










# The Concise Guide to PHARMACOLOGY 2023/24: Nuclear hormone receptors

Stephen P. H. Alexander<sup>1</sup> , John A. Cidlowski<sup>2</sup> , Eamonn Kelly<sup>3</sup>, Alistair A. Mathie<sup>4</sup> , John A. Peters<sup>5</sup> ,  
Emma L. Veale<sup>6</sup> , Jane F. Armstrong<sup>7</sup> , Elena Faccenda<sup>7</sup> , Simon D. Harding<sup>7</sup> , Jamie A. Davies<sup>7</sup> , Laurel Coons<sup>8</sup>,  
Peter J. Fuller<sup>9</sup>, Kenneth S. Korach<sup>10</sup> and Morag J. Young<sup>11</sup>

<sup>1</sup>School of Life Sciences, University of Nottingham Medical School, Nottingham, NG7 2UH, UK, <sup>2</sup>National Institute of Environmental Health Sciences, National Institutes of Health, Department of Health and Human Services, Research Triangle Park, NC 27709, USA, <sup>3</sup>School of Allied Health Sciences, University of Bristol, Bristol, BS8 1TD, UK, <sup>4</sup>School of Engineering, Arts, Science and Technology, University of Suffolk, Ipswich, IP4 1QJ, UK, <sup>5</sup>Neuroscience Division, Medical Education Institute, Ninewells Hospital and Medical School, University of Dundee, Dundee, DD1 9SY, UK, <sup>6</sup>Medway School of Pharmacy, The Universities of Greenwich and Kent at Medway, Anson Building, Central Avenue, Chatham Maritime, Chatham, Kent, ME4 4TB, UK, <sup>7</sup>Centre for Discovery Brain Sciences, University of Edinburgh, Edinburgh, EH8 9XD, UK, <sup>8</sup>Duke University Medical Center, Durham, NC, USA, <sup>9</sup>Hudson Institute of Medical Research, Clayton, Australia, <sup>10</sup>National Institute of Health, Research Triangle Park, NC, USA, <sup>11</sup>Monash University, Melbourne, Australia



## Abstract

The Concise Guide to PHARMACOLOGY 2023/24 is the sixth in this series of biennial publications. The Concise Guide provides concise overviews, mostly in tabular format, of the key properties of approximately 1800 drug targets, and nearly 6000 interactions with about 3900 ligands. There is an emphasis on selective pharmacology (where available), plus links to the open access knowledgebase source of drug targets and their ligands (<https://www.guidetopharmacology.org/>), which provides more detailed views of target and ligand properties. Although the Concise Guide constitutes almost 500 pages, the material presented is substantially reduced compared to information and links presented on the website. It provides a permanent, citable, point-in-time record that will survive database updates. The full contents of this section can be found at <http://onlinelibrary.wiley.com/doi/10.1111/bph.16179>. Nuclear hormone receptors are one of the six major pharmacological targets into which the Guide is divided, with the others being: G protein-coupled receptors, 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 landscape format of the Concise Guide is designed to facilitate comparison of related targets from material contemporary to mid-2023, and supersedes data presented in the 2021/22, 2019/20, 2017/18, 2015/16 and 2013/14 Concise Guides and previous Guides to Receptors and Channels. It is produced in close conjunction with the Nomenclature and Standards Committee of the International Union of Basic and Clinical Pharmacology (NC-IUPHAR), therefore, providing official IUPHAR classification and nomenclature for human drug targets, where appropriate.

## Conflict of interest

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

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**Overview:** Nuclear 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

S224	1A. Thyroid hormone receptors	S230	2A. Hepatocyte nuclear factor-4 receptors	S234	5A. Fushi tarazu F1-like receptors
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S227	1F. Retinoic acid-related orphans	S232	2F. COUP-TF-like receptors	S237	3A. Estrogen receptors
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## 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** [1, 40]) are nuclear hormone receptors of the NR1A family, with diverse roles regulating macronutrient metabolism, cognition and cardiovascular homeostasis. TRs are activated by thyroxine ( $T_4$ ) 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 TR $\beta$  [108].

Nomenclature	Thyroid hormone receptor- $\alpha$	Thyroid hormone receptor- $\beta$
Systematic nomenclature	NR1A1	NR1A2
HGNC, UniProt	<a href="#">THRA</a> , <a href="#">P10827</a>	<a href="#">THRB</a> , <a href="#">P10828</a>
Rank order of potency	triiodothyronine > T <sub>4</sub>	triiodothyronine > T <sub>4</sub>
Agonists	dextrothyroxine [19]	dextrothyroxine [19]
Selective agonists	–	sobetirome [24, 128]

**Comments:** An interaction with integrin  $\alpha V\beta 3$  has been suggested to underlie plasma membrane localization of TRs and non-genomic signalling [8]. One splice variant, TR $\alpha_2$ , 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 on 1A. Thyroid hormone receptors

- Elbers LP *et al.* (2016) Thyroid Hormone Mimetics: the Past, Current Status and Future Challenges. *Curr Atheroscler Rep* **18**: 14 [PMID:26886134]
- Mendoza A *et al.* (2017) New insights into thyroid hormone action. *Pharmacol Ther* **173**: 135-145 [PMID:28174093]
- 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]

## 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** [1, 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 [48].

