IUPHAR/BPS Guide to Pharmacology CITE
https://doi.org/10.2218/gtopdb/F30/2020.4

Glycoprotein hormone receptors (version 2020.4) in the IUPHAR/BPS Guide to Pharmacology Database

Sabine Costagliola[1], James A. Dias[2], Marvin Gershengorn[3], Adam J. Pawson[4], Deborah L. Segaloff[5], Axel P.N. Themmen[6] and Gilbert Vassart[1]

1. Université Libre de Bruxelles, Belgium
2. New York State Department of Health, USA
3. National Institutes of Health, USA
4. The University of Edinburgh, UK
5. University of Iowa, USA
6. Erasmus University Medical Cente, The Netherlands

Abstract

Glycoprotein hormone receptors (**provisional nomenclature [45]**) are activated by a non-covalent heterodimeric glycoprotein made up of a common α chain (glycoprotein hormone common alpha subunit *CGA*, P01215), with a unique β chain that confers the biological specificity toFSH, LH, hCG or TSH. There is binding cross-reactivity across the endogenous agonists for each of the glycoprotein hormone receptors. The deglycosylated hormones appear to exhibit reduced efficacy at these receptors [120].

Contents

This is a citation summary for Glycoprotein hormone receptors in the Guide to Pharmacology database (GtoPdb). It exists purely as an adjunct to the database to facilitate the recognition of citations to and from the database by citation analyzers. Readers will almost certainly want to visit the relevant sections of the database which are given here under database links.

GtoPdb is an expert-driven guide to pharmacological targets and the substances that act on them. GtoPdb is a reference work which is most usefully represented as an on-line database. As in any publication this work should be appropriately cited, and the papers it cites should also be recognized. This document provides a citation for the relevant parts of the database, and also provides a reference list for the research cited by those parts.

Please note that the database version for the citations given in GtoPdb are to the most recent preceding version in which the family or its subfamilies and targets were substantially changed. The links below are to the current version. If you need to consult the cited version, rather than the most recent version, please contact the GtoPdb curators.

Database links

Glycoprotein hormone receptors
http://www.guidetopharmacology.org/GRAC/FamilyDisplayForward?familyId=30
Introduction to Glycoprotein hormone receptors
http://www.guidetopharmacology.org/GRAC/FamilyIntroductionForward?familyId=30
Receptors
FSH receptor
http://www.guidetopharmacology.org/GRAC/ObjectDisplayForward?objectId=253
LH receptor
http://www.guidetopharmacology.org/GRAC/ObjectDisplayForward?objectId=254
TSH receptor
http://www.guidetopharmacology.org/GRAC/ObjectDisplayForward?objectId=255

