic acid receptors	5966	2B. Retinoid X receptors	5973	6A. Germ cell nuclear factor receptors
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5961	1D. Rev-Erb receptors	5968	2E. Tailless-like receptors	5975	Steroid hormone receptors
5962	1F. Retinoic acid-related orphans	5969	2F. COUP-TF-like receptors	5975	3A. Estrogen receptors
5963	1H. Liver X receptor-like receptors	5970	3B. Estrogen-related receptors	5976	3C. 3-Ketosteroid receptors
5964	1I. Vitamin D receptor-like receptors	5971	4A. Nerve growth factor 1B-like receptors		

1A. Thyroid hormone receptors

Nuclear hormone receptors → 1A. Thyroid hormone receptors

Overview: Thyroid hormone receptors (TRs, nomenclature as agreed by the **NC-IUPHAR Subcommittee on Nuclear Hormone Receptors [41]**) are nuclear hormone receptors of the NR1A family, with diverse roles regulating macronutrient metabolism, cognition and cardiovascular homeostasis. TRs are activated by thyroxine (T₄) and thyroid hormone (triiodothyronine). Once activated by a ligand, the receptor acts as a transcription factor either as a monomer, homodimer or heterodimer with members of the retinoid X receptor family. NH-3 has been described as an antagonist at TRs with modest selectivity for TRβ [111].

Nomenclature	Thyroid hormone receptor-α	Thyroid hormone receptor-β
Systematic nomenclature	NR1A1	NR1A2
HGNC, UniProt	THRA, P10827	THRB, P10828
Rank order of potency	triiodothyronine > T ₄	triiodothyronine > T ₄
Agonists	dextrothyroxine [20]	dextrothyroxine [20]
Selective agonists	–	sobetirome (pK _d 10.2) [27, 133]

Comments: An interaction with integrin αVβ3 has been suggested to underlie plasma membrane localization of TRs and non-genomic signalling [9]. One splice variant, TRα₂, lacks a functional DNA-binding domain and appears to act as a transcription suppressor. Although radioligand binding assays have been described for these receptors, the radioligands are not commercially available.

Further Reading

- Bianco AC. (2011) Minireview: cracking the metabolic code for thyroid hormone signaling. *Endocrinology* **152**: 3306-11 [PMID:21712363]
- Brent GA. (2012) Mechanisms of thyroid hormone action. *J. Clin. Invest.* **122**: 3035-43 [PMID:22945636]
- Flamant F *et al.* (2006) International Union of Pharmacology. LIX. The pharmacology and classification of the nuclear receptor superfamily: thyroid hormone receptors. *Pharmacol. Rev.* **58**: 705-11 [PMID:17132849]
- Pramfalk C *et al.* (2011) Role of thyroid receptor β in lipid metabolism. *Biochim. Biophys. Acta* **1812**: 929-37 [PMID:21194564]
- Sirakov M *et al.* (2011) The thyroid hormones and their nuclear receptors in the gut: from developmental biology to cancer. *Biochim. Biophys. Acta* **1812**: 938-46 [PMID:21194566]
- Tancevski I *et al.* (2011) Thyromimetics: a journey from bench to bed-side. *Pharmacol. Ther.* **131**: 33-9 [PMID:21504761]

1B. Retinoic acid receptors

Nuclear hormone receptors → 1B. Retinoic acid receptors

Overview: Retinoic acid receptors (**nomenclature as agreed by the NC-IUPHAR Subcommittee on Nuclear Hormone Receptors [46]**) are nuclear hormone receptors of the NR1B family activated by the vitamin A-derived agonists **tretinoin** (ATRA) and **alitretinoin**, and the RAR-selective synthetic agonists **TTNPB** and **adapalene**. **BMS493** is a family-selective antagonist [47].

Nomenclature	Retinoic acid receptor- α	Retinoic acid receptor- β	Retinoic acid receptor- γ
Systematic nomenclature	NR1B1	NR1B2	NR1B3
HGNC, UniProt	RARA , P10276	RARB , P10826	RARG , P13631
Agonists	tretinoin (pEC ₅₀ 7.8) [26]	tretinoin (pEC ₅₀ 7.9) [26]	tretinoin (pEC ₅₀ 9.7) [26]
(Sub)family-selective agonists	tazarotene (pEC ₅₀ 7.2) [26]	tazarotene (pEC ₅₀ 9.1) [26], adapalene (pK _i 7.5) [25]	tazarotene (pEC ₅₀ 7.4) [26], adapalene (pK _i 6.9) [25]
Selective agonists	BMS753 (pK _i 8.7) [53], Ro 40-6055 (pK _d 8.2) [33], tamibarotene (pIC ₅₀ 6.9) [65, 108, 146]	AC261066 (pEC ₅₀ 7.9–8.1) [90], AC55649 (pEC ₅₀ 6.5–7.3) [90]	AHPN (pK _i 7.1) [25]
Selective antagonists	Ro 41-5253 (pIC ₅₀ 6.3–7.2) [2, 70]	–	MM 11253 [77]

Comments: **Ro 41-5253** has been suggested to be a PPAR γ agonist [131]. **LE135** is an antagonist with selectivity for RAR α and RAR β compared with RAR γ [85].

Further Reading

- Bour G *et al.* (2007) Protein kinases and the proteasome join in the combinatorial control of transcription by nuclear retinoic acid receptors. *Trends Cell Biol.* **17**: 302-9 [PMID:17467991]
- Duong V *et al.* (2011) The molecular physiology of nuclear retinoic acid receptors. From health to disease. *Biochim. Biophys. Acta* **1812**: 1023-31 [PMID:20970498]
- Germain P *et al.* (2006) International Union of Pharmacology. LX. Retinoic acid receptors. *Pharmacol. Rev.* **58**: 712-25 [PMID:17132850]
- Maden M. (2007) Retinoic acid in the development, regeneration and maintenance of the nervous system. *Nat. Rev. Neurosci.* **8**: 755-65 [PMID:17882253]
- Mark M *et al.* (2006) Function of retinoid nuclear receptors: lessons from genetic and pharmacological dissections of the retinoic acid signaling pathway during mouse embryogenesis. *Annu. Rev. Pharmacol. Toxicol.* **46**: 451-80 [PMID:16402912]

1C. Peroxisome proliferator-activated receptors

Nuclear hormone receptors → 1C. Peroxisome proliferator-activated receptors

Overview: Peroxisome proliferator-activated receptors (PPARs, nomenclature as agreed by the **NC-IUPHAR Subcommittee on Nuclear Hormone Receptors [101]**) are nuclear hormone receptors of the NR1C family, with diverse roles regulating lipid homeostasis, cellular differentiation, proliferation and the immune response. PPARs have many potential endogenous agonists [14, 101], including 15-deoxy- $\Delta^{12,14}$ -PGJ₂, prosta-

cyclin (PGI₂), many fatty acids and their oxidation products, lysophosphatidic acid (LPA) [98], 13-HODE, 15S-HETE, Paz-PC, azelaoyl-PAF and leukotriene B₄ (LTB₄). Bezafibrate acts as a non-selective agonist for the PPAR family [159]. These receptors also bind hypolipidaemic drugs (PPAR α) and anti-diabetic thiazolidinediones (PPAR γ), as well as many non-steroidal anti-inflammatory drugs, such as sulindac and indomethacin. Once

activated by a ligand, the receptor forms a heterodimer with members of the retinoid X receptor family and can act as a transcription factor. Although radioligand binding assays have been described for all three receptors, the radioligands are not commercially available. Commonly, receptor occupancy studies are conducted using fluorescent ligands and truncated forms of the receptor limited to the ligand binding domain.