Nomenclature	Retinoic acid receptor- $\alpha$	Retinoic acid receptor- $\beta$	Retinoic acid receptor- $\gamma$
Systematic nomenclature	NR1B1	NR1B2	NR1B3
HGNC, UniProt	<a href="#">RARA</a> , <a href="#">P10276</a>	<a href="#">RARB</a> , <a href="#">P10826</a>	<a href="#">RARG</a> , <a href="#">P13631</a>
Agonists	<a href="#">tretinoin</a> [23]	<a href="#">tretinoin</a> [23]	<a href="#">tretinoin</a> [23]
Sub/family-selective agonists	<a href="#">tazarotene</a> [23]	<a href="#">tazarotene</a> [23], <a href="#">adapalene</a> [22]	<a href="#">tazarotene</a> [23], <a href="#">adapalene</a> [22]
Selective agonists	<a href="#">BMS753</a> [45], <a href="#">tamibarotene</a> [146], <a href="#">Ro 40-6055</a> [31]	<a href="#">AC261066</a> [87], <a href="#">AC55649</a> [86, 87]	<a href="#">AHPN</a> [22]
Selective antagonists	<a href="#">Ro 41-5253</a> (pIC <sub>50</sub> 6.3–7.2) [2, 68]	–	<a href="#">MM 11253</a> [75]

**Comments:** [Ro 41-5253](#) has been suggested to be a PPAR $\gamma$  agonist [127]. [LE135](#) is an antagonist with selectivity for RAR $\alpha$  and RAR $\beta$  compared with RAR $\gamma$  [83].

**Further reading on 1B. Retinoic acid receptors**

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]

Larange A *et al.* (2016) Retinoic Acid and Retinoic Acid Receptors as Pleiotropic Modulators of the Immune System. *Annu Rev Immunol* **34**: 369-94 [PMID:27168242]  
 Saeed A *et al.* (2017) The interrelationship between bile acid and vitamin A homeostasis. *Biochim Biophys Acta* **1862**: 496-512 [PMID:28111285]

# 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** [1, 99]) 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 [13, 99], including 15-deoxy- $\Delta^{12,14}$ -PGJ<sub>2</sub>, prostacyclin

(PGI<sub>2</sub>), many fatty acids and their oxidation products, lysophosphatidic acid (LPA) [96], 13-HODE, 15S-HETE, Paz-PC, azelaoyl-PAF and leukotriene B<sub>4</sub> (LTB<sub>4</sub>). Bezafibrate acts as a non-selective agonist for the PPAR family [155]. These receptors also bind hypolipidaemic drugs (PPAR $\alpha$ ) and anti-diabetic thiazolidinediones (PPAR $\gamma$ ), 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- $\alpha$	Peroxisome proliferator-activated receptor- $\beta/\delta$	Peroxisome proliferator-activated receptor- $\gamma$
Systematic nomenclature	NR1C1	NR1C2	NR1C3
HGNC, UniProt	PPARA, Q07869	PPARD, Q03181	PPARG, P37231
Selective agonists	GW7647 [17, 18], CP-775146 [66], pirinixic acid [155], gemfibrozil [29]	GW0742X [51, 140], GW501516 [110]	GW1929 [17], bardoxxolone (Partial agonist) [149], rosiglitazone [58, 79, 161], troglitazone [58, 161], pioglitazone [58, 125, 161], ciglitazone [58]
Selective antagonists	GW6471 (pIC <sub>50</sub> 6.6) [158]	GSK0660 (pIC <sub>50</sub> 6.5) [129]	T0070907 (pK <sub>i</sub> 9) [76], GW9662 (Irreversible inhibition) (pIC <sub>50</sub> 8.1) [77], CDDO-Me (pK <sub>i</sub> 6.9) [149]

**Comments:** As with the estrogen receptor antagonists, many agents show tissue-selective efficacy (*e.g.* [12, 107, 122]). Agonists with mixed activity at PPAR $\alpha$  and PPAR $\gamma$  have also been described (*e.g.* [32, 54, 159]).

**Further reading on 1C. Peroxisome proliferator-activated receptors**

Cheang WS *et al.* (2015) The peroxisome proliferator-activated receptors in cardiovascular diseases: experimental benefits and clinical challenges. *Br J Pharmacol* **172**: 5512-22 [PMID:25438608]  
 Gross B *et al.* (2017) PPARs in obesity-induced T2DM, dyslipidaemia and NAFLD. *Nat Rev Endocrinol* **13**: 36-49 [PMID:27636730]

Hallenborg P *et al.* (2016) The elusive endogenous adipogenic PPAR $\gamma$  agonists: Lining up the suspects. *Prog Lipid Res* **61**: 149-62 [PMID:26703188]  
 Michalik L *et al.* (2006) International Union of Pharmacology. LXI. Peroxisome proliferator-activated receptors. *Pharmacol Rev* **58**: 726-41 [PMID:17132851]  
 Sauer S. (2015) Ligands for the Nuclear Peroxisome Proliferator-Activated Receptor Gamma. *Trends Pharmacol Sci* **36**: 688-704 [PMID:26435213]

## 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** [1, 7]) have yet to be officially paired with an endogenous ligand, but are thought to be activated by heme.

