THE CONCISE GUIDE TO PHARMACOLOGY 2019/20: Nuclear hormone receptors

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Abstract

The Concise Guide to PHARMACOLOGY 2019/20 is the fourth in this series of biennial publications. The Concise Guide provides concise overviews of the key properties of nearly 1800 human drug targets with an emphasis on selective pharmacology (where available), plus links to the open access knowledgebase source of drug targets and their ligands (www.guidetopharmacology.org), which provides more detailed views of target and ligand properties. Although the Concise Guide represents approximately 400 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.14750. 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-2019, and supersedes data presented in the 2017/18, 2015/16 and 2013/14 Concise Guides and previous Guides to Receptors and Channels. It is produced in close conjunction with the International Union of Basic and Clinical Pharmacology Committee on Receptor Nomenclature and Drug Classification (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

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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 [39]) 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 TRβ [105].

| Nomenclature | Thyroid hormone receptor-α | Thyroid hormone receptor-β |
|--------------|---------------------------|---------------------------|
| Systematic nomenclature | NR1A1 | NR1A2 |
| HGNC, UniProt | THRA, P10827 | THRβ, P10828 |
| Rank order of potency | triiodothyronine > T_4 | triiodothyronine > T_4 |
| Agonists | dextrothyroxine [17] | dextrothyroxine [17] |
| Selective agonists | – | sobetirome [23, 125] |

Comments: An interaction with integrin αVβ3 has been suggested to underlie plasma membrane localization of TRs and non-genomic signalling [6]. 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.

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Full Contents of ConciseGuide: http://onlinelibrary.wiley.com/doi/10.1111/bph.14750/full
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]

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]

Mendoza A et al. (2017) New insights into thyroid hormone action. Pharmacol. Ther. 173:135-145 [PMID:28174093]

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 [44]) 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 [45].

| 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 [22]           | tretinoin [22]           | tretinoin [22]           |
| Sub/family-selective agonists     | tazarotene [22]          | tazarotene [22], adapalene [21] | tazarotene [22], adapalene [21] |
| Selective agonists                | BMS753 [51], tamibarotene [143], Ro 40-6055 [30] | AC261066 [84], AC55649 [83, 84] | AHPN [21] |
| Selective antagonists             | Ro 41-5253 (pIC50 6.3–7.2) [1, 65] | – | MM 11253 [72] |

Comments: Ro 41-5253 has been suggested to be a PPARγ agonist [124]. LE135 is an antagonist with selectivity for RARα and RARβ compared with RARγ [80].

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]

Searchable database: http://www.guidetopharmacology.org/index.jsp
Full Contents of ConciseGuide: http://onlinelibrary.wiley.com/doi/10.1111/bph.14750/full
1C. Peroxisome proliferator-activated receptors

**Overview:** Peroxisome proliferator-activated receptors (PPARs, nomenclature as agreed by the NC-IUPHAR Subcommittee on Nuclear Hormone Receptors [96]) 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 [11, 96], including 15-deoxy-Δ12,14-PGJ2, prostacyclin (PGI2), many fatty acids and their oxidation products, lysophosphatidic acid (LPA) [93], 13-HODE, 15S-HETE, Paz-PC, azelaoyl-PAF and leukotriene B4 (LTB4). Bezafibrate acts as a non-selective agonist for the PPAR family [152]. These receptors also bind hypolipidaemic drugs (PPARα) and anti-diabetic thiazolidinediones (PPARγ), 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 | PPARA, Q07869 | PPARD, Q03181 | PPARG, P37231 |
| Selective agonists | GW7647 [15, 16], CP-775146 [63], pirinixic acid [152], gemfibrozil [28] | GW0742X [48, 137], GW501516 [107] | GW1929 [15], bardoxolone (Partial agonist) [146], rosiglitazone [55, 76, 158], pioglitazone [55, 122, 158], ciglitazone [55] |
| Selective antagonists | GW6471 (pIC50 6.6) [155] | GSK0660 (pIC50 6.5) [126] | T0070907 (pKi 9) [73], GW9662 (Irreversible inhibition) (pIC50 8.1) [74], CDDO-Me (pKi 6.9) [146] |

**Comments:** As with the estrogen receptor antagonists, many agents show tissue-selective efficacy (e.g. [10, 104, 119]). Agonists with mixed activity at PPARα and PPARγ have also been described (e.g. [31, 50, 156]).