Nomenclature	Peroxisome proliferator-activated receptor- α	Peroxisome proliferator-activated receptor- β/δ	Peroxisome proliferator-activated receptor- γ
Systematic nomenclature	NR1C1	NR1C2	NR1C3
HGNC, UniProt	<i>PPARA</i> , Q07869	<i>PPARD</i> , Q03181	<i>PPARG</i> , P37231
Agonists	–	–	mesalazine (pIC ₅₀ 1.8) [126]
Selective agonists	GW7647 (pEC ₅₀ 8.2) [18, 19], CP-775146 (pEC ₅₀ 7.3) [68], pirinixic acid (pEC ₅₀ 5.3) [159], gemfibrozil (pEC ₅₀ 4.2) [31], ciprofibrate	GW0742X (pIC ₅₀ 9) [50, 144], GW501516 (pEC ₅₀ 9) [113]	GW1929 (pK _i 8.8) [18], bardoxolone (Partial agonist) (pK _i 8) [153], rosiglitazone (pK _d 7.4) [59, 81, 165], rosiglitazone (pK _i 6.9) [88], troglitazone (pIC ₅₀ 6.3) [59, 165], pioglitazone (pIC ₅₀ 6.2) [59, 129, 165], troglitazone (pK _i 5.8) [8], ciglitazone (pEC ₅₀ 4.6) [59]
Selective antagonists	GW6471 (pIC ₅₀ 6.6) [162]	GSK0660 (pIC ₅₀ 6.5) [134]	T0070907 (pK _i 9) [78], GW9662 (Irreversible inhibition) (pIC ₅₀ 8.1) [79], CDDO-Me (pK _i 6.9) [153]

Comments: As with the estrogen receptor antagonists, many agents show tissue-selective efficacy (*e.g.* [13, 110, 125]). Agonists with mixed activity at PPAR α and PPAR γ have also been described (*e.g.* [35, 52, 163]).

Further Reading

- Huang JV *et al.* (2012) PPAR- γ as a therapeutic target in cardiovascular disease: evidence and uncertainty. *J. Lipid Res.* **53**: 1738–54 [PMID:22685322]
- Michalik L *et al.* (2006) International Union of Pharmacology. LXI. Peroxisome proliferator-activated receptors. *Pharmacol. Rev.* **58**: 726–41 [PMID:17132851]
- Michalik L *et al.* (2008) PPARs Mediate Lipid Signaling in Inflammation and Cancer. *PPAR Res* **2008**: 134059 [PMID:19125181]
- Peters JM *et al.* (2012) The role of peroxisome proliferator-activated receptors in carcinogenesis and chemoprevention. *Nat. Rev. Cancer* **12**: 181–95 [PMID:22318237]
- Pirat C *et al.* (2012) Targeting peroxisome proliferator-activated receptors (PPARs): development of modulators. *J. Med. Chem.* **55**: 4027–61 [PMID:22260081]
- Varga T *et al.* (2011) PPARs are a unique set of fatty acid regulated transcription factors controlling both lipid metabolism and inflammation. *Biochim. Biophys. Acta* **1812**: 1007–22 [PMID:21382489]
- Youssef J *et al.* (2011) Peroxisome proliferator-activated receptors and cancer: challenges and opportunities. *Br. J. Pharmacol.* **164**: 68–82 [PMID:21449912]

1D. Rev-Erb receptors

Nuclear hormone receptors → 1D. Rev-Erb receptors

Overview: Rev-erb receptors (**nomenclature as agreed by the NC-IUPHAR Subcommittee on Nuclear Hormone Receptors [7]**) have yet to be officially paired with an endogenous ligand, but are thought to be activated by heme.

Nomenclature	Rev-Erb- α	Rev-Erb- β
Systematic nomenclature	NR1D1	NR1D2
HGNC, UniProt	NR1D1 , P20393	NR1D2 , Q14995
Endogenous agonists	heme (Selective) [122 , 164]	heme (Selective) [122 , 164]
Selective agonists	GSK4112 (pEC ₅₀ 6.4) [51], GSK4112 (pIC ₅₀ 5.6) [73]	–
Selective antagonists	SR8278 (pIC ₅₀ 6.5) [73]	–

Further Reading

- Benoit G *et al.* (2006) International Union of Pharmacology. LXVI. Orphan nuclear receptors. *Pharmacol. Rev.* **58**: 798-836 [[PMID:17132856](#)]
- Duez H *et al.* (2009) Rev-erb-alpha: an integrator of circadian rhythms and metabolism. *J. Appl. Physiol.* **107**: 1972-80 [[PMID:19696364](#)]
- Germain P *et al.* (2006) Overview of nomenclature of nuclear receptors. *Pharmacol. Rev.* **58**: 685-704 [[PMID:17132848](#)]
- Huang P *et al.* (2010) Structural overview of the nuclear receptor superfamily: insights into physiology and therapeutics. *Annu. Rev. Physiol.* **72**: 247-72 [[PMID:20148675](#)]
- Phelan CA *et al.* (2010) Structure of Rev-erbalph bound to N-CoR reveals a unique mechanism of nuclear receptor-co-repressor interaction. *Nat. Struct. Mol. Biol.* **17**: 808-14 [[PMID:20581824](#)]
- Sladek FM. (2011) What are nuclear receptor ligands? *Mol. Cell. Endocrinol.* **334**: 3-13 [[PMID:20615454](#)]
- Yin L *et al.* (2010) Nuclear receptor Rev-erbalph: a heme receptor that coordinates circadian rhythm and metabolism. *Nucl Recept Signal* **8**: e001 [[PMID:20414452](#)]

1F. Retinoic acid-related orphans

Nuclear hormone receptors → 1F. Retinoic acid-related orphans

Overview: Retinoic acid receptor-related orphan receptors (ROR, nomenclature as agreed by the [NC-IUPHAR Subcommittee on Nuclear Hormone Receptors \[7\]](#)) have yet to be assigned a definitive endogenous ligand, although ROR α may be synthesized with a ‘captured’ agonist such as [cholesterol \[66, 67\]](#).

Nomenclature	RAR-related orphan receptor- α	RAR-related orphan receptor- β	RAR-related orphan receptor- γ
Systematic nomenclature	NR1F1	NR1F2	NR1F3
HGNC, UniProt	RORA, P35398	RORB, Q92753	RORC, P51449
Endogenous agonists	cholesterol (Selective) [67 , 115]	–	–
Selective agonists	7-hydroxycholesterol [15] , cholesterol sulphate [15, 67]	–	–

Comments: [tretinoin](#) shows selectivity for ROR β within the ROR family [[139](#)]. ROR α has been suggested to be a nuclear receptor responding to [melatonin \[158\]](#).

Further Reading

Benoit G *et al.* (2006) International Union of Pharmacology. LXVI. Orphan nuclear receptors. *Pharmacol. Rev.* **58**: 798-836 [[PMID:17132856](#)]

1H. Liver X receptor-like receptors

Nuclear hormone receptors → 1H. Liver X receptor-like receptors

Overview: Liver X and farnesoid X receptors (LXR and FXR, **nomenclature as agreed by the NC-IUPHAR Subcommittee on Nuclear Hormone Receptors [105]**) are members of a steroid analogue-activated nuclear receptor subfamily, which form heterodimers with members of the retinoid X receptor family. Endogenous ligands for LXRs include hydroxycholesterols (OHC), while FXRs appear to be activated by bile acids.

Nomenclature	Farnesoid X receptor	Farnesoid X receptor-β	Liver X receptor-α	Liver X receptor-β
Systematic nomenclature	NR1H4	NR1H5	NR1H3	NR1H2
HGNC, UniProt	<i>NR1H4</i> , Q96R11	<i>NR1H5P</i> , –	<i>NR1H3</i> , Q13133	<i>NR1H2</i> , P55055
Potency order	chenodeoxycholic acid > lithocholic acid, deoxycholic acid [93, 116]	–	20S-hydroxycholesterol, 22R-hydroxycholesterol, 24(S)-hydroxycholesterol > 25-hydroxycholesterol, 27-hydroxycholesterol [80]	20S-hydroxycholesterol, 22R-hydroxycholesterol, 24(S)-hydroxycholesterol > 25-hydroxycholesterol, 27-hydroxycholesterol [80]
Endogenous agonists	–	lanosterol (pEC ₅₀ 6) [114] – Mouse	–	–
Selective agonists	GW4064 (pEC ₅₀ 7.8) [95], obeticholic acid (pEC ₅₀ 7) [117], fexaramine (pEC ₅₀ 6.6) [36]	–	–	–
Selective antagonists	guggulsterone (pIC ₅₀ 5.7–6) [161]	–	–	–

Comments: T0901317 [123] and GW3965 [28] are synthetic agonists acting at both LXRα and LXRβ with less than 10-fold selectivity.