Nomenclature	Rev-Erb- $\alpha$	Rev-Erb- $\beta$
Systematic nomenclature	NR1D1	NR1D2
HGNC, UniProt	<a href="#">NR1D1</a> , <a href="#">P20393</a>	<a href="#">NR1D2</a> , <a href="#">Q14995</a>
Endogenous agonists	<a href="#">heme</a> [119, 160]	<a href="#">heme</a> [95, 119, 160]
Selective agonists	<a href="#">GSK4112</a> [52], <a href="#">GSK4112</a> [71]	–
Selective antagonists	<a href="#">SR8278</a> (pIC <sub>50</sub> 6.5) [71]	–

### Further reading on 1D. Rev-Erb receptors

- Benoit G *et al.* (2006) International Union of Pharmacology. LXVI. Orphan nuclear receptors. *Pharmacol Rev* **58**: 798-836 [[PMID:17132856](#)]
- Gonzalez-Sanchez E *et al.* (2015) Nuclear receptors in acute and chronic cholestasis. *Dig Dis* **33**: 357-66 [[PMID:26045270](#)]
- Gustafson CL *et al.* (2015) Emerging models for the molecular basis of mammalian circadian timing. *Biochemistry* **54**: 134-49 [[PMID:25303119](#)]
- Sousa EH *et al.* (2017) Drug discovery targeting heme-based sensors and their coupled activities. *J Inorg Biochem* **167**: 12-20 [[PMID:27893989](#)]

## 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** [1, 7]) have yet to be assigned a definitive endogenous ligand, although ROR $\alpha$  may be synthesized with a 'captured' agonist such as [cholesterol](#) [64, 65].

Nomenclature	RAR-related orphan receptor- $\alpha$	RAR-related orphan receptor- $\beta$	RAR-related orphan receptor- $\gamma$
Systematic nomenclature	NR1F1	NR1F2	NR1F3
HGNC, UniProt	<a href="#">RORA</a> , <a href="#">P35398</a>	<a href="#">RORB</a> , <a href="#">Q92753</a>	<a href="#">RORC</a> , <a href="#">P51449</a>
Endogenous agonists	<a href="#">cholesterol</a> [65, 112]	–	–
Selective agonists	<a href="#">7-hydroxycholesterol</a> [14], <a href="#">cholesterol sulphate</a> [14, 65]	–	–
Comments	–	–	The immune system function of RORC proteins most likely resides with expression of the ROR $\gamma$ t isoform by immature CD4 <sup>+</sup> /CD8 <sup>+</sup> cells in the thymus [34, 139] and in lymphoid tissue inducer (LTi) cells [35].

**Comments:** [Tretinoin](#) shows selectivity for ROR $\beta$  within the ROR family [134]. ROR $\alpha$  has been suggested to be a nuclear receptor responding to [melatonin](#) [154].

### Further reading on 1F. Retinoic acid-related orphans

- Benoit G *et al.* (2006) International Union of Pharmacology. LXVI. Orphan nuclear receptors. *Pharmacol Rev* **58**: 798-836 [PMID:17132856]
- Cyr P *et al.* (2016) Recent progress on nuclear receptor ROR $\gamma$  modulators. *Bioorg Med Chem Lett* **26**: 4387-4393 [PMID:27542308]
- Germain P *et al.* (2006) Overview of nomenclature of nuclear receptors. *Pharmacol Rev* **58**: 685-704 [PMID:17132848]
- Guillemot-Legris O *et al.* (2016) Oxysterols in Metabolic Syndrome: From Bystander Molecules to Bioactive Lipids. *Trends Mol Med* **22**: 594-614 [PMID:27286741]
- Mutemberezi V *et al.* (2016) Oxysterols: From cholesterol metabolites to key mediators. *Prog Lipid Res* **64**: 152-169 [PMID:27687912]

## 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** [1, 103]) 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. In humans and primates, *NR1H5P* is a pseudogene. However, in other mammals, it encodes a functional nuclear hormone receptor that appears to be involved in cholesterol biosynthesis [111].

Nomenclature	Farnesoid X receptor	Farnesoid X receptor- $\beta$	Liver X receptor- $\alpha$	Liver X receptor- $\beta$
Systematic nomenclature	NR1H4	NR1H5	NR1H3	NR1H2
HGNC, UniProt	<a href="#">NR1H4</a> , <a href="#">Q96RI1</a>	<a href="#">NR1H5P</a> , –	<a href="#">NR1H3</a> , <a href="#">Q13133</a>	<a href="#">NR1H2</a> , <a href="#">P55055</a>
Potency order	chenodeoxycholic acid > lithocholic acid, deoxycholic acid [90, 113]	–	20S-hydroxycholesterol, 22R-hydroxycholesterol, 24(S)-hydroxycholesterol > 25-hydroxycholesterol, 27-hydroxycholesterol [78]	20S-hydroxycholesterol, 22R-hydroxycholesterol, 24(S)-hydroxycholesterol > 25-hydroxycholesterol, 27-hydroxycholesterol [78]
Endogenous agonists	–	lanosterol [111] – Mouse	–	–
Selective agonists	<a href="#">GW4064</a> [92], <a href="#">obeticholic acid</a> [114], <a href="#">fexaramine</a> [33]	–	–	–
Selective antagonists	<a href="#">guggulsterone</a> (pIC <sub>50</sub> 5.7–6) [157]	–	–	–

**Comments:** [T0901317](#) [120] and [GW3965](#) [25] are synthetic agonists acting at both LXR $\alpha$  and LXR $\beta$  with less than 10-fold selectivity.