References

1. Abel MH, Wootton AN, Wilkins V, Huhtaniemi I, Knight PG and Charlton HM. (2000) The effect of a null

mutation in the follicle-stimulating hormone receptor gene on mouse reproduction. *Endocrinology* **141**: 1795-803 [PMID:10803590]
2. Aharoni D, Dantes A, Oren M and Amsterdam A. (1995) cAMP-mediated signals as determinants for apoptosis in primary granulosa cells. *Exp. Cell Res.* **218**: 271-82 [PMID:7537693]
3. Aittomäki K, Herva R, Stenman UH, Juntunen K, Ylöstalo P, Hovatta O and de la Chapelle A. (1996) Clinical features of primary ovarian failure caused by a point mutation in the follicle-stimulating hormone receptor gene. *J. Clin. Endocrinol. Metab.* **81**: 3722-6 [PMID:8855829]
4. Aittomäki K, Lucena JL, Pakarinen P, Sistonen P, Tapanainen J, Gromoll J, Kaskikari R, Sankila EM, Lehväslaiho H and Engel AR *et al.*. (1995) Mutation in the follicle-stimulating hormone receptor gene causes hereditary hypergonadotropic ovarian failure. *Cell* **82**: 959-68 [PMID:7553856]
5. Akamizu T, Ikuyama S, Saji M, Kosugi S, Kozak C, McBride OW and Kohn LD. (1990) Cloning, chromosomal assignment, and regulation of the rat thyrotropin receptor: expression of the gene is regulated by thyrotropin, agents that increase cAMP levels, and thyroid autoantibodies. *Proc. Natl. Acad. Sci. U.S.A.* **87**: 5677-81 [PMID:1696008]
6. Alberti L, Proverbio MC, Costagliola S, Romoli R, Boldrighini B, Vigone MC, Weber G, Chiumello G, Beck-Peccoz P and Persani L. (2002) Germline mutations of TSH receptor gene as cause of nonautoimmune subclinical hypothyroidism. *J. Clin. Endocrinol. Metab.* **87**: 2549-55 [PMID:12050212]
7. Allgeier A, Offermanns S, Van Sande J, Spicher K, Schultz G and Dumont JE. (1994) The human thyrotropin receptor activates G-proteins Gs and Gq/11. *J. Biol. Chem.* **269**: 13733-5 [PMID:8188646]
8. Ando T, Latif R, Pritsker A, Moran T, Nagayama Y and Davies TF. (2002) A monoclonal thyroid-stimulating antibody. *J. Clin. Invest.* **110**: 1667-74 [PMID:12464672]
9. Arey BJ, Deecher DC, Shen ES, Stevis PE, Meade Jr EH, Wrobel J, Frail DE and López FJ. (2002) Identification and characterization of a selective, nonpeptide follicle-stimulating hormone receptor antagonist. *Endocrinology* **143**: 3822-9 [PMID:12239093]
10. Ascoli M, Fanelli F and Segaloff DL. (2002) The lutropin/choriogonadotropin receptor, a 2002 perspective. *Endocr. Rev.* **23**: 141-74 [PMID:11943741]
11. Babu PS, Danilovich N and Sairam MR. (2001) Hormone-induced receptor gene splicing: enhanced expression of the growth factor type I follicle-stimulating hormone receptor motif in the developing mouse ovary as a new paradigm in growth regulation. *Endocrinology* **142**: 381-9 [PMID:11145601]
12. Baccetti B, Collodel G, Costantino-Ceccarini E, Eshkol A, Gambera L, Moretti E, Strazza M and Piomboni P. (1998) Localization of human follicle-stimulating hormone in the testis. *FASEB J.* **12**: 1045-54 [PMID:9707177]
13. Balla A, Danilovich N, Yang Y and Sairam MR. (2003) Dynamics of ovarian development in the FORKO immature mouse: structural and functional implications for ovarian reserve. *Biol. Reprod.* **69**: 1281-93 [PMID:12801993]