**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 PPARγ 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]

Searchable database: [http://www.guidetopharmacology.org/index.jsp](http://www.guidetopharmacology.org/index.jsp)

Full Contents of ConciseGuide: [http://onlinelibrary.wiley.com/doi/10.1111/bph.14750/full](http://onlinelibrary.wiley.com/doi/10.1111/bph.14750/full)
1D. Rev-Erb receptors

Overview: Rev-erb receptors (nomenclature as agreed by the NC-IUPHAR Subcommittee on Nuclear Hormone Receptors [5]) 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 [116, 157] | heme [92, 116, 157] |
| Selective agonists | GSK4112 [49], GSK4112 [68] | – |
| Selective antagonists | SR8278 (pIC₅₀ 6.5) [68] | – |

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 [5]) have yet to be assigned a definitive endogenous ligand, although RORα may be synthesized with a ‘captured’ agonist such as cholesterol [61, 62].

| 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 [62, 109] | – | – |
| Selective agonists | 7-hydroxycholesterol [12], cholesterol sulphate [12, 62] | – | – |
| Comments | – | – | The immune system function of RORC proteins most likely resides with expression of the RORγt isoform by immature CD4⁺/CD8⁺ cells in the thymus [33, 136] and in lymphoid tissue inducer (LTi) cells [34]. |

**Comments:** Tretinoin shows selectivity for RORβ within the ROR family [131]. RORα has been suggested to be a nuclear receptor responding to melatonin [151].

**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 RORγ 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 [100]) 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, NR1HSP is a pseudogene. However, in other mammals, it encodes a functional nuclear hormone receptor that appears to be involved in cholesterol biosynthesis [108].

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### Nomenclature

| Systematic nomenclature | Farnesoid X receptor | Farnesoid X receptor-β | Liver X receptor-α | Liver X receptor-β |
|-------------------------|----------------------|------------------------|--------------------|--------------------|
| NR1H4                   | NR1H5                | NR1H3                  | NR1H2              |
| HGNC, UniProt           | NR1H4, Q96R1         | NR1H5P, –              | NR1H3, Q13133      | NR1H2, P55055      |

### Potency order

- chenodeoxycholic acid > lithocholic acid, deoxycholic acid [87, 110]

### Endogenous agonists

- lanosterol [108] – Mouse

### Selective agonists

- GW4064 [89], obeticholic acid [111], fexaramine [32]

### Selective antagonists

- guggulsterone (pIC₅₀ 5.7–6) [154]

### Comments

T0901317 [117] and GW3965 [24] are synthetic agonists acting at both LXRα and LXRβ with less than 10-fold selectivity.

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

- Courtley 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, 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]
- 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]

## 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 [100]) 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 [100].
### Nomenclature

| Nomenclature | Vitamin D receptor | Pregnan X receptor | Constitutive androstane receptor |
|--------------|--------------------|--------------------|----------------------------------|
| Systematic nomenclature | NR1I1 | NR1I2 | NR1I3 |
| HGNC, UniProt | VDR, P11473 | NR1I2, O75469 | NR1I3, Q14994 |

### Further reading on 11. 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]

#### 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 [5]. While linoleic acid has been identified as the endogenous ligand for HNF4α its function remains ambiguous [160]. HNF4γ 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 [160] | – |
| Selective antagonists | Bt6015 [67] | – |
| Comments | HNF4α has constitutive transactivation activity [160] and binds DNA as a homodimer [59]. | – |
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]
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]
Lu H. (2016) Crosstalk of HNF4α 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 4α (HNF4α) in cell proliferation and cancer. Gene Expr. 16: 101-8 [PMID:25700366]