**Further reading on 1H. Liver X receptor-like receptors**

Courtney R *et al.* (2016) LXR Regulation of Brain Cholesterol: From Development to Disease. *Trends Endocrinol Metab* **27**: 404-414 [PMID:27113081]

El-Gendy BEM *et al.* (2018) Recent Advances in the Medicinal Chemistry of Liver X Receptors. *J Med Chem* **61**: 10935-10956 [PMID:30004226]

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]

Merlen G *et al.* (2017) Bile acids and their receptors during liver regeneration: "Dangerous protectors". *Mol Aspects Med* **56**: 25-33 [PMID:28302491]

Moore DD *et al.* (2006) International Union of Pharmacology. LXII. The NR1H and NR1I receptors: constitutive androstane receptor, pregnene 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]

Mouzat K *et al.* (2016) Liver X receptors: from cholesterol regulation to neuroprotection-a new barrier against neurodegeneration in amyotrophic lateral sclerosis? *Cell Mol Life Sci* **73**: 3801-8 [PMID:27510420]

Schulman IG. (2017) Liver X receptors link lipid metabolism and inflammation. *FEBS Lett* **591**: 2978-2991 [PMID:28555747]

## 1I. Vitamin D receptor-like receptors

Nuclear hormone receptors → 1I. 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** [1, 103]) are members of the NR1I 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 [103].

Nomenclature	Vitamin D receptor	Pregnane X receptor	Constitutive androstane receptor
Systematic nomenclature	NR111	NR112	NR113
HGNC, UniProt	<a href="#">VDR</a> , <a href="#">P11473</a>	<a href="#">NR112</a> , <a href="#">O75469</a>	<a href="#">NR113</a> , <a href="#">Q14994</a>
Endogenous agonists	<a href="#">1,25-dihydroxyvitamin D3</a> [11, 38]	<a href="#">17β-estradiol</a> [63]	–
Selective agonists	<a href="#">seocalcitol</a> [26, 153], <a href="#">doxercalciferol</a>	<a href="#">hyperforin</a> [104, 152], <a href="#">5β-pregnane-3,20-dione</a> [63], <a href="#">lovastatin</a> [80], <a href="#">rifampicin</a> [15, 80]	<a href="#">TCPOBOP</a> [144] – Mouse, <a href="#">CITCO</a> [89]
Selective antagonists	<a href="#">TEI-9647</a> (pIC <sub>50</sub> 8.2) [124] – Chicken, <a href="#">ZK159222</a> (pIC <sub>50</sub> 7.5) [41, 59]	–	–
Comments	–	–	<a href="#">Clotrimazole</a> [105] and <a href="#">T0901317</a> [67] although acting at other targets, function as antagonists of the constitutive androstane receptor.

**Further reading on 1I. Vitamin D receptor-like receptors**

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

Long MD *et al.* (2015) Vitamin D receptor and RXR in the post-genomic era. *J Cell Physiol* **230**: 758-66 [PMID:25335912]

Moore DD *et al.* (2006) International Union of Pharmacology. LXII. The NR1H and NR1I receptors: constitutive androstane receptor, pregnene 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]



## 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** [1, 7]. While linoleic acid has been identified as the endogenous ligand for HNF4 $\alpha$  its function remains ambiguous [163]. HNF4 $\gamma$  has yet to be paired with an endogenous ligand.

Nomenclature	Hepatocyte nuclear factor-4 $\alpha$	Hepatocyte nuclear factor-4 $\gamma$
Systematic nomenclature	NR2A1	NR2A2
HGNC, UniProt	<a href="#">HNF4A</a> , <a href="#">P41235</a>	<a href="#">HNF4G</a> , <a href="#">Q14541</a>
Endogenous agonists	<a href="#">linoleic acid</a> [163]	–
Selective antagonists	<a href="#">BI6015</a> [70]	–
Comments	HNF4 $\alpha$ has constitutive transactivation activity [163] and binds DNA as a homodimer [62].	

### Further reading on 2A. Hepatocyte nuclear factor-4 receptors

- Benoit G *et al.* (2006) International Union of Pharmacology. LXVI. Orphan nuclear receptors. *Pharmacol Rev* **58**: 798-836 [PMID:17132856]
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- Germain P *et al.* (2006) Overview of nomenclature of nuclear receptors. *Pharmacol Rev* **58**: 685-704 [PMID:17132848]
- Lu H. (2016) Crosstalk of HNF4 $\alpha$  with extracellular and intracellular signaling pathways in the regulation of hepatic metabolism of drugs and lipids. *Acta Pharm Sin B* **6**: 393-408 [PMID:27709008]
- Walesky C *et al.* (2015) Role of hepatocyte nuclear factor 4 $\alpha$  (HNF4 $\alpha$ ) in cell proliferation and cancer. *Gene Expr* **16**: 101-8 [PMID:25700366]

## 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** [1, 47]) are NR2B family members activated by [alitretinoin](#) and the RXR-selective agonists [bexarotene](#) and [LG100268](#), sometimes referred to as rexinoids. [UVI3003](#) [106] and [HX 531](#) [36] have been described as a pan-RXR antagonists. These receptors form RXR-RAR heterodimers and RXR-RXR homodimers [21, 94].