14. Bambino TH and Hsueh AJ. (1981) Direct inhibitory effect of glucocorticoids upon testicular luteinizing hormone receptor and steroidogenesis in vivo and in vitro. *Endocrinology* **108**: 2142-8 [PMID:6262050]
15. Barrios-De-Tomasi J, Timossi C, Merchant H, Quintanar A, Avalos JM, Andersen CY and Ulloa-Aguirre A. (2002) Assessment of the in vitro and in vivo biological activities of the human follicle-stimulating isohormones. *Mol. Cell. Endocrinol.* **186**: 189-98 [PMID:11900895]
16. Behre HM, Greb RR, Mempel A, Sonntag B, Kiesel L, Kaltwasser P, Seliger E, Röpke F, Gromoll J and Nieschlag E *et al.*. (2005) Significance of a common single nucleotide polymorphism in exon 10 of the follicle-stimulating hormone (FSH) receptor gene for the ovarian response to FSH: a pharmacogenetic approach to controlled ovarian hyperstimulation. *Pharmacogenet. Genomics* **15**: 451-6 [PMID:15970792]
17. Beubler E, Hinterleitner T and Horina G. (1990) Protein kinase C and intestinal fluid secretion: involvement of prostaglandin E2 but not of 5-hydroxytryptamine. *Eur. J. Pharmacol.* **182**: 543-8 [PMID:2171950]
18. Biebermann H, Schöneberg T, Krude H, Gudermann T and Grüters A. (2000) Constitutively activating TSH-receptor mutations as a molecular cause of non-autoimmune hyperthyroidism in childhood. *Langenbecks Arch Surg* **385**: 390-392 [PMID:11127522]
19. Biebermann H, Schöneberg T, Schulz A, Krause G, Grüters A, Schultz G and Gudermann T. (1998) A conserved tyrosine residue (Y601) in transmembrane domain 5 of the human thyrotropin receptor serves as a molecular switch to determine G-protein coupling. *FASEB J.* **12**: 1461-71 [PMID:9806755]
20. Bukovsky A, Indrapichate K, Fujiwara H, Cekanova M, Ayala ME, Dominguez R, Caudle MR, Wimalsena J, Elder RF and Copas P *et al.*. (2003) Multiple luteinizing hormone receptor (LHR) protein variants, interspecies reactivity of anti-LHR mAb clone 3B5, subcellular localization of LHR in human placenta, pelvic floor and brain, and possible role for LHR in the development of abnormal pregnancy, pelvic floor disorders and Alzheimer's disease. *Reprod. Biol. Endocrinol.* **1**: 46 [PMID:12816543]
21. Camp TA, Rahal JO and Mayo KE. (1991) Cellular localization and hormonal regulation of follicle-stimulating hormone and luteinizing hormone receptor messenger RNAs in the rat ovary. *Mol. Endocrinol.* **5**: 1405-17 [PMID:1723141]
22. Channing CP, Sakai CN and Bahl OP. (1978) Role of the carbohydrate residues of human chorionic gonadotropin in binding and stimulation of adenosine 3',5'-monophosphate accumulation by porcine granulosa cells. *Endocrinology* **103**: 341-8 [PMID:217642]
23. Clifton-Bligh RJ, Gregory JW, Ludgate M, John R, Persani L, Asteria C, Beck-Peccoz P and Chatterjee VK. (1997) Two novel mutations in the thyrotropin (TSH) receptor gene in a child with resistance to TSH. *J Clin Endocrinol Metab* **82**: 1094-1100 [PMID:9100579]
24. Conti M. (2002) Specificity of the cyclic adenosine 3',5'-monophosphate signal in granulosa cell function. *Biol. Reprod.* **67**: 1653-61 [PMID:12444038]