2B. Retinoid X receptors

Overview: Retinoid X receptors (nomenclature as agreed by the NC-IUPHAR Subcommittee on Nuclear Hormone Receptors [43]) are NR2B family members activated by altretinoin and the RXR-selective agonists bexarotene and LG100268, sometimes referred to as rexinoids. UVI3003 [103] and HX 531 [35] have been described as a pan-RXR antagonists. These receptors form RXR-RAR heterodimers and RXR-RXR homodimers [20, 91].

| 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 [14, 19, 138] | bexarotene [14, 19, 138] | bexarotene [14, 19, 138] |
| Selective agonists | CD3254 [46] | – | – |

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]

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2C. Testicular receptors

Nuclear hormone receptors → 2C. Testicular receptors

Overview: Testicular receptors (nomenclature as agreed by the NC-IUPHAR Subcommittee on Nuclear Hormone Receptors [5]) 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 [166], tretinoin [166]|
| Comments               | Forms a heterodimer with TR4; gene disruption appears without effect on testicular development or function [127]. | 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]

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 [5]) 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 [71, 99]. | – |
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 [5]) have yet to be officially paired with an endogenous ligand.

| Nomenclature    | COUP-TF1 | Systematic nomenclature | NR2F1 | COUP-TF2 | Systematic nomenclature | NR2F2, P24468 | V-erbA-related gene | Systematic nomenclature | NR2F6, P10588 |
|-----------------|----------|-------------------------|-------|----------|-------------------------|----------------|---------------------|-------------------------|---------------------|
| HGNC, UniProt   | NR2F1    | PRF2F, P10589           |       | NR2F2    | PRF2F, P10589           |       | V-erbA-related gene | PRF2F, P10588           |         |
| Comments         | Gene disruption is perinatally lethal [115]. | Gene disruption is embryonically lethal [112]. | Gene disruption impairs CNS development [148]. |

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 [5]) have yet to be officially paired with an endogenous ligand.

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### Nomenclature

| Nomenclature          | Systematic nomenclature | HGNC, UniProt | Comments |
|-----------------------|-------------------------|---------------|----------|
| Estrogen-related receptor-α | NR3B1                  | ESRRA, P11474 | Activated by some dietary flavonoids [133]; activated by the synthetic agonist GSK4716 [169] and blocked by XCT790 [153]. |
| Estrogen-related receptor-β | NR3B2                  | ESRRB, O95718 | May be activated by DY131 [159]. |
| Estrogen-related receptor-γ | NR3B3                  | ESRRG, P62508 | May be activated by DY131 [159]. |

### 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 β (ERRβ) - 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]

### 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 [5]) have yet to be officially paired with an endogenous ligand.

| Nomenclature | Systematic nomenclature | HGNC, UniProt | Comments |
|--------------|-------------------------|---------------|----------|
| Nerve Growth factor IB | NR4A1                | NR4A1, P22736 | An endogenous agonist, cytosporone B, has been described [161], although structural analysis and molecular modelling has not identified a ligand binding site [3, 38, 147]. |
| Nuclear receptor related 1 | NR4A2                | NR4A2, P43354 | Neuron-derived orphan receptor 1 |
| PF4             | NR4A3                | NR4A3, Q92570 | –         |

### 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]

### Searchable database:

http://www.guidetopharmacology.org/index.jsp
Full Contents of ConciseGuide: http://onlinelibrary.wiley.com/doi/10.1111/bph.14750/full
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 [8]) 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 [29] and SID7969543 [85]. | –                        |

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 [5]) have yet to be officially paired with an endogenous ligand.

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

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Full Contents of ConciseGuide: http://onlinelibrary.wiley.com/doi/10.1111/bph.14750/full
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) Miniature: 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]

0B. DAX-like receptors

Nuclear hormone receptors → 0B. DAX-like receptors

Overview: Dax-like receptors (nomenclature as agreed by the NC-IUPHAR Subcommittee on Nuclear Hormone Receptors [5]) 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 on 0B. 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) Miniature: 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 [27, 82]) 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 (HSP90AB1, P08238) and immunophilin FKBP52:FKBP4, Q02790), which are shed on binding the steroid hormone. Although rapid signalling phenomena are observed [79, 114], 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

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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 [142]. A 7TM receptor responsive to estrogen (GPER1, Q99527, also known as GPR30, see [113]) has been described. Human orthologues of 7TM ‘membrane progestin receptors’ (PAQR7, PAQR8 and PAQR5), initially discovered in fish [167, 168], appear to localize to intracellular membranes and respond to ‘non-genomic’ progesterone analogues independently of G proteins [129].