Nomenclature	Retinoid X receptor- $\alpha$	Retinoid X receptor- $\beta$	Retinoid X receptor- $\gamma$
Systematic nomenclature	NR2B1	NR2B2	NR2B3
HGNC, UniProt	<a href="#">RXRA</a> , <a href="#">P19793</a>	<a href="#">RXRB</a> , <a href="#">P28702</a>	<a href="#">RXRG</a> , <a href="#">P48443</a>
Sub/family-selective agonists	bexarotene [16, 20, 141]	bexarotene [16, 20, 141]	bexarotene [16, 20, 141]
Selective agonists	<a href="#">CD3254</a> [49]	–	–

### Further reading on 2B. Retinoid X receptors

- Germain P *et al.* (2006) International Union of Pharmacology. LXIII. Retinoid X receptors. *Pharmacol Rev* **58**: 760-72 [PMID:17132853]
- Long MD *et al.* (2015) Vitamin D receptor and RXR in the post-genomic era. *J Cell Physiol* **230**: 758-66 [PMID:25335912]
- Menéndez-Gutiérrez MP *et al.* (2017) The multi-faceted role of retinoid X receptor in bone remodeling. *Cell Mol Life Sci* **74**: 2135-2149 [PMID:28105491]

## 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	<a href="#">NR2C1</a> , <a href="#">P13056</a>	<a href="#">NR2C2</a> , <a href="#">P49116</a>
Endogenous agonists	–	retinol [169], tretinoin [169]
Comments	Forms a heterodimer with TR4; gene disruption appears without effect on testicular development or function [130].	Forms a heterodimer with TR2.

### Further reading on 2C. Testicular receptors

- 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]
- Safe S *et al.* (2014) Minireview: role of orphan nuclear receptors in cancer and potential as drug targets. *Mol Endocrinol* **28**: 157-72 [PMID:24295738]
- Wu D *et al.* (2016) The emerging roles of orphan nuclear receptors in prostate cancer. *Biochim Biophys Acta* **1866**: 23-36 [PMID:27264242]

## 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	<a href="#">NR2E1</a> , <a href="#">Q9Y466</a>	<a href="#">NR2E3</a> , <a href="#">Q9Y5X4</a>
Agonists	<a href="#">BMS493</a> [53], <a href="#">tretinoin</a> [53]	–
Comments	Gene disruption is associated with abnormal brain development [74, 102].	–

### Further reading on 2E. Tailless-like receptors

Benod C *et al.* (2016) TLX: An elusive receptor. *J Steroid Biochem Mol Biol* **157**: 41-7 [PMID:26554934]

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]

O'Leary JD *et al.* (2018) Regulation of behaviour by the nuclear receptor TLX. *Genes Brain Behav* **17**: e12357 [PMID:27790850]

## 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 [1, 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	<a href="#">NR2F1</a> , <a href="#">P10589</a>	<a href="#">NR2F2</a> , <a href="#">P24468</a>	<a href="#">NR2F6</a> , <a href="#">P10588</a>
Comments	Gene disruption is perinatally lethal [118].	Gene disruption is embryonically lethal [115].	Gene disruption impairs CNS development [151].

### Further reading on 2F. COUP-TF-like receptors

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]

Wu D *et al.* (2016) The emerging roles of orphan nuclear receptors in prostate cancer. *Biochim Biophys Acta* **1866**: 23-36 [PMID:27264242]  
 Wu SP *et al.* (2016) Choose your destiny: Make a cell fate decision with COUP-TFII. *J Steroid Biochem Mol Biol* **157**: 7-12 [PMID:26658017]

## 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- $\alpha$	Estrogen-related receptor- $\beta$	Estrogen-related receptor- $\gamma$
Systematic nomenclature	NR3B1	NR3B2	NR3B3
HGNC, UniProt	<a href="#">ESRRA</a> , <a href="#">P11474</a>	<a href="#">ESRRB</a> , <a href="#">O95718</a>	<a href="#">ESRRG</a> , <a href="#">P62508</a>
Comments	Activated by some dietary flavonoids [136]; activated by the synthetic agonist <a href="#">GSK4716</a> [172] and blocked by <a href="#">XCT790</a> [156].	May be activated by <a href="#">DY131</a> [162].	May be activated by <a href="#">DY131</a> [162].

### Further reading on 3B. Estrogen-related receptors

Benoit G *et al.* (2006) International Union of Pharmacology. LXVI. Orphan nuclear receptors. *Pharmacol Rev* **58**: 798-836 [PMID:17132856]  
 Divekar SD *et al.* (2016) Estrogen-related receptor  $\beta$  (ERR $\beta$ ) - renaissance receptor or receptor renaissance? *Nucl Recept Signal* **14**: e002 [PMID:27507929]  
 Germain P *et al.* (2006) Overview of nomenclature of nuclear receptors. *Pharmacol Rev* **58**: 685-704 [PMID:17132848]

Tam IS *et al.* (2016) There and back again: The journey of the estrogen-related receptors in the cancer realm. *J Steroid Biochem Mol Biol* **157**: 13-9 [PMID:26151739]  
 Wu D *et al.* (2016) The emerging roles of orphan nuclear receptors in prostate cancer. *Biochim Biophys Acta* **1866**: 23-36 [PMID:27264242]