25. Corvilain B, Laurent E, Lecomte M, Vansande J and Dumont JE. (1994) Role of the cyclic adenosine 3',5'-monophosphate and the phosphatidylinositol-Ca2+ cascades in mediating the effects of thyrotropin and iodide on hormone synthesis and secretion in human thyroid slices. *J. Clin. Endocrinol. Metab.* **79**: 152-9 [PMID:8027219]
26. Costagliola S, Bonomi M, Morgenthaler NG, Van Durme J, Panneels V, Refetoff S and Vassart G. (2004) Delineation of the discontinuous-conformational epitope of a monoclonal antibody displaying full in vitro and in vivo thyrotropin activity. *Mol. Endocrinol.* **18**: 3020-34 [PMID:15319453]
27. Costagliola S, Franssen JD, Bonomi M, Urizar E, Willnich M, Bergmann A and Vassart G. (2002) Generation of a mouse monoclonal TSH receptor antibody with stimulating activity. *Biochem. Biophys. Res. Commun.* **299**: 891-6 [PMID:12470663]
28. Costagliola S, Panneels V, Bonomi M, Koch J, Many MC, Smits G and Vassart G. (2002) Tyrosine sulfation is required for agonist recognition by glycoprotein hormone receptors. *EMBO J.* **21**: 504-13 [PMID:11847099]
29. Crisanti P, Omri B, Hughes E, Meduri G, Hery C, Clauser E, Jacquemin C and Saunier B. (2001) The expression of thyrotropin receptor in the brain. *Endocrinology* **142**: 812-822 [PMID:11159854]
30. de Roux N, Misrahi M, Brauner R, Houang M, Carel JC, Granier M, Le Bouc Y, Ghinea N, Boumedienne A and Toublanc JE *et al.*. (1996) Four families with loss of function mutations of the thyrotropin receptor*J. Clin. Endocrinol. Metab.* **81**: 4229-35 [PMID:8954020]
31. de Roux N, Polak M, Couet J, Leger J, Czernichow P, Milgrom E and Misrahi M. (1996) A neomutation of the thyroid-stimulating hormone receptor in a severe neonatal hyperthyroidism. *J. Clin. Endocrinol. Metab.* **81**: 2023-6 [PMID:8964822]
32. Dias JA and Van Roey P. (2001) Structural biology of human follitropin and its receptor*Arch. Med. Res.* **32**: 510-9 [PMID:11750726]
33. Dierich A, Sairam MR, Monaco L, Fimia GM, Gansmuller A, LeMeur M and Sassone-Corsi P. (1998) Impairing follicle-stimulating hormone (FSH) signaling in vivo: targeted disruption of the FSH receptor leads to aberrant gametogenesis and hormonal imbalance. *Proc. Natl. Acad. Sci. U.S.A.* **95**: 13612-7 [PMID:9811848]
34. Dirnhofer S, Berger C, Hermann M, Steiner G, Madersbacher S and Berger P. (1998) Coexpression of gonadotropic hormones and their corresponding FSH- and LH/CG-receptors in the human prostate. *Prostate* **35**: 212-20 [PMID:9582090]
35. Doherty E, Pakarinen P, Tiitinen A, Kiilavuori A, Huhtaniemi I, Forrest S and Aittomäki K. (2002) A Novel mutation in the FSH receptor inhibiting signal transduction and causing primary ovarian failure. *J Clin Endocrinol Metab* **87**: 1151-1155 [PMID:11889179]
36. Donadeu FX and Ascoli M. (2005) The differential effects of the gonadotropin receptors on aromatase expression in primary cultures of immature rat granulosa cells are highly dependent on the density of receptors expressed and the activation of the inositol phosphate cascade. *Endocrinology* **146**: 3907-16 [PMID:15919743]
37. Dumont JE, Lamy F, Roger P and Maenhaut C. (1992) Physiological and pathological regulation of thyroid cell proliferation and differentiation by thyrotropin and other factors. *Physiol. Rev.* **72**: 667-97 [PMID:1320763]
38. Duprez L, Parma J, Costagliola S, Hermans J, Van Sande J, Dumont JE and Vassart G. (1997) Constitutive activation of the TSH receptor by spontaneous mutations affecting the N-terminal extracellular domain. *FEBS Lett.* **409**: 469-74 [PMID:9224711]
39. Duprez L, Parma J, Van Sande J, Allgeier A, Leclère J, Schvartz C, Delisle MJ, Decoulx M, Orgiazzi J and Dumont J *et al.*. (1994) Germline mutations in the thyrotropin receptor gene cause non-autoimmune autosomal dominant hyperthyroidism. *Nat. Genet.* **7**: 396-401 [PMID:7920658]
40. Englund EE, Neumann S, Eliseeva E, McCoy JG, Titus S, Zheng W, Southall N, Shin P, Leister W and Thomas CJ *et al.*. (2011) The Synthesis and Evaluation of Dihydroquinazolin-4-ones and Quinazolin-4-ones as Thyroid Stimulating Hormone Receptor Agonists. *Medchemcomm* **2**: 1016-1020 [PMID:22408719]
41. Esapa CT, Duprez L, Ludgate M, Mustafa MS, Kendall-Taylor P, Vassart G and Harris PE. (1999) A novel thyrotropin receptor mutation in an infant with severe thyrotoxicosis. *Thyroid* **9**: 1005-10 [PMID:10560955]
42. Eskola V, Rannikko A, Huhtaniemi I and Warren DW. (1994) Ontogeny of the inhibitory guanine nucleotide-binding regulatory protein in the rat testis: mRNA expression and modulation of LH and FSH action. *Mol. Cell. Endocrinol.* **102**: 63-8 [PMID:7926274]
43. Fan QR and Hendrickson WA. (2005) Structure of human follicle-stimulating hormone in complex with its receptor. *Nature* **433**: 269-77 [PMID:15662415]
44. Flack MR, Froehlich J, Bennet AP, Anasti J and Nisula BC. (1994) Site-directed mutagenesis defines the individual roles of the glycosylation sites on follicle-stimulating hormone. *J. Biol. Chem.* **269**: 14015-20 [PMID:8188681]
45. Foord SM, Bonner TI, Neubig RR, Rosser EM, Pin JP, Davenport AP, Spedding M and Harmar AJ. (2005) International Union of Pharmacology. XLVI. G protein-coupled receptor list. *Pharmacol. Rev.* **57**: 279-88 [PMID:15914470]
46. Führer D, Holzapfel HP, Wonerow P, Scherbaum WA and Paschke R. (1997) Somatic mutations in the thyrotropin receptor gene and not in the Gs alpha protein gene in 31 toxic thyroid nodules. *J. Clin. Endocrinol. Metab.* **82**: 3885-91 [PMID:9360556]
47. Führer D, Wonerow P, Willgerodt H and Paschke R. (1997) Identification of a new thyrotropin receptor germline mutation (Leu629Phe) in a family with neonatal onset of autosomal dominant nonautoimmune