Further Reading

- A-González N *et al.* (2011) Liver X receptors as regulators of macrophage inflammatory and metabolic pathways. *Biochim. Biophys. Acta* **1812**: 982-94 [PMID:21193033]
- Calkin AC *et al.* (2010) Liver x receptor signaling pathways and atherosclerosis. *Arterioscler. Thromb. Vasc. Biol.* **30**: 1513-8 [PMID:20631351]
- Chen WD *et al.* (2011) Nuclear bile acid receptor FXR in the hepatic regeneration. *Biochim. Biophys. Acta* **1812**: 888-92 [PMID:21167938]
- Claudel T *et al.* (2011) Role of nuclear receptors for bile acid metabolism, bile secretion, cholestasis, and gallstone disease. *Biochim. Biophys. Acta* **1812**: 867-78 [PMID:21194565]
- El-Hajjaji FZ *et al.* (2011) Liver X receptors, lipids and their reproductive secrets in the male. *Biochim. Biophys. Acta* **1812**: 974-81 [PMID:21334438]
- Gadaleta RM *et al.* (2010) Bile acids and their nuclear receptor FXR: Relevance for hepatobiliary and gastrointestinal disease. *Biochim. Biophys. Acta* **1801**: 683-92 [PMID:20399894]
- Gardmo C *et al.* (2011) Proteomics for the discovery of nuclear bile acid receptor FXR targets. *Biochim. Biophys. Acta* **1812**: 836-41 [PMID:21439373]
- Kemper JK. (2011) Regulation of FXR transcriptional activity in health and disease: Emerging roles of FXR cofactors and post-translational modifications. *Biochim. Biophys. Acta* **1812**: 842-50 [PMID:21130162]
- Matsubara T *et al.* (2013) FXR signaling in the enterohepatic system. *Mol. Cell. Endocrinol.* **368**: 17-29 [PMID:22609541]
- Moore DD *et al.* (2006) International Union of Pharmacology. LXII. The NR1H and NR1I receptors: constitutive androstane receptor, pregnane X receptor, farnesoid X receptor alpha, farnesoid X receptor beta, liver X receptor alpha, liver X receptor beta, and vitamin D receptor. *Pharmacol. Rev.* **58**: 742-59 [PMID:17132852]

11. Vitamin D receptor-like receptors

Nuclear hormone receptors → 11. Vitamin D receptor-like receptors

Overview: Vitamin D (VDR), Pregnane X (PXR) and Constitutive Androstane (CAR) receptors (**nomenclature as agreed by the NC-IUPHAR Subcommittee on Nuclear Hormone Receptors [105]**) are members of the NR11 family of nuclear receptors, which form heterodimers with members of the retinoid X receptor family. PXR and CAR are activated by a range of exogenous compounds, with no established endogenous physiological agonists, although high concentrations of bile acids and bile pigments activate PXR and CAR [105].

Nomenclature	Vitamin D receptor	Pregnane X receptor	Constitutive androstane receptor
Systematic nomenclature	NR111	NR112	NR113
HGNC, UniProt	VDR , P11473	NR112 , O75469	NR113 , Q14994
Endogenous agonists	1,25-dihydroxyvitamin D3 (pK _d 8.9–9.2) [12 , 39]	17β-estradiol (Selective) [64]	–
Selective agonists	seocalcitol (pK _d 9.6) [29 , 157], doxercalciferol	hyperforin (pEC ₅₀ 7.6) [106 , 156], 5β-pregnane-3,20-dione (pIC ₅₀ 6.4) [64], lovastatin (pEC ₅₀ 5.3–6) [82], rifampicin (pEC ₅₀ 5.5–6) [16 , 82]	TCPOBOP (pEC ₅₀ 7.7) [149] – Mouse, CITCO (pEC ₅₀ 7.3) [92]
Selective antagonists	TEI-9647 (pIC ₅₀ 8.2) [128] – Chicken, ZK159222 (pIC ₅₀ 7.5) [42 , 60]	–	–
Comments	–	–	clotrimazole [107] and T0901317 [69] although acting at other sites, function as antagonists of the constitutive androstane receptor.

Further Reading

- Bikle DD. (2011) Vitamin D: an ancient hormone. *Exp. Dermatol.* **20**: 7-13 [[PMID:21197695](#)]
- Campbell FC *et al.* (2010) The yin and yang of vitamin D receptor (VDR) signaling in neoplastic progression: operational networks and tissue-specific growth control. *Biochem. Pharmacol.* **79**: 1-9 [[PMID:19737544](#)]
- Chen Y *et al.* (2012) Nuclear receptors in the multidrug resistance through the regulation of drug-metabolizing enzymes and drug transporters. *Biochem. Pharmacol.* **83**: 1112-26 [[PMID:22326308](#)]
- Cheng J *et al.* (2012) Pregnane X receptor as a target for treatment of inflammatory bowel disorders. *Trends Pharmacol. Sci.* **33**: 323-30 [[PMID:22609277](#)]
- Ihunnah CA *et al.* (2011) Nuclear receptor PXR, transcriptional circuits and metabolic relevance. *Biochim. Biophys. Acta* **1812**: 956-63 [[PMID:21295138](#)]
- Kachaylo EM *et al.* (2011) Constitutive androstane receptor (CAR) is a xenosensor and target for therapy. *Biochemistry Mosc.* **76**: 1087-97 [[PMID:22098234](#)]
- Moore DD *et al.* (2006) International Union of Pharmacology. LXII. The NR1H and NR1I receptors: constitutive androstane receptor, pregnane X receptor, farnesoid X receptor alpha, farnesoid X receptor beta, liver X receptor alpha, liver X receptor beta, and vitamin D receptor. *Pharmacol. Rev.* **58**: 742-59 [[PMID:17132852](#)]
- Plum LA *et al.* (2010) Vitamin D, disease and therapeutic opportunities. *Nat Rev Drug Discov* **9**: 941-55 [[PMID:21119732](#)]
- Staudinger JL *et al.* (2013) Nuclear-receptor-mediated regulation of drug- and bile-acid-transporter proteins in gut and liver. *Drug Metab. Rev.* **45**: 48-59 [[PMID:23330541](#)]

2A. Hepatocyte nuclear factor-4 receptors

Nuclear hormone receptors → 2A. Hepatocyte nuclear factor-4 receptors

Overview: The nomenclature of hepatocyte nuclear factor-4 receptors is agreed by the **NC-IUPHAR Subcommittee on Nuclear Hormone Receptors** [7]. While linoleic acid has been identified as the endogenous ligand for HNF4 α its function remains ambiguous [167]. HNF4 γ has yet to be paired with an endogenous ligand.