## 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	<a href="#">Nerve Growth factor IB</a>	<a href="#">Nuclear receptor related 1</a>	<a href="#">Neuron-derived orphan receptor 1</a>
Systematic nomenclature	NR4A1	NR4A2	NR4A3
HGNC, UniProt	<a href="#">NR4A1, P22736</a>	<a href="#">NR4A2, P43354</a>	<a href="#">NR4A3, Q92570</a>
Comments	An endogenous agonist, <a href="#">cytosporone B</a> , has been described [164], although structural analysis and molecular modelling has not identified a ligand binding site [4, 39, 150].	–	–

### Further reading on 4A. Nerve growth factor IB-like receptors

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]

Ranhotra HS. (2015) The NR4A orphan nuclear receptors: mediators in metabolism and diseases. *J Recept Signal Transduct Res* **35**: 184-8 [PMID:25089663]

Rodríguez-Calvo R *et al.* (2017) The NR4A subfamily of nuclear receptors: potential new therapeutic targets for the treatment of inflammatory diseases. *Expert Opin Ther Targets* **21**: 291-304 [PMID:28055275]

Safe S *et al.* (2016) Nuclear receptor 4A (NR4A) family - orphans no more. *J Steroid Biochem Mol Biol* **157**: 48-60 [PMID:25917081]

## 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	<a href="#">Steroidogenic factor 1</a>	<a href="#">Liver receptor homolog-1</a>
Systematic nomenclature	NR5A1	NR5A2
HGNC, UniProt	<a href="#">NR5A1, Q13285</a>	<a href="#">NR5A2, O00482</a>
Comments	Reported to be inhibited by <a href="#">AC45594</a> [30] and <a href="#">SID7969543</a> [88].	–

### Further reading on 5A. Fushi tarazu F1-like receptors

Benoit G *et al.* (2006) International Union of Pharmacology. LXVI. Orphan nuclear receptors. *Pharmacol Rev* **58**: 798-836 [PMID:17132856]  
Garattini E *et al.* (2016) Lipid-sensors, enigmatic-orphan and orphan nuclear receptors as therapeutic targets in breast-cancer. *Oncotarget* **7**: 42661-42682 [PMID:26894976]  
Germain P *et al.* (2006) Overview of nomenclature of nuclear receptors. *Pharmacol Rev* **58**: 685-704 [PMID:17132848]

Zhi X *et al.* (2016) Structures and regulation of non-X orphan nuclear receptors: A retinoid hypothesis. *J Steroid Biochem Mol Biol* **157**: 27-40 [PMID:26159912]  
Zimmer V *et al.* (2015) Nuclear receptor variants in liver disease. *Dig Dis* **33**: 415-9 [PMID:26045277]

## 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 on 6A. Germ cell nuclear factor receptors

Benoit G *et al.* (2006) International Union of Pharmacology. LXVI. Orphan nuclear receptors. *Pharmacol Rev* **58**: 798-836 [PMID:17132856]  
Garattini E *et al.* (2016) Lipid-sensors, enigmatic-orphan and orphan nuclear receptors as therapeutic targets in breast-cancer. *Oncotarget* **7**: 42661-42682 [PMID:26894976]  
Germain P *et al.* (2006) Overview of nomenclature of nuclear receptors. *Pharmacol Rev* **58**: 685-704 [PMID:17132848]

Safe S *et al.* (2014) Minireview: role of orphan nuclear receptors in cancer and potential as drug targets. *Mol Endocrinol* **28**: 157-72 [PMID:24295738]  
Zhi X *et al.* (2016) Structures and regulation of non-X orphan nuclear receptors: A retinoid hypothesis. *J Steroid Biochem Mol Biol* **157**: 27-40 [PMID:26159912]

## 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	NROB1	NROB2
HGNC, UniProt	<a href="#">NROB1</a> , <a href="#">P51843</a>	<a href="#">NROB2</a> , <a href="#">Q15466</a>

### Further reading on OB. DAX-like receptors

- Benoit G *et al.* (2006) International Union of Pharmacology. LXVI. Orphan nuclear receptors. *Pharmacol Rev* **58**: 798-836 [PMID:17132856]
- Garattini E *et al.* (2016) Lipid-sensors, enigmatic-orphan and orphan nuclear receptors as therapeutic targets in breast-cancer. *Oncotarget* **7**: 42661-42682 [PMID:26894976]
- Germain P *et al.* (2006) Overview of nomenclature of nuclear receptors. *Pharmacol Rev* **58**: 685-704 [PMID:17132848]
- Safe S *et al.* (2014) Minireview: role of orphan nuclear receptors in cancer and potential as drug targets. *Mol Endocrinol* **28**: 157-72 [PMID:24295738]
- Wu D *et al.* (2016) The emerging roles of orphan nuclear receptors in prostate cancer. *Biochim Biophys Acta* **1866**: 23-36 [PMID:27264242]

## 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** [1, 28, 85]) are nuclear hormone receptors of the NR3 class, with endogenous agonists that may be divided into 3-hydroxysteroids (**estrone** and **17 $\beta$ -estradiol**) and 3-ketosteroids (**dihydrotestosterone** [DHT], **aldosterone**, **cortisol**, **corticosterone**, **progesterone** and **testosterone**). These receptors exist as dimers coupled with chaperone molecules (such as **hsp90 $\beta$**  (**HSP90A1**, **P08238**) and immunophilin FKBP52:**FKBP4**, **Q02790**), which are shed on binding the steroid hormone. Al-

though rapid signalling phenomena are observed [82, 117], 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 AGAACAnnnTGTTCT (*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  $\kappa$ B (NF- $\kappa$ B). Splice variants of each of these receptors can form functional or non-functional monomers that can dimerize to form functional or non-functional re-

ceptors. 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 [145]. A 7TM receptor responsive to estrogen (**GPER1**, **Q99527**, also known as GPR30, see [116]) has been described. Human orthologues of 7TM 'membrane progesterin receptors' (**PAQR7**, **PAQR8** and **PAQR5**), initially discovered in fish [170, 171], appear to localize to intracellular membranes and respond to 'non-genomic' progesterone analogues independently of G proteins [132].