hyperthyroidism. *J. Clin. Endocrinol. Metab.* **82**: 4234-8 [PMID:9398746]
48. Gagné N, Parma J, Deal C, Vassart G and Van Vliet G. (1998) Apparent congenital athyreosis contrasting with normal plasma thyroglobulin levels and associated with inactivating mutations in the thyrotropin receptor gene: are athyreosis and ectopic thyroid distinct entities? *J. Clin. Endocrinol. Metab.* **83**: 1771-5 [PMID:9589691]
49. Galet C and Ascoli M. (2005) The differential binding affinities of the luteinizing hormone (LH)/choriogonadotropin receptor for LH and choriogonadotropin are dictated by different extracellular domain residues. *Mol Endocrinol* **19**: 1263-1276 [PMID:15677709]
50. Gilchrist RL, Ryu KS, Ji I and Ji TH. (1996) The luteinizing hormone/chorionic gonadotropin receptor has distinct transmembrane conductors for cAMP and inositol phosphate signals. *J. Biol. Chem.* **271**: 19283-7 [PMID:8702611]
51. Glinoer D. (1997) The regulation of thyroid function in pregnancy: pathways of endocrine adaptation from physiology to pathology. *Endocr. Rev.* **18**: 404-33 [PMID:9183570]
52. Gloaguen P, Crépieux P, Heitzler D, Poupon A and Reiter E. (2011) Mapping the follicle-stimulating hormone-induced signaling networks. *Front Endocrinol (Lausanne)* **2**: 45 [PMID:22666216]
53. Grover A, Smith CE, Gregory M, Cyr DG, Sairam MR and Hermo L. (2005) Effects of FSH receptor deletion on epididymal tubules and sperm morphology, numbers, and motility. *Mol. Reprod. Dev.* **72**: 135-44 [PMID:15973687]
54. Grüters A, Schöneberg T, Biebermann H, Krude H, Krohn HP, Dralle H and Gudermann T. (1998) Severe congenital hyperthyroidism caused by a germ-line neo mutation in the extracellular portion of the thyrotropin receptor. *J. Clin. Endocrinol. Metab.* **83**: 1431-6 [PMID:9589634]
55. Gudermann T, Birnbaumer M and Birnbaumer L. (1992) Evidence for dual coupling of the murine luteinizing hormone receptor to adenylyl cyclase and phosphoinositide breakdown and Ca2+ mobilization. Studies with the cloned murine luteinizing hormone receptor expressed in L cells. *J. Biol. Chem.* **267**: 4479-88 [PMID:1311310]
56. Guo T, Adang AE, Dolle RE, Dong G, Fitzpatrick D, Geng P, Ho KK, Kultgen SG, Liu R and McDonald E *et al.*. (2004) Small molecule biaryl FSH receptor agonists. Part 1: Lead discovery via encoded combinatorial synthesis. *Bioorg. Med. Chem. Lett.* **14**: 1713-6 [PMID:15026056]
57. Guo T, Adang AE, Dong G, Fitzpatrick D, Geng P, Ho KK, Jibilian CH, Kultgen SG, Liu R and McDonald E *et al.*. (2004) Small molecule biaryl FSH receptor agonists. Part 2: Lead optimization via parallel synthesis. *Bioorg. Med. Chem. Lett.* **14**: 1717-20 [PMID:15026057]
58. Hirakawa T and Ascoli M. (2003) A constitutively active somatic mutation of the human lutropin receptor found in Leydig cell tumors activates the same families of G proteins as germ line mutations associated with Leydig cell hyperplasia. *Endocrinology* **144**: 3872-8 [PMID:12933660]
59. Hirakawa T, Galet C and Ascoli M. (2002) MA-10 cells transfected with the human lutropin/choriogonadotropin receptor (hLHR): a novel experimental paradigm to study the functional properties of the hLHR. *Endocrinology* **143**: 1026-35 [PMID:11861529]
60. Holzapfel HP, Führer D, Wonerow P, Weinland G, Scherbaum WA and Paschke R. (1997) Identification of constitutively activating somatic thyrotropin receptor mutations in a subset of toxic multinodular goiters. *J. Clin. Endocrinol. Metab.* **82**: 4229-33 [PMID:9398745]
61. Holzapfel HP, Wonerow P, von Petrykowski W, Henschen M, Scherbaum WA and Paschke R. (1997) Sporadic congenital hyperthyroidism due to a spontaneous germline mutation in the thyrotropin receptor gene. *J. Clin. Endocrinol. Metab.* **82**: 3879-84 [PMID:9360555]
62. Hsu SY, Kudo M, Chen T, Nakabayashi K, Bhalla A, van der Spek PJ, van Duin M and Hsueh AJ. (2000) The three subfamilies of leucine-rich repeat-containing G protein-coupled receptors (LGR): identification of LGR6 and LGR7 and the signaling mechanism for LGR7. *Mol. Endocrinol.* **14**: 1257-71 [PMID:10935549]
63. Hsu SY, Nakabayashi K, Nishi S, Kumagai J, Kudo M, Sherwood OD and Hsueh AJ. (2002) Activation of orphan receptors by the hormone relaxin. *Science* **295**: 671-4 [PMID:11809971]
64. Huhtaniemi I. (2000) The Parkes lecture. Mutations of gonadotrophin and gonadotrophin receptor genes: what do they teach us about reproductive physiology? *J. Reprod. Fertil.* **119**: 173-86 [PMID:10864828]
65. Ji I, Lee C, Song Y, Conn PM and Ji TH. (2002) Cis- and trans-activation of hormone receptors: the LH receptor. *Mol. Endocrinol.* **16**: 1299-308 [PMID:12040016]
66. Jia XC, Oikawa M, Bo M, Tanaka T, Ny T, Boime I and Hsueh AJ. (1991) Expression of human luteinizing hormone (LH) receptor: interaction with LH and chorionic gonadotropin from human but not equine, rat, and ovine species. *Mol Endocrinol* **5**: 759-768 [PMID:1922095]
67. Jiang X, Liu H, Chen X, Chen PH, Fischer D, Sriraman V, Yu HN, Arkinstall S and He X. (2012) Structure of follicle-stimulating hormone in complex with the entire ectodomain of its receptor. *Proc. Natl. Acad. Sci. U.S.A.* **109**: 12491-6 [PMID:22802634]
68. Jordan N, Williams N, Gregory JW, Evans C, Owen M and Ludgate M. (2003) The W546X mutation of the thyrotropin receptor gene: potential major contributor to thyroid dysfunction in a Caucasian population. *J. Clin. Endocrinol. Metab.* **88**: 1002-5 [PMID:12629076]
69. Karges B, Gidenne S, Aumas C, Haddad F, Kelly PA, Milgrom E and de Roux N. (2005) Zero-length cross-linking reveals that tight interactions between the extracellular and transmembrane domains of the luteinizing hormone receptor persist during receptor activation. *Mol. Endocrinol.* **19**: 2086-98 [PMID:15878956]
70. Keene JL, Nishimori K, Galway AB, Hsueh AJW and Boime I. (1994) Recombinant deglycosylated human FSH is an antagonist of human FSH action in cultured rat granulosa cells. *Endocrinology Journal* **2**: 175-179