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 [70], estrone [70] | – |
| Selective agonists | propylpyrazoletriol [69, 130], ethinylestradiol [58] | WAY200070 [88], diarylpropionitrile [95, 130], prinaberel [26, 88] |
| Sub/family-selective antagonists | bazedoxifene (pIC₅₀ 7.6) [98] | bazedoxifene (pIC₅₀ 7.1) [98] |
| Selective antagonists | clomiphene (pKᵢ 8.9) [2], methyl-piperidino-pyrazole (pKᵢ 8.6) [134] | R,R-THC (pKᵢ 8.4) [94, 135], PHTPP (pKᵢ 6.9) [165] |

**Comments:** R,R-THC exhibits partial agonist activity at ERα [94, 135]. 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 [106].
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 β 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 [27, 82]) 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).

| Nomenclature | Androgen receptor | Glucocorticoid receptor | Mineralocorticoid receptor | Progesterone receptor |
|--------------|-------------------|------------------------|-----------------------------|-----------------------|
| Systematic nomenclature | NR3C4 | NR3C1 | NR3C2 | NR3C3 |
| HGNC, UniProt | AR, P10275 | | | |
| Rank order of potency | dihydrotestosterone > testosterone | cortisol, corticosterone > aldosterone, deoxycorticisone | | |
| Endogenous agonists | dihydrotestosterone [139] | | | |
| Selective agonists | testosterone propionate [90], mibolerone [47], fluoxymesterone [57], methyltrienolone [145], dromostanolone propionate | fluticasone propionate [8], fluonisolidine [2], beclometasone [2], methylprednisolone [2], budesonide [97] | | |
| Selective antagonists | bicalutamide (pK<sub>i</sub> 7.7) [66], PF0998425 (pIC<sub>50</sub> 7.1–7.5) [81], enzalutamide (pIC<sub>50</sub> 7.4) [140], nilutamide (pIC<sub>50</sub> 7.1–7.7) [128], hydroxyflutamide (pEC<sub>50</sub> 6.6) [145], galetone (pIC<sub>50</sub> 6.4) [53], flutamide (Displacement of [3H]testosterone from wild-type androgen receptors) (pK<sub>i</sub> 5.4) [144] | onapristone (pIC<sub>50</sub> 7.6) [162], ZK112993 | finerenone (pIC<sub>50</sub> 7.7) [18], eplerenone (pK<sub>i</sub> 6.9) [4], onapristone (pIC<sub>50</sub> 6.3) [162], RU28318, ZK112993 | ulipristal acetate (pIC<sub>50</sub> 9.7) [118], mifepristone (Mixed) (pK<sub>i</sub> 9) [164], onapristone (pK<sub>i</sub> 7.7) [52], ZK112993 |
| Labelled ligands | | [3H]dihydrotestosterone (Selective Agonist), [3H]methyltrienolone (Selective Agonist), [3H]mibolerone (Agonist) | [3H]dexamethasone (Agonist) | [3H]aldosterone (Selective Agonist) [42, 132] – Rat | [3H]ORG2058 (Selective Agonist) |

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Full Contents of ConciseGuide: [http://onlinelibrary.wiley.com/doi/10.1111/bph.14750/full](http://onlinelibrary.wiley.com/doi/10.1111/bph.14750/full)
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 [41, 78]. 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]

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:28077888]
Weikum ER et al. (2017) Glucocorticoid receptor control of transcription: precision and plasticity via allosterry. Nat. Rev. Mol. Cell Biol. 18: 159-174 [PMID:28053348]