## 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 [1]. 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	<a href="#">Estrogen receptor-<math>\alpha</math></a>	<a href="#">Estrogen receptor-<math>\beta</math></a>
Systematic nomenclature	NR3A1	NR3A2
HGNC, UniProt	<a href="#">ESR1</a> , <a href="#">P03372</a>	<a href="#">ESR2</a> , <a href="#">Q92731</a>
Endogenous agonists	<a href="#">estriol</a> [73], <a href="#">estrone</a> [73]	–
Selective agonists	<a href="#">propylpyrazoneletriol</a> [72, 133], <a href="#">ethinylestradiol</a> [61]	<a href="#">WAY200070</a> [91], <a href="#">diarylpropionitrile</a> [98, 133], <a href="#">prinaberel</a> [27, 91]
Sub/family-selective antagonists	<a href="#">bazedoxifene</a> (pIC <sub>50</sub> 7.6) [101]	<a href="#">bazedoxifene</a> (pIC <sub>50</sub> 7.1) [101]
Selective antagonists	<a href="#">clomiphene</a> (pK <sub>i</sub> 8.9) [3], <a href="#">methyl-piperidino-pyrazole</a> (pK <sub>i</sub> 8.6) [137]	<a href="#">R,R-THC</a> (pK <sub>i</sub> 8.4) [97, 138], <a href="#">PHTPP</a> (pK <sub>i</sub> 6.9) [168]

**Comments:** [R,R-THC](#) exhibits partial agonist activity at ER $\alpha$  [97, 138]. Estrogen receptors may be blocked non-selectively by [tamoxifen](#) and [raloxifene](#) and labelled by [<sup>3</sup>H]17 $\beta$ -[estradiol](#) and [<sup>3</sup>H][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 ER $\alpha$ -selective estrogen receptor modulator [109].

### Further reading on 3A. Estrogen receptors

Coons LA *et al.* (2017) DNA Sequence Constraints Define Functionally Active Steroid Nuclear Receptor Binding Sites in Chromatin. *Endocrinology* **158**: 3212-3234 [PMID:28977594]  
 Dahlman-Wright K *et al.* (2006) International Union of Pharmacology. LXIV. Estrogen receptors. *Pharmacol Rev* **58**: 773-81 [PMID:17132854]  
 Gonzalez-Sanchez E *et al.* (2015) Nuclear receptors in acute and chronic cholestasis. *Dig Dis* **33**: 357-66 [PMID:26045270]

Hewitt SC *et al.* (2016) What's new in estrogen receptor action in the female reproductive tract. *J Mol Endocrinol* **56**: R55-71 [PMID:26826253]  
 Jameera Begam A *et al.* (2017) Estrogen receptor agonists/antagonists in breast cancer therapy: A critical review. *Bioorg Chem* **71**: 257-274 [PMID:28274582]  
 Warner M *et al.* (2017) Estrogen Receptor  $\beta$  as a Pharmaceutical Target. *Trends Pharmacol Sci* **38**: 92-99 [PMID:27979317]



## 3C. 3-Ketosteroid receptors

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

**Overview:** Steroid hormone receptors (**nomenclature as agreed by the NC-IUPHAR Subcommittee on Nuclear Hormone Receptors** [1, 28, 85]) are nuclear hormone receptors of the NR3 class, with endogenous agonists that may be divided into 3-hydroxysteroids (**estrone** and **17 $\beta$ -estradiol**) and 3-ketosteroids (**dihydrotestosterone** [DHT], **aldosterone**, **cortisol**, **corticosterone**, **progesterone** and **testosterone**). For rodent GR and MR, the physiological ligand is corticosterone rather than cortisol.

Nomenclature	<b>Androgen receptor</b>	<b>Glucocorticoid receptor</b>
Systematic nomenclature	NR3C4	NR3C1
HGNC, UniProt	<a href="#">AR</a> , <a href="#">P10275</a>	<a href="#">NR3C1</a> , <a href="#">P04150</a>
Rank order of potency	<b>dihydrotestosterone</b> > <b>testosterone</b>	<b>cortisol</b> , <b>corticosterone</b> $\gg$ <b>aldosterone</b> , <b>deoxycortisone</b> [123]
Endogenous agonists	<b>dihydrotestosterone</b> [142]	–
Selective agonists	<b>testosterone propionate</b> [93], <b>mibolerone</b> [50], <b>fluoxymesterone</b> [60], <b>methyltrienolone</b> [148], <b>dromostanolone propionate</b>	<b>fluticasone propionate</b> [10], <b>flunisolide</b> [3], <b>beclometasone</b> [3], <b>methylprednisolone</b> [3], <b>betamethasone</b> [3], <b>budesonide</b> [100]
Selective antagonists	<b>bicalutamide</b> (pK <sub>i</sub> 7.7) [69], <b>PF0998425</b> (pIC <sub>50</sub> 7.1–7.5) [84], <b>enzalutamide</b> (pIC <sub>50</sub> 7.4) [143], <b>nilutamide</b> (pIC <sub>50</sub> 7.1–7.1) [131], <b>hydroxyflutamide</b> (pEC <sub>50</sub> 6.6) [148], <b>galeterone</b> (pIC <sub>50</sub> 6.4) [56], <b>flutamide</b> (Displacement of <sup>3</sup> [H] testosterone from wild-type androgen receptors) (pK <sub>i</sub> 5.4) [147]	<b>onapristone</b> (pIC <sub>50</sub> 7.6) [165], <b>ZK112993</b>
Labelled ligands	<b>[<sup>3</sup>H]dihydrotestosterone</b> (Selective Agonist), <b>[<sup>3</sup>H]methyltrienolone</b> (Selective Agonist), <b>[<sup>3</sup>H]mibolerone</b> (Agonist)	<b>[<sup>3</sup>H]dexamethasone</b> (Agonist)