71. Kopp P, Muirhead S, Jourdain N, Gu WX, Jameson JL and Rodd C. (1997) Congenital hyperthyroidism caused by a solitary toxic adenoma harboring a novel somatic mutation (serine281-->isoleucine) in the extracellular domain of the thyrotropin receptor. *J. Clin. Invest.* **100**: 1634-9 [PMID:9294132]
72. Kosugi S, Hai N, Okamoto H, Sugawa H and Mori T. (2000) A novel activating mutation in the thyrotropin receptor gene in an autonomously functioning thyroid nodule developed by a Japanese patient. *Eur. J. Endocrinol.* **143**: 471-7 [PMID:11022192]
73. Krohn K, Führer D, Holzapfel HP and Paschke R. (1998) Clonal origin of toxic thyroid nodules with constitutively activating thyrotropin receptor mutations. *J. Clin. Endocrinol. Metab.* **83**: 130-4 [PMID:9435429]
74. Kumagai J, Hsu SY, Matsumi H, Roh JS, Fu P, Wade JD, Bathgate RA and Hsueh AJ. (2002) INSL3/Leydig insulin-like peptide activates the LGR8 receptor important in testis descent. *J. Biol. Chem.* **277**: 31283-6 [PMID:12114498]
75. Kühn B and Gudermann T. (1999) The luteinizing hormone receptor activates phospholipase C via preferential coupling to Gi2. *Biochemistry* **38**: 12490-8 [PMID:10493819]
76. Latif R, Graves P and Davies TF. (2002) Ligand-dependent inhibition of oligomerization at the human thyrotropin receptor. *J. Biol. Chem.* **277**: 45059-67 [PMID:12223484]
77. Laugwitz KL, Allgeier A, Offermanns S, Spicher K, Van Sande J, Dumont JE and Schultz G. (1996) The human thyrotropin receptor: a heptahelical receptor capable of stimulating members of all four G protein families. *Proc. Natl. Acad. Sci. U.S.A.* **93**: 116-20 [PMID:8552586]
78. Lecerf L, Rouiller-Fabre V, Levacher C, Gautier C, Saez JM and Habert R. (1993) Stimulatory effect of follicle-stimulating hormone on basal and luteinizing hormone-stimulated testosterone secretions by the fetal rat testis in vitro. *Endocrinology* **133**: 2313-8 [PMID:8404683]
79. Lee YS, Poh L and Loke KY. (2002) An activating mutation of the thyrotropin receptor gene in hereditary non-autoimmune hyperthyroidism. *J. Pediatr. Endocrinol. Metab.* **15**: 211-5 [PMID:11874187]
80. Lei ZM, Mishra S, Zou W, Xu B, Foltz M, Li X and Rao CV. (2001) Targeted disruption of luteinizing hormone/human chorionic gonadotropin receptor gene. *Mol. Endocrinol.* **15**: 184-200 [PMID:11145749]
81. Libert F, Lefort A, Gerard C, Parmentier M, Perret J, Ludgate M, Dumont JE and Vassart G. (1989) Cloning, sequencing and expression of the human thyrotropin (TSH) receptor: evidence for binding of autoantibodies. *Biochem Biophys Res Commun* **165**: 1250-1255 [PMID:2610690]
82. Liu G, Duranteau L, Carel JC, Monroe J, Doyle DA and Shenker A. (1999) Leydig-cell tumors caused by an activating mutation of the gene encoding the luteinizing hormone receptor. *N. Engl. J. Med.* **341**: 1731-6 [PMID:10580072]
83. Loosfelt H, Pichon C, Jolivet A, Misrahi M, Caillou B, Jamous M, Vannier B and Milgrom E. (1992) Two-subunit structure of the human thyrotropin receptor. *Proc. Natl. Acad. Sci. U.S.A.* **89**: 3765-9 [PMID:1570295]
84. Maclean D, Holden F, Davis AM, Scheuerman RA, Yanofsky S, Holmes CP, Fitch WL, Tsutsui K, Barrett RW and Gallop MA. (2004) Agonists of the follicle stimulating hormone receptor from an encoded thiazolidinone library. *J Comb Chem* **6**: 196-206 [PMID:15002967]
85. Marians RC, Ng L, Blair HC, Unger P, Graves PN and Davies TF. (2002) Defining thyrotropin-dependent and -independent steps of thyroid hormone synthesis by using thyrotropin receptor-null mice. *Proc. Natl. Acad. Sci. U.S.A.* **99**: 15776-81 [PMID:12432094]
86. Matzuk MM, Keene JL and Boime I. (1989) Site specificity of the chorionic gonadotropin N-linked oligosaccharides in signal transduction. *J. Biol. Chem.* **264**: 2409-14 [PMID:2536708]
87. McFarland KC, Sprengel R, Phillips HS, Köhler M, Rosemblit N, Nikolics K, Segaloff DL and Seeburg PH. (1989) Lutropin-choriogonadotropin receptor: an unusual member of the G protein-coupled receptor family. *Science* **245**: 494-9 [PMID:2502842]
88. Meduri G, Touraine P, Beau I, Lahuna O, Desroches A, Vacher-Lavenu MC, Kuttenn F and Misrahi M. (2003) Delayed puberty and primary amenorrhea associated with a novel mutation of the human follicle-stimulating hormone receptor: clinical, histological, and molecular studies. *J. Clin. Endocrinol. Metab.* **88**: 3491-8 [PMID:12915623]
89. Minegishi T, Nakamura K, Takakura Y, Ibuki Y, Igarashi M and Minegish T [corrected to Minegishi T]. (1991) Cloning and sequencing of human FSH receptor cDNA. *Biochem. Biophys. Res. Commun.* **175**: 1125-30 [PMID:1709010]
90. Minegishi T, Nakamura K, Takakura Y, Miyamoto K, Hasegawa Y, Ibuki Y, Igarashi M and Minegish T [corrected to Minegishi T]. (1990) Cloning and sequencing of human LH/hCG receptor cDNA. *Biochem. Biophys. Res. Commun.* **172**: 1049-54 [PMID:2244890]
91. Minegishi T, Tano M, Shinozaki H, Nakamura K, Abe Y, Ibuki Y and Miyamoto K. (1997) Dual coupling and down regulation of human FSH receptor in CHO cells. *Life Sci.* **60**: 2043-50 [PMID:9180358]
92. Montanelli L, Delbaere A, Di Carlo C, Nappi C, Smits G, Vassart G and Costagliola S. (2004) A mutation in the follicle-stimulating hormone receptor as a cause of familial spontaneous ovarian hyperstimulation syndrome. *J. Clin. Endocrinol. Metab.* **89**: 1255-8 [PMID:15080154]
93. Müller T, Gromoll J and Simoni M. (2003) Absence of exon 10 of the human luteinizing hormone (LH) receptor impairs LH, but not human chorionic gonadotropin action. *J. Clin. Endocrinol. Metab.* **88**: 2242-9 [PMID:12727981]
94. Nagashima T, Murakami M, Onigata K, Morimura T, Nagashima K, Mori M and Morikawa A. (2001) Novel inactivating missense mutations in the thyrotropin receptor gene in Japanese children with resistance to thyrotropin. *Thyroid* **11**: 551-9 [PMID:11442002]