Nomenclature	Hepatocyte nuclear factor-4- α	Hepatocyte nuclear factor-4- γ
Systematic nomenclature	NR2A1	NR2A2
HGNC, UniProt	HNF4A , P41235	HNF4G , Q14541
Endogenous agonists	linoleic acid (Selective) [167]	–
Selective antagonists	BI6015 [72]	–
Comments	HNF4 α has constitutive transactivation activity [167] and binds DNA as a homodimer [63].	–

Further Reading

Benoit G *et al.* (2006) International Union of Pharmacology. LXVI. Orphan nuclear receptors. *Pharmacol. Rev.* **58**: 798-836 [[PMID:17132856](#)]
 Germain P *et al.* (2006) Overview of nomenclature of nuclear receptors. *Pharmacol. Rev.* **58**: 685-704 [[PMID:17132848](#)]
 Huang P *et al.* (2010) Structural overview of the nuclear receptor superfamily: insights into physiol-

ogy and therapeutics. *Annu. Rev. Physiol.* **72**: 247-72 [[PMID:20148675](#)]
 Hwang-Verslues WW *et al.* (2010) HNF4 α -role in drug metabolism and potential drug target? *Curr Opin Pharmacol* **10**: 698-705 [[PMID:20833107](#)]
 Sladek FM. (2011) What are nuclear receptor ligands? *Mol. Cell. Endocrinol.* **334**: 3-13 [[PMID:20615454](#)]

2B. Retinoid X receptors

Nuclear hormone receptors → 2B. Retinoid X receptors

Overview: Retinoid X receptors (**nomenclature as agreed by the NC-IUPHAR Subcommittee on Nuclear Hormone Receptors [45]**) are NR2B family members activated by [alitretinoin](#) and the RXR-selective agonists [bexarotene](#) and [LG100268](#), sometimes referred to as rexinoids. [UVI3003 \[109\]](#) and [HX 531 \[37\]](#) have been described as a pan-RXR antagonists. These receptors form RXR-RAR heterodimers and RXR-RXR homodimers [\[23, 97\]](#).

Nomenclature	Retinoid X receptor-α	Retinoid X receptor-β	Retinoid X receptor-γ
Systematic nomenclature	NR2B1	NR2B2	NR2B3
HGNC, UniProt	RXRA, P19793	RXRB, P28702	RXRG, P48443
(Sub)family-selective agonists	bexarotene (pIC ₅₀ 7.4) [17, 22, 146]	bexarotene (pIC ₅₀ 7.7) [17, 22, 146]	bexarotene (pIC ₅₀ 7.5) [17, 22, 146]
Selective agonists	CD3254 (pIC ₅₀ 8.5) [48]	–	–

Further Reading

- Bour G *et al.* (2007) Protein kinases and the proteasome join in the combinatorial control of transcription by nuclear retinoic acid receptors. *Trends Cell Biol.* **17**: 302-9 [\[PMID:17467991\]](#)
- Duong V *et al.* (2011) The molecular physiology of nuclear retinoic acid receptors. From health to disease. *Biochim. Biophys. Acta* **1812**: 1023-31 [\[PMID:20970498\]](#)
- Germain P *et al.* (2006) International Union of Pharmacology. LXIII. Retinoid X receptors. *Pharmacol. Rev.* **58**: 760-72 [\[PMID:17132853\]](#)
- Lefebvre P *et al.* (2010) Retinoid X receptors: common heterodimerization partners with distinct functions. *Trends Endocrinol. Metab.* **21**: 676-83 [\[PMID:20674387\]](#)
- Maden M. (2007) Retinoic acid in the development, regeneration and maintenance of the nervous system. *Nat. Rev. Neurosci.* **8**: 755-65 [\[PMID:17882253\]](#)
- Mark M *et al.* (2006) Function of retinoid nuclear receptors: lessons from genetic and pharmacological dissections of the retinoic acid signaling pathway during mouse embryogenesis. *Annu. Rev. Pharmacol. Toxicol.* **46**: 451-80 [\[PMID:16402912\]](#)
- Pérez E *et al.* (2011) Modulation of RXR function through ligand design. *Biochim Biophys Acta* [\[PMID:21515403\]](#)

2C. Testicular receptors

Nuclear hormone receptors → 2C. Testicular receptors

Overview: Testicular receptors (**nomenclature as agreed by the NC-IUPHAR Subcommittee on Nuclear Hormone Receptors [7]**) have yet to be officially paired with an endogenous ligand, although testicular receptor 4 has been reported to respond to retinoids.

Nomenclature	Testicular receptor 2	Testicular receptor 4
Systematic nomenclature	NR2C1	NR2C2
HGNC, UniProt	NR2C1 , P13056	NR2C2 , P49116
Endogenous agonists	–	retinol (Selective) [173], tretinoin (Selective) [173]
Comments	Forms a heterodimer with TR4; gene disruption appears without effect on testicular development or function [135].	Forms a heterodimer with TR2.

Further Reading

- Benoit G *et al.* (2006) International Union of Pharmacology. LXVI. Orphan nuclear receptors. *Pharmacol. Rev.* **58**: 798-836 [[PMID:17132856](#)]
- Duez H *et al.* (2009) Rev-erb-alpha: an integrator of circadian rhythms and metabolism. *J. Appl. Physiol.* **107**: 1972-80 [[PMID:19696364](#)]
- Germain P *et al.* (2006) Overview of nomenclature of nuclear receptors. *Pharmacol. Rev.* **58**: 685-704 [[PMID:17132848](#)]
- Huang P *et al.* (2010) Structural overview of the nuclear receptor superfamily: insights into physiology and therapeutics. *Annu. Rev. Physiol.* **72**: 247-72 [[PMID:20148675](#)]
- Phelan CA *et al.* (2010) Structure of Rev-erbalpha bound to N-CoR reveals a unique mechanism of nuclear receptor-co-repressor interaction. *Nat. Struct. Mol. Biol.* **17**: 808-14 [[PMID:20581824](#)]
- Schimmer BP *et al.* (2010) Minireview: steroidogenic factor 1: its roles in differentiation, development, and disease. *Mol. Endocrinol.* **24**: 1322-37 [[PMID:20203099](#)]
- Sladek FM. (2011) What are nuclear receptor ligands? *Mol. Cell. Endocrinol.* **334**: 3-13 [[PMID:20615454](#)]
- Yin L *et al.* (2010) Nuclear receptor Rev-erbalpha: a heme receptor that coordinates circadian rhythm and metabolism. *Nucl Recept Signal* **8**: e001 [[PMID:20414452](#)]
- Zhang Y *et al.* (2011) Role of nuclear receptor SHP in metabolism and cancer. *Biochim. Biophys. Acta* **1812**: 893-908 [[PMID:20970497](#)]
- Zhao Y *et al.* (2010) NR4A orphan nuclear receptors: transcriptional regulators of gene expression in metabolism and vascular biology. *Arterioscler. Thromb. Vasc. Biol.* **30**: 1535-41 [[PMID:20631354](#)]

2E. Tailless-like receptors

Nuclear hormone receptors → 2E. Tailless-like receptors

Overview: Tailless-like receptors (**nomenclature as agreed by the NC-IUPHAR Subcommittee on Nuclear Hormone Receptors [7]**) have yet to be officially paired with an endogenous ligand.

Nomenclature	TLX	PNR
Systematic nomenclature	NR2E1	NR2E3
HGNC, UniProt	NR2E1 , Q9Y466	NR2E3 , Q9Y5X4
Comments	Gene disruption is associated with abnormal brain development [76 , 104].	–

Further Reading

- Benoit G *et al.* (2006) International Union of Pharmacology. LXVI. Orphan nuclear receptors. *Pharmacol. Rev.* **58**: 798-836 [[PMID:17132856](#)]
- Germain P *et al.* (2006) Overview of nomenclature of nuclear receptors. *Pharmacol. Rev.* **58**: 685-704 [[PMID:17132848](#)]
- Gui H *et al.* (2011) A tale of tailless. *Dev. Neurosci.* **33**: 1-13 [[PMID:21124006](#)]
- Huang P *et al.* (2010) Structural overview of the nuclear receptor superfamily: insights into physiology and therapeutics. *Annu. Rev. Physiol.* **72**: 247-72 [[PMID:20148675](#)]
- Sladek FM. (2011) What are nuclear receptor ligands? *Mol. Cell. Endocrinol.* **334**: 3-13 [[PMID:20615454](#)]

2F. COUP-TF-like receptors

Nuclear hormone receptors → 2F. COUP-TF-like receptors

Overview: COUP-TF-like receptors (**nomenclature as agreed by the NC-IUPHAR Subcommittee on Nuclear Hormone Receptors [7]**) have yet to be officially paired with an endogenous ligand.