Nomenclature	<b>Mineralocorticoid receptor</b>	<b>Progesterone receptor</b>
Systematic nomenclature	NR3C2	NR3C3
HGNC, UniProt	<a href="#">NR3C2</a> , <a href="#">P08235</a>	<a href="#">PGR</a> , <a href="#">P06401</a>
Rank order of potency	<b>corticosterone</b> , <b>cortisol</b> , <b>aldosterone</b> , <b>progesterone</b> [123]	<b>progesterone</b>
Endogenous agonists	<b>deoxycorticosterone</b> [123], <b>aldosterone</b> [57, 123], <b>cortisol</b> [57, 123], <b>corticosterone</b>	<b>progesterone</b> [37]
Selective agonists	–	<b>medroxyprogesterone</b> (Affinity at human PR-A) [166], <b>ORG2058</b> , <b>levonorgestrel</b> [9, 126]
Selective antagonists	<b>finerenone</b> (pIC <sub>50</sub> 7.7) [5], <b>eplerenone</b> (pK <sub>i</sub> 6.9) [6], <b>onapristone</b> (pIC <sub>50</sub> 6.3) [165], <b>RU28318</b> , <b>ZK112993</b>	<b>ulipristal acetate</b> (pIC <sub>50</sub> 9.7) [121], <b>mifepristone</b> (Mixed) (pK <sub>i</sub> 9) [167], <b>onapristone</b> (pK <sub>i</sub> 7.7) [55], <b>ZK112993</b>
Labelled ligands	<b>[<sup>3</sup>H]aldosterone</b> (Selective Agonist) [44, 135] – Rat	<b>[<sup>3</sup>H]ORG2058</b> (Selective Agonist)
Comments	Pre-receptor ligand specificity is provided for the MR in tissues associated with maintenance of sodium homeostasis by the co-expression of 11 $\beta$ -hydroxysteroid dehydrogenase type II which converts cortisol (corticosterone in rodents) to their inactive forms. Given the increasing use of <i>Danio rerio</i> (zebrafish) as an experimental model, it is important to note that progesterone (and spironolactone) is a MR agonist in fish [42].	–

**Comments:** [<sup>3</sup>H]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, 81]. Mutations in AR underlie testicular feminization and androgen insensitivity syndromes, spinal and bulbar muscular atrophy (Kennedy's disease).

### Further reading on 3C. 3-Ketosteroid receptors

- Baker ME *et al.* (2017) 30 YEARS OF THE MINERALOCORTICOID RECEPTOR: Evolution of the mineralocorticoid receptor: sequence, structure and function. *J Endocrinol* **234**: T1-T16 [PMID:28468932]
- Carroll JS *et al.* (2017) Deciphering the divergent roles of progestogens in breast cancer. *Nat Rev Cancer* **17**: 54-64 [PMID:27885264]
- Cohen DM *et al.* (2017) Nuclear Receptor Function through Genomics: Lessons from the Glucocorticoid Receptor. *Trends Endocrinol Metab* **28**: 531-540 [PMID:28495406]
- de Kloet ER *et al.* (2017) Brain mineralocorticoid receptor function in control of salt balance and stress-adaptation. *Physiol Behav* **178**: 13-20 [PMID:28089704]
- Garg D *et al.* (2017) Progesterone-Mediated Non-Classical Signaling. *Trends Endocrinol Metab* **28**: 656-668 [PMID:28651856]
- Lu NZ *et al.* (2006) International Union of Pharmacology. LXV. The pharmacology and classification of the nuclear receptor superfamily: glucocorticoid, mineralocorticoid, progesterone, and androgen receptors. *Pharmacol Rev* **58**: 782-97 [PMID:17132855]
- Lucas-Herald AK *et al.* (2017) Genomic and non-genomic effects of androgens in the cardiovascular system: clinical implications. *Clin Sci* **131**: 1405-1418 [PMID:28645930]
- Wadosky KM *et al.* (2017) Androgen receptor splice variants and prostate cancer: From bench to bedside. *Oncotarget* **8**: 18550-18576 [PMID:28077788]
- Weikum ER *et al.* (2017) Glucocorticoid receptor control of transcription: precision and plasticity via allostery. *Nat Rev Mol Cell Biol* **18**: 159-174 [PMID:28053348]

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