95. Nagayama Y, Kaufman KD, Seto P and Rapoport B. (1989) Molecular cloning, sequence and functional expression of the cDNA for the human thyrotropin receptor. *Biochem. Biophys. Res. Commun.* **165**: 1184-90 [PMID:2558651]
96. Nakabayashi K, Kudo M, Kobilka B and Hsueh AJ. (2000) Activation of the luteinizing hormone receptor following substitution of Ser-277 with selective hydrophobic residues in the ectodomain hinge region. *J Biol Chem* **275**: 30264-30271 [PMID:10889210]
97. Nakabayashi K, Matsumi H, Bhalla A, Bae J, Mosselman S, Hsu SY and Hsueh AJ. (2002) Thyrostimulin, a heterodimer of two new human glycoprotein hormone subunits, activates the thyroid-stimulating hormone receptor. *J. Clin. Invest.* **109**: 1445-52 [PMID:12045258]
98. Osuga Y, Hayashi M, Kudo M, Conti M, Kobilka B and Hsueh AJ. (1997) Co-expression of defective luteinizing hormone receptor fragments partially reconstitutes ligand-induced signal generation. *J. Biol. Chem.* **272**: 25006-12 [PMID:9312107]
99. Pabon JE, Bird JS, Li X, Huang ZH, Lei ZM, Sanfilippo JS, Yussman MA and Rao CV. (1996) Human skin contains luteinizing hormone/chorionic gonadotropin receptors. *J. Clin. Endocrinol. Metab.* **81**: 2738-41 [PMID:8675605]
100. Pabon JE, Li X, Lei ZM, Sanfilippo JS, Yussman MA and Rao CV. (1996) Novel presence of luteinizing hormone/chorionic gonadotropin receptors in human adrenal glands. *J. Clin. Endocrinol. Metab.* **81**: 2397-400 [PMID:8964884]
101. Palmer SS, Mckenna S and Arkinstall S. (2005) Discovery of new molecules for the future treatment of infertility. *Reproductive Biomedicine Online 10 Suppl (Proceedings: Gonadotropins from Basic Research to Clinical Practice; Munich Germany.* 45-54
102. Park SM, Clifton-Bligh RJ, Betts P and Chatterjee VK. (2004) Congenital hypothyroidism and apparent athyreosis with compound heterozygosity or compensated hypothyroidism with probable hemizygosity for inactivating mutations of the TSH receptor. *Clin. Endocrinol. (Oxf)* **60**: 220-7 [PMID:14725684]
103. Parma J, Duprez L, Van Sande J, Cochaux P, Gervy C, Mockel J, Dumont J and Vassart G. (1993) Somatic mutations in the thyrotropin receptor gene cause hyperfunctioning thyroid adenomas. *Nature* **365**: 649-51 [PMID:8413627]
104. Parma J, Duprez L, Van Sande J, Hermans J, Rocmans P, Van Vliet G, Costagliola S, Rodien P, Dumont JE and Vassart G. (1997) Diversity and prevalence of somatic mutations in the thyrotropin receptor and Gs alpha genes as a cause of toxic thyroid adenomas. *J Clin Endocrinol Metab* **82**: 2695-2701 [PMID:9253356]
105. Paschke R, Tonacchera M, Van Sande J, Parma J and Vassart G. (1994) Identification and functional characterization of two new somatic mutations causing constitutive activation of the thyrotropin receptor in hyperfunctioning autonomous adenomas of the thyroid. *J. Clin. Endocrinol. Metab.* **79**: 1785-9 [PMID:7989485]
106. Perret J, Ludgate M, Libert F, Gerard C, Dumont JE, Vassart G and Parmentier M. (1990) Stable expression of the human TSH receptor in CHO cells and characterization of differentially expressing clones. *Biochem. Biophys. Res. Commun.* **171**: 1044-50 [PMID:2171505]
107. Persani L, Lania A, Alberti L, Romoli R, Mantovani G, Filetti S, Spada A and Conti M. (2000) Induction of specific phosphodiesterase isoforms by constitutive activation of the cAMP pathway in autonomous thyroid adenomas. *J. Clin. Endocrinol. Metab.* **85**: 2872-8 [PMID:10946896]
108. Postiglione MP, Parlato R, Rodriguez-Mallon A, Rosica A, Mithbaokar P, Maresca M, Marians RC, Davies TF, Zannini MS and De Felice M *et al.*. (2002) Role of the thyroid-stimulating hormone receptor signaling in development and differentiation of the thyroid gland. *Proc. Natl. Acad. Sci. U.S.A.* **99**: 15462-7 [PMID:12432093]
109. Powell BL, Piersma D, Kevenaar ME, van Staveren IL, Themmen AP, Iacopetta BJ and Berns EM. (2003) Luteinizing hormone signaling and breast cancer: polymorphisms and age of onset. *J. Clin. Endocrinol. Metab.* **88**: 1653-7 [PMID:12679452]
110. Rannikko A, Pakarinen P, Manna PR, Beau I, Misrahi M, Aittomäki K and Huhtaniemi I. (2002) Functional characterization of the human FSH receptor with an inactivating Ala189Val mutation. *Mol. Hum. Reprod.* **8**: 311-7 [PMID:11912278]
111. Rapoport B, Chazenbalk GD, Jaume JC and McLachlan SM. (1998) The thyrotropin (TSH) receptor: interaction with TSH and autoantibodies. *Endocr. Rev.* **19**: 673-716 [PMID:9861544]
112. Ringkananont U, Van Durme J, Montanelli L, Ugrasbul F, Yu YM, Weiss RE, Refetoff S and Grasberger H. (2006) Repulsive separation of the cytoplasmic ends of transmembrane helices 3 and 6 is linked to receptor activation in a novel thyrotropin receptor mutant (M626I). *Mol. Endocrinol.* **20**: 893-903 [PMID:16339276]
113. Risbridger GP, Robertson DM and de Kretser DM. (1982) The effects of chronic human chorionic gonadotropin treatment on Leydig cell function. *Endocrinology* **110**: 138-45 [PMID:6274616]
114. Rodien P, Brémont C, Sanson ML, Parma J, Van Sande J, Costagliola S, Luton JP, Vassart G and Duprez L. (1998) Familial gestational hyperthyroidism caused by a mutant thyrotropin receptor hypersensitive to human chorionic gonadotropin. *N. Engl. J. Med.* **339**: 1823-6 [PMID:9854118]
115. Roess DA and Smith SM. (2003) Self-association and raft localization of functional luteinizing hormone receptors. *Biol. Reprod.* **69**: 1765-70 [PMID:12890728]
116. Rommerts FF, Cooke BA, Van der Kemp JW and van der Molen HJ. (1973) Effect of luteinizing hormone on 3',5'-cyclic AMP and testosterone production in isolated interstitial tissue of rat testis. *FEBS Lett* **33**: 114-118 [PMID:4352930]
117. Russo D, Arturi F, Schlumberger M, Caillou B, Monier R, Filetti S and Suárez HG. (1995) Activating