Nomenclature	COUP-TF1	COUP-TF2	V-erbA-related gene
Systematic nomenclature	NR2F1	NR2F2	NR2F6
HGNC, UniProt	NR2F1 , P10589	NR2F2 , P24468	NR2F6 , P10588
Comments	Gene disruption is perinatally lethal [121].	Gene disruption is embryonically lethal [118].	Gene disruption impairs CNS development [155].

Further Reading

Benoit G *et al.* (2006) International Union of Pharmacology. LXVI. Orphan nuclear receptors. *Pharmacol. Rev.* **58**: 798-836 [PMID:17132856]
Germain P *et al.* (2006) Overview of nomenclature of nuclear receptors. *Pharmacol. Rev.* **58**: 685-704 [PMID:17132848]
Huang P *et al.* (2010) Structural overview of the nuclear receptor superfamily: insights into physiol-

ogy and therapeutics. *Annu. Rev. Physiol.* **72**: 247-72 [PMID:20148675]
Lin FJ *et al.* (2011) Coup d'Etat: an orphan takes control. *Endocr. Rev.* **32**: 404-21 [PMID:21257780]
Sladek FM. (2011) What are nuclear receptor ligands? *Mol. Cell. Endocrinol.* **334**: 3-13 [PMID:20615454]

3B. Estrogen-related receptors

Nuclear hormone receptors → 3B. Estrogen-related receptors

Overview: Estrogen-related receptors (**nomenclature as agreed by the NC-IUPHAR Subcommittee on Nuclear Hormone Receptors [7]**) have yet to be officially paired with an endogenous ligand.

Nomenclature	Estrogen-related receptor- α	Estrogen-related receptor- β	Estrogen-related receptor- γ
Systematic nomenclature	NR3B1	NR3B2	NR3B3
HGNC, UniProt	ESRRA , P11474	ESRRB , O95718	ESRRG , P62508
Comments	Activated by some dietary flavonoids [141]; activated by the synthetic agonist GSK4716 [176] and blocked by XCT790 [160].	May be activated by DY131 [166].	May be activated by DY131 [166].

Further Reading

- Benoit G *et al.* (2006) International Union of Pharmacology. LXVI. Orphan nuclear receptors. *Pharmacol. Rev.* **58**: 798-836 [[PMID:17132856](#)]
- Deblois G *et al.* (2011) Functional and physiological genomics of estrogen-related receptors (ERRs) in health and disease. *Biochim. Biophys. Acta* **1812**: 1032-40 [[PMID:21172432](#)]
- Deblois G *et al.* (2013) Oestrogen-related receptors in breast cancer: control of cellular metabolism and beyond. *Nat. Rev. Cancer* **13**: 27-36 [[PMID:23192231](#)]
- Germain P *et al.* (2006) Overview of nomenclature of nuclear receptors. *Pharmacol. Rev.* **58**: 685-704 [[PMID:17132848](#)]
- Huang P *et al.* (2010) Structural overview of the nuclear receptor superfamily: insights into physiology and therapeutics. *Annu. Rev. Physiol.* **72**: 247-72 [[PMID:20148675](#)]
- Hwang-Verslues WW *et al.* (2010) HNF4 α -role in drug metabolism and potential drug target? *Curr Opin Pharmacol* **10**: 698-705 [[PMID:20833107](#)]
- Sladek FM. (2011) What are nuclear receptor ligands? *Mol. Cell. Endocrinol.* **334**: 3-13 [[PMID:20615454](#)]

4A. Nerve growth factor IB-like receptors

Nuclear hormone receptors → 4A. Nerve growth factor IB-like receptors

Overview: Nerve growth factor IB-like receptors (**nomenclature as agreed by the NC-IUPHAR Subcommittee on Nuclear Hormone Receptors [7]**) have yet to be officially paired with an endogenous ligand.

Nomenclature	Nerve Growth factor IB	Nuclear receptor related 1	Neuron-derived orphan receptor 1
Systematic nomenclature	NR4A1	NR4A2	NR4A3
HGNC, UniProt	NR4A1 , P22736	NR4A2 , P43354	NR4A3 , Q92570
Comments	An endogenous agonist, cytosporone B , has been described [168], although structural analysis and molecular modelling has not identified a ligand binding site [4 , 40 , 154].	–	–

Further Reading

Benoit G *et al.* (2006) International Union of Pharmacology. LXVI. Orphan nuclear receptors. *Pharmacol. Rev.* **58**: 798-836 [[PMID:17132856](#)]
 Germain P *et al.* (2006) Overview of nomenclature of nuclear receptors. *Pharmacol. Rev.* **58**: 685-704 [[PMID:17132848](#)]
 Huang P *et al.* (2010) Structural overview of the nuclear receptor superfamily: insights into physiology and therapeutics. *Annu. Rev. Physiol.* **72**: 247-72 [[PMID:20148675](#)]
 McMorrow JP *et al.* (2011) Inflammation: a role for NR4A orphan nuclear receptors? *Biochem. Soc. Trans.* **39**: 688-93 [[PMID:21428963](#)]
 Mohan HM *et al.* (2012) Molecular pathways: the role of NR4A orphan nuclear receptors in cancer.

Clin. Cancer Res. **18**: 3223-8 [[PMID:22566377](#)]
 Pearen MA *et al.* (2010) Minireview: Nuclear hormone receptor 4A signaling: implications for metabolic disease. *Mol. Endocrinol.* **24**: 1891-903 [[PMID:20392876](#)]
 Sladek FM. (2011) What are nuclear receptor ligands? *Mol. Cell. Endocrinol.* **334**: 3-13 [[PMID:20615454](#)]
 Zhao Y *et al.* (2010) NR4A orphan nuclear receptors: transcriptional regulators of gene expression in metabolism and vascular biology. *Arterioscler. Thromb. Vasc. Biol.* **30**: 1535-41 [[PMID:20631354](#)]
 van Tiel CM *et al.* (2012) NR4A1 in the vessel wall. *J. Steroid Biochem. Mol. Biol.* **130**: 186-93 [[PMID:21277978](#)]

5A. Fushi tarazu F1-like receptors

Nuclear hormone receptors → 5A. Fushi tarazu F1-like receptors

Overview: Fushi tarazu F1-like receptors (**nomenclature as agreed by the NC-IUPHAR Subcommittee on Nuclear Hormone Receptors [7]**) have yet to be officially paired with an endogenous ligand.

Nomenclature	Steroidogenic factor 1	Liver receptor homolog-1
Systematic nomenclature	NR5A1	NR5A2
HGNC, UniProt	NR5A1 , Q13285	NR5A2 , O00482
Comments	Reported to be inhibited by AC45594 [32] and SID7969543 [91].	–

Further Reading

- Benoit G *et al.* (2006) International Union of Pharmacology. LXVI. Orphan nuclear receptors. *Pharmacol. Rev.* **58**: 798-836 [[PMID:17132856](#)]
- Büdefeld T *et al.* (2012) Steroidogenic factor 1 and the central nervous system. *J. Neuroendocrinol.* **24**: 225-35 [[PMID:21668533](#)]
- El-Khairi R *et al.* (2011) Role of DAX-1 (NR0B1) and steroidogenic factor-1 (NR5A1) in human adrenal function. *Endocr Dev* **20**: 38-46 [[PMID:21164257](#)]
- Fernandez-Marcos PJ *et al.* (2011) Emerging actions of the nuclear receptor LRH-1 in the gut. *Biochim. Biophys. Acta* **1812**: 947-55 [[PMID:21194563](#)]
- Ferraz-de-Souza B *et al.* (2011) Steroidogenic factor-1 (SF-1, NR5A1) and human disease. *Mol. Cell. Endocrinol.* **336**: 198-205 [[PMID:21078366](#)]
- Germain P *et al.* (2006) Overview of nomenclature of nuclear receptors. *Pharmacol. Rev.* **58**: 685-704 [[PMID:17132848](#)]
- Huang P *et al.* (2010) Structural overview of the nuclear receptor superfamily: insights into physiology and therapeutics. *Annu. Rev. Physiol.* **72**: 247-72 [[PMID:20148675](#)]
- Lazarus KA *et al.* (2012) Therapeutic potential of Liver Receptor Homolog-1 modulators. *J. Steroid Biochem. Mol. Biol.* **130**: 138-46 [[PMID:22266285](#)]
- Mlynarczuk J *et al.* (2010) The role of the orphan receptor SF-1 in the development and function of the ovary. *Reprod Biol* **10**: 177-93 [[PMID:21113200](#)]
- Schimmer BP *et al.* (2010) Minireview: steroidogenic factor 1: its roles in differentiation, development, and disease. *Mol. Endocrinol.* **24**: 1322-37 [[PMID:20203099](#)]
- Sladek FM. (2011) What are nuclear receptor ligands? *Mol. Cell. Endocrinol.* **334**: 3-13 [[PMID:20615454](#)]

6A. Germ cell nuclear factor receptors

Nuclear hormone receptors → 6A. Germ cell nuclear factor receptors

Overview: Germ cell nuclear factor receptors (**nomenclature as agreed by the NC-IUPHAR Subcommittee on Nuclear Hormone Receptors [7]**) have yet to be officially paired with an endogenous ligand.

Nomenclature	Germ cell nuclear factor
Systematic nomenclature	NR6A1
HGNC, UniProt	NR6A1 , Q15406

Further Reading

- Benoit G *et al.* (2006) International Union of Pharmacology. LXVI. Orphan nuclear receptors. *Pharmacol. Rev.* **58**: 798-836 [[PMID:17132856](#)]
- Germain P *et al.* (2006) Overview of nomenclature of nuclear receptors. *Pharmacol. Rev.* **58**: 685-704 [[PMID:17132848](#)]
- Huang P *et al.* (2010) Structural overview of the nuclear receptor superfamily: insights into physiology and therapeutics. *Annu. Rev. Physiol.* **72**: 247-72 [[PMID:20148675](#)]
- Sladek FM. (2011) What are nuclear receptor ligands? *Mol. Cell. Endocrinol.* **334**: 3-13 [[PMID:20615454](#)]

OB. DAX-like receptors

Nuclear hormone receptors → OB. DAX-like receptors

Overview: Dax-like receptors (**nomenclature as agreed by the NC-IUPHAR Subcommittee on Nuclear Hormone Receptors [7]**) have yet to be officially paired with an endogenous ligand.

Nomenclature	DAX1	SHP
Systematic nomenclature	NR0B1	NR0B2
HGNC, UniProt	NR0B1 , P51843	NR0B2 , Q15466

Further Reading

- Benoit G *et al.* (2006) International Union of Pharmacology. LXVI. Orphan nuclear receptors. *Pharmacol. Rev.* **58**: 798-836 [[PMID:17132856](#)]
- Chanda D *et al.* (2008) Molecular basis of endocrine regulation by orphan nuclear receptor Small Heterodimer Partner. *Endocr. J.* **55**: 253-68 [[PMID:17984569](#)]
- Ehrlund A *et al.* (2012) Ligand-independent actions of the orphan receptors/corepressors DAX-1 and SHP in metabolism, reproduction and disease. *J. Steroid Biochem. Mol. Biol.* **130**: 169-79 [[PMID:21550402](#)]
- El-Khairi R *et al.* (2011) Role of DAX-1 (NR0B1) and steroidogenic factor-1 (NR5A1) in human adrenal function. *Endocr Dev* **20**: 38-46 [[PMID:21164257](#)]
- Germain P *et al.* (2006) Overview of nomenclature of nuclear receptors. *Pharmacol. Rev.* **58**: 685-704 [[PMID:17132848](#)]
- Huang P *et al.* (2010) Structural overview of the nuclear receptor superfamily: insights into physiology and therapeutics. *Annu. Rev. Physiol.* **72**: 247-72 [[PMID:20148675](#)]
- Mlynarczuk J *et al.* (2010) The role of the orphan receptor SF-1 in the development and function of the ovary. *Reprod Biol* **10**: 177-93 [[PMID:21113200](#)]
- Sladek FM. (2011) What are nuclear receptor ligands? *Mol. Cell. Endocrinol.* **334**: 3-13 [[PMID:20615454](#)]
- Zhang Y *et al.* (2011) Role of nuclear receptor SHP in metabolism and cancer. *Biochim. Biophys. Acta* **1812**: 893-908 [[PMID:20970497](#)]

Steroid hormone receptors

Nuclear hormone receptors → Steroid hormone receptors

Overview: Steroid hormone receptors (**nomenclature as agreed by the NC-IUPHAR Subcommittee on Nuclear Hormone Receptors [30, 89]**) are nuclear hormone receptors of the NR3 class, with endogenous agonists that may be divided into 3-hydroxysteroids (*estrone* and *17β-estradiol*) and 3-ketosteroids (*dihydrotestosterone* [DHT], *aldosterone*, *cortisol*, *corticosterone*, *progesterone* and *testosterone*). These receptors exist as dimers coupled with chaperone molecules (such as *hsp90β* (*HSP90A1*, *P08238*) and immunophilin *FKBP52:FKBP4*, *Q02790*), which are shed on binding the steroid hormone. Although rapid signalling

phenomena are observed [84, 120], the principal signalling cascade appears to involve binding of the activated receptors to nuclear hormone response elements of the genome, with a 15-nucleotide consensus sequence AGAACAnnnTGTCT (*i.e.* an inverted palindrome) as homo- or heterodimers. They also affect transcription by protein-protein interactions with other transcription factors, such as activator protein 1 (AP-1) and nuclear factor κB (NF-κB). Splice variants of each of these receptors can form functional or non-functional monomers that can dimerize to form functional or non-functional receptors. For example, alternative

splicing of PR mRNA produces A and B monomers that combine to produce functional AA, AB and BB receptors with distinct characteristics [150].

A 7TM receptor responsive to estrogen (*GPER1*, *Q99527*, also known as GPR30, see [119]) has been described. Human orthologues of 7TM 'membrane progesterin receptors' (*PAQR7*, *PAQR8* and *PAQR5*), initially discovered in fish [174, 175], appear to localize to intracellular membranes and respond to 'non-genomic' progesterone analogues independently of G proteins [137].

3A. Estrogen receptors

Nuclear hormone receptors → Steroid hormone receptors → 3A. Estrogen receptors

Overview: Estrogen receptor (ER) activity regulates diverse physiological processes *via* transcriptional modulation of target genes. The selection of target genes and the magnitude of the response, be it induction or repression, are determined by many factors, including the effect of the hormone ligand and DNA binding on ER structural conformation, and the local cellular regulatory environment. The cellular environment defines the specific complement of DNA enhancer and promoter elements present and the availability of coregulators to form functional transcription complexes. Together, these determinants control the resulting biological response.

Nomenclature	Estrogen receptor-α	Estrogen receptor-β
Systematic nomenclature	NR3A1	NR3A2
HGNC, UniProt	ESR1 , P03372	ESR2 , Q92731
Endogenous agonists	estriol (pK _i 8.7) [75], estrone (pK _i 8.5) [75]	–
Selective agonists	propylpyrazoletriol (pK _i 9.6) [74, 138], ethinyl estradiol (pIC ₅₀ 8.7) [62]	WAY200070 (pIC ₅₀ 8.5–9) [94], diarylpropionitril (pK _i 8.6) [100, 138], prinaberel (pIC ₅₀ 8.3) [94]
(Sub)family-selective antagonists	bazedoxifene (pIC ₅₀ 7.6) [103]	bazedoxifene (pIC ₅₀ 7.1) [103]
Selective antagonists	clomiphene (pK _i 8.9) [3], methyl-piperidino-pyrazole (pK _i 8.6) [142]	R,R-THC (pK _i 8.4) [99, 143], PHTPP (pK _i 6.9) [172]

Comments: [R,R-THC](#) exhibits partial agonist activity at ERα [99, 143]. Estrogen receptors may be blocked non-selectively by [tamoxifen](#) and [raloxifene](#) and labelled by [³H]17β-estradiol and [³H]tamoxifen. Many agents thought initially to be antagonists

at estrogen receptors appear to have tissue-specific efficacy (*e.g.* [Tamoxifen](#) is an antagonist at estrogen receptors in the breast, but is an agonist at estrogen receptors in the uterus), hence the descriptor SERM (selective estrogen receptor modulator) or

SnuRM (selective nuclear receptor modulator). [Y134](#) has been suggested to be an ERα-selective estrogen receptor modulator [112].

3C. 3-Ketosteroid receptors

Nuclear hormone receptors → Steroid hormone receptors → 3C. 3-Ketosteroid receptors

Nomenclature	Androgen receptor	Glucocorticoid receptor	Mineralocorticoid receptor	Progesterone receptor
Systematic nomenclature	NR3C4	NR3C1	NR3C2	NR3C3
HGNC, UniProt	AR , P10275	NR3C1 , P04150	NR3C2 , P08235	PGR , P06401
Rank order of potency	dihydrotestosterone > testosterone	cortisol, corticosterone >> aldosterone, deoxycortisone [127]	corticosterone, cortisol, aldosterone, progesterone [127]	progesterone
Endogenous agonists	dihydrotestosterone (p <i>K_d</i> 9.3) [147]	–	aldosterone (Selective) (p <i>C₅₀</i> 9.8–10) [58 , 127]	progesterone (Selective) (p <i>EC₅₀</i> 8.8) [38]
Agonists	methyltestosterone (Androgen receptor promoter activity in luciferase reporter assay) (p <i>EC₅₀</i> 9.7) [1], danazol (p <i>K_i</i> 8) [24] – Rat, ethylestrenol, nandrolone	–	–	–
Selective agonists	testosterone propionate (p <i>K_i</i> 9.6) [96], mibolerone (p <i>C₅₀</i> 9) [49], fluoxymesterone (p <i>K_i</i> 8.2) [61], methyltrienolone (p <i>EC₅₀</i> <5) [152], dromostanolone propionate	fluticasone propionate (p <i>C₅₀</i> 9.3) [11], clobetasol propionate (p <i>K_i</i> 9.2) [3], desoximetasone (p <i>K_i</i> 8.9) [3], fluorometholone (p <i>K_i</i> 8.8) [3], flunisolide (p <i>K_i</i> 8.6) [3], difflorasone diacetate (p <i>K_i</i> 8.5) [3], flucinolone acetone (p <i>C₅₀</i> 8.5) [3], beclometasone (p <i>K_i</i> 8.4) [3], methylprednisolone (p <i>K_i</i> 8.3) [3], flucinonide (p <i>C₅₀</i> 8.3) [3], betamethasone (p <i>C₅₀</i> 8.1) [3], budesonide (p <i>EC₅₀</i> 7.9) [102], triamcinolone (p <i>C₅₀</i> 7.7) [87], ZK216348 (p <i>C₅₀</i> 7.7) [132], ciclesonide (p <i>K_i</i> 7.4) [6], prednisone (p <i>K_i</i> 6.3) [3], RU26988 – Unknown, RU28362, difluprednate [145], fluticasone	–	medroxyprogesterone (Affinity at human PR-A) (p <i>K_i</i> 9.5) [170], ORG2058, levonorgestrel [10 , 130]

(continued)				
Nomenclature	Androgen receptor	Glucocorticoid receptor	Mineralocorticoid receptor	Progesterone receptor
Antagonists	cyproterone acetate (pK _i 7.8) [55]	mifepristone (pK _d 9.4) [57, 127]	nimodipine (inhibition of aldosterone-induced luciferase activity in a reporter system driven by the mineralocorticoid receptor ligand binding domain) (pIC ₅₀ 6.8) [34]	–
Selective antagonists	bicalutamide (pK _i 7.7) [71], PF0998425 (pIC ₅₀ 7.1–7.5) [86], enzalutamide (pIC ₅₀ 7.4) [148], nilutamide (pIC ₅₀ 7.1–7.1) [136], hydroxyflutamide (pEC ₅₀ 6.6) [152], galeterone (pIC ₅₀ 6.4) [56], flutamide (Displacement of ³ [H] testosterone from wild-type androgen receptors) (pK _i 5.4) [151]	onapristone (pIC ₅₀ 7.6) [169], ZK112993	finerenone (pIC ₅₀ 7.7) [21], eplerenone (pK _i 6.9) [5], onapristone (pIC ₅₀ 6.3) [169], RU28318, ZK112993	ulipristal acetate (pIC ₅₀ 9.7) [124], mifepristone (Mixed) (pK _i 9) [171], onapristone (pK _i 7.7) [54], ZK112993
Labelled ligands	[³ H]dihydrotestosterone (Selective Agonist), [³ H]methyltrienolone (Selective Agonist), [³ H]mibolerone (Agonist)	[³ H]dexamethasone (Agonist)	[³ H]aldosterone (Selective Agonist) (pK _d 9.5–9.4) [44, 140] – Rat	[³ H]ORG2058 (Selective Agonist)

Comments: [³H]dexamethasone also binds to MR *in vitro*. PR antagonists have been suggested to subdivide into Type I (*e.g.* onapristone) and Type II (*e.g.* ZK112993) groups. These groups appear to promote binding of PR to DNA with different efficacies and evoke distinct conformational changes in the receptor, leading to a transcription-neutral complex [43, 83]. Mutations in AR underlie testicular feminization and androgen insensitivity syndromes, spinal and bulbar muscular atrophy (Kennedy's disease).

References

1. Akita K *et al.* (2013) [24177288]
2. Apfel C *et al.* (1992) [1323127]
3. Auerbach SS *et al.* National Toxicology Program: Dept of Health and Human Services. Accessed on 02/05/2014. [DrugMatrix](#).
4. Baker KD *et al.* (2003) [12809604]
5. Bell MG *et al.* (2007) [18038968]
6. Belvisi MG *et al.* (2005) [15878996]
7. Benoit G *et al.* (2006) [17132856]
8. Berger J *et al.* (1996) [8828476]
9. Bergh JJ *et al.* (2005) [15802494]
10. Bergink EW *et al.* (1983) [6645495]
11. Biggadike K *et al.* (2000) [10633034]
12. Bishop JE *et al.* (1994) [7976510]
13. Bishop-Bailey D *et al.* (2000) [11030710]
14. Bishop-Bailey D *et al.* (2003) [12749590]
15. Bitsch F *et al.* (2003) [14622968]
16. Blumberg B *et al.* (1998) [9784494]
17. Boehm MF *et al.* (1994) [8071941]
18. Brown KK *et al.* (1999) [10389847]
19. Brown PJ *et al.* (2001) [11354382]
20. Brun LD *et al.* (1980) [6777394]
21. Bärfacker L *et al.* (2012) [22791416]
22. Canan Koch SS *et al.* (1999) [10052980]
23. Chambon P. (1996) [8801176]
24. Chamness GC *et al.* (1980) [7355922]
25. Charpentier B *et al.* (1995) [8544175]
26. Charton J *et al.* (2009) [19058965]
27. Chiellini G *et al.* (1998) [9653548]
28. Collins JL *et al.* (2002) [11985463]
29. Colston KW *et al.* (1992) [1472092]
30. Dahlman-Wright K *et al.* (2006) [17132854]
31. De Filippis B *et al.* (2011) [21889235]
32. Del Tredici AL *et al.* (2008) [18055761]
33. Delescluse C *et al.* (1991) [1656191]
34. Dietz JD *et al.* (2008) [18250364]
35. Doebber TW *et al.* (2004) [15120604]
36. Downes M *et al.* (2003) [12718892]
37. Ebisawa M *et al.* (1999) [10748721]
38. Edwards JP *et al.* (1998) [9667968]
39. Erben RG *et al.* (2002) [12089348]
40. Flaig R *et al.* (2005) [15716272]
41. Flamant F *et al.* (2006) [17132849]
42. Fujishima T *et al.* (2003) [12901907]
43. Gass EK *et al.* (1998) [9528977]
44. Ge RS *et al.* (2005) [16188378]
45. Germain P *et al.* (2006) [17132853]
46. Germain P *et al.* (2006) [17132850]
47. Germain P *et al.* (2009) [19477412]
48. Germain P *et al.* (2002) [11805839]
49. Giwercman A *et al.* (2000) [10852459]
50. Graham TL *et al.* (2005) [15939051]
51. Grant D *et al.* (2010) [20677822]
52. Guo Q *et al.* (2004) [14701675]
53. Géhin M *et al.* (1999) [10421757]
54. Hamann LG *et al.* (1996) [8627601]
55. Hamann LG *et al.* (1998) [9484511]
56. Handratta VD *et al.* (2005) [15828836]
57. Heikinheimo O *et al.* (1987) [3560943]
58. Hellal-Levy C *et al.* (1999) [10611474]
59. Henke DR *et al.* (1998) [9836620]
60. Herdick M *et al.* (2000) [11094341]
61. Higuchi RI *et al.* (2007) [17439112]
62. Jain N *et al.* (2006) [16722623]
63. Jiang G *et al.* (1995) [7651430]
64. Jones SA *et al.* (2000) [10628745]
65. Kagechika H *et al.* (1988) [3184125]
66. Kallen J *et al.* (2004) [14722075]
67. Kallen JA *et al.* (2002) [12467577]
68. Kane CD *et al.* (2009) [18971326]
69. Kanno Y *et al.* (2013) [23665929]
70. Keidel S *et al.* (1994) [8264595]
71. Kinoyama I *et al.* (2006) [16420057]
72. Kiselyuk A *et al.* (2012) [22840769]
73. Kojetin D *et al.* (2010) [21043485]
74. Kraichely DM *et al.* (2000) [11014206]
75. Kuiper GG *et al.* (1997) [9048584]
76. Land PW *et al.* (2003) [12902391]
77. Le Q *et al.* (2000) [10723137]
78. Lee G *et al.* (2002) [11877444]
79. Leesnitzer LM *et al.* (2002) [12022867]
80. Lehmann JM *et al.* (1997) [9013544]
81. Lehmann JM *et al.* (1997) [9013583]
82. Lehmann JM *et al.* (1998) [9727070]
83. Leonhardt SA *et al.* (1998) [9849965]
84. Levin ER. (2008) [18784332]
85. Li E. (1999) [10331664]
86. Li JJ *et al.* (2008) [18921992]
87. Lind U *et al.* (2000) [10747884]
88. Liu KG *et al.* (2001) [11720854]
89. Lu NZ *et al.* (2006) [17132855]
90. Lund BW *et al.* (2005) [16302793]
91. Madoux F *et al.* (2008) [18334597]
92. Maglich JM *et al.* (2003) [12611900]
93. Makishima M *et al.* (1999) [10334992]
94. Malamas MS *et al.* (2004) [15456246]
95. Maloney PR *et al.* (2000) [10956205]
96. Manfredi MC *et al.* (2007) [17574413]
97. Mangelsdorf DJ *et al.* (1995) [8521508]
98. McIntyre TM *et al.* (2003) [12502787]
99. Meyers MJ *et al.* (1999) [10395487]
100. Meyers MJ *et al.* (2001) [11708925]
101. Michalik L *et al.* (2006) [17132851]
102. Millan DS *et al.* (2011) [21880489]
103. Miller CP *et al.* (2001) [11356100]
104. Monaghan AP *et al.* (1997) [9394001]
105. Moore DD *et al.* (2006) [17132852]
106. Moore LB *et al.* (2000) [10852961]
107. Moore LB *et al.* (2000) [10748001]
108. Nagy L *et al.* (1995) [7791761]
109. Nahous V *et al.* (2007) [17947383]
110. Nakamuta M *et al.* (2002) [11991651]
111. Nguyen NH *et al.* (2002) [12109914]
112. Ning M *et al.* (2007) [17115070]
113. Oliver WR *et al.* (2001) [11309497]
114. Otte K *et al.* (2003) [12529392]
115. Paravicini G *et al.* (1996) [8858107]
116. Parks DJ *et al.* (1999) [10334993]
117. Pellicciari R *et al.* (2002) [12166927]
118. Pereira FA *et al.* (1999) [10215630]
119. Prossnitz ER *et al.* (2008) [18271749]
120. Prossnitz ER *et al.* (2009) [19389460]
121. Qiu Y *et al.* (1997) [9271116]
122. Raghuram S *et al.* (2007) [18037887]
123. Repa JJ *et al.* (2000) [10968783]
124. Rewinkel J *et al.* (2008) [18243712]
125. Rocchi S *et al.* (2001) [11684010]
126. Rousseaux C *et al.* (2005) [15824083]
127. Rupperecht R *et al.* (1993) [8282004]
128. Saito N *et al.* (2006) [17125259]
129. Sakamoto J *et al.* (2000) [11095972]
130. Schindler AE *et al.* (2003) [14670641]
131. Schupp M *et al.* (2007) [17290005]
132. Schäcke H *et al.* (2004) [14694204]
133. Sharma SK *et al.* (1977) [269396]
134. Shearer BG *et al.* (2008) [17975020]
135. Shyr CR *et al.* (2002) [12052874]
136. Simard J *et al.* (1997) [9111629]
137. Smith JL *et al.* (2008) [18603275]
138. Stauffer SR *et al.* (2000) [11150164]
139. Stehlin-Gaon C *et al.* (2003) [12958591]
140. Stephenson G *et al.* (1984) [6320679]
141. Suetsugi M *et al.* (2003) [14638870]
142. Sun J *et al.* (2002) [11861516]
143. Sun J *et al.* (1999) [9927308]
144. Sznajdman ML *et al.* (2003) [12699745]
145. Tajika T *et al.* (2011) [21182429]
146. Thacher SM *et al.* (2000) [10637371]
147. Tilley WD *et al.* (1989) [2911578]
148. Tran C *et al.* (2009) [19359544]
149. Tzamelis I *et al.* (2000) [10757780]
150. Vegeto E *et al.* (1993) [8264658]
151. Wakabayashi K *et al.* (2008) [18571420]
152. Wang LG *et al.* (1998) [10076535]
153. Wang Y *et al.* (2000) [11043571]
154. Wang Z *et al.* (2003) [12774125]
155. Warnecke M *et al.* (2005) [15741322]
156. Wentworth JM *et al.* (2000) [10974665]
157. Wiberg K *et al.* (1995) [8573413]
158. Wiesenberg I *et al.* (1995) [7885826]
159. Willson TM *et al.* (2000) [10691680]
160. Willy PJ *et al.* (2004) [15184675]
161. Wu J *et al.* (2002) [12089353]
162. Xu HE *et al.* (2002) [11845213]
163. Xu Y *et al.* (2004) [15115385]
164. Yin L *et al.* (2007) [18006707]
165. Young PW *et al.* (1998) [9454824]
166. Yu DD *et al.* (2005) [15713377]
167. Yuan X *et al.* (2009) [19440305]
168. Zhan Y *et al.* (2008) [18690216]
169. Zhi L *et al.* (2003) [12781198]
170. Zhi L *et al.* (1998) [9464360]
171. Zhi L *et al.* (2003) [12781197]
172. Zhou HB *et al.* (2007) [17228884]
173. Zhou XE *et al.* (2011) [21068381]
174. Zhu Y *et al.* (2003) [12601167]
175. Zhu Y *et al.* (2003) [12574519]