mutations of the TSH receptor in differentiated thyroid carcinomas. *Oncogene* **11**: 1907-11 [PMID:7478621]
118. Russo D, Betterle C, Arturi F, Chiefari E, Girelli ME and Filetti S. (2000) A novel mutation in the thyrotropin (TSH) receptor gene causing loss of TSH binding but constitutive receptor activation in a family with resistance to TSH. *J. Clin. Endocrinol. Metab.* **85**: 4238-42 [PMID:11095460]
119. Russo D, Wong MG, Costante G, Chiefari E, Treseler PA, Arturi F, Filetti S and Clark OH. (1999) A Val 677 activating mutation of the thyrotropin receptor in a Hürthle cell thyroid carcinoma associated with thyrotoxicosis. *Thyroid* **9**: 13-7 [PMID:10037070]
120. Sairam MR. (1989) Role of carbohydrates in glycoprotein hormone signal transduction.*FASEB J.* **3**: 1915-26 [PMID:2542111]
121. Sanders J, Allen F, Jeffreys J, Bolton J, Richards T, Depraetere H, Nakatake N, Evans M, Kiddie A and Premawardhana LD *et al.*. (2005) Characteristics of a monoclonal antibody to the thyrotropin receptor that acts as a powerful thyroid-stimulating autoantibody antagonist. *Thyroid* **15**: 672-82 [PMID:16053383]
122. Sanders J, Evans M, Premawardhana LD, Depraetere H, Jeffreys J, Richards T, Furmaniak J and Rees Smith B. (2003) Human monoclonal thyroid stimulating autoantibody. *Lancet* **362**: 126-8 [PMID:12867115]
123. Sanders J, Jeffreys J, Depraetere H, Richards T, Evans M, Kiddie A, Brereton K, Groenen M, Oda Y and Furmaniak J *et al.*. (2002) Thyroid-stimulating monoclonal antibodies. *Thyroid* **12**: 1043-50 [PMID:12593717]
124. Shenker A. (2002) Activating mutations of the lutropin choriogonadotropin receptor in precocious puberty. *Recept. Channels* **8**: 3-18 [PMID:12408104]
125. Shenker A, Laue L, Kosugi S, Merendino Jr JJ, Minegishi T and Cutler Jr GB. (1993) A constitutively activating mutation of the luteinizing hormone receptor in familial male precocious puberty. *Nature* **365**: 652-4 [PMID:7692306]
126. Smits G, Campillo M, Govaerts C, Janssens V, Richter C, Vassart G, Pardo L and Costagliola S. (2003) Glycoprotein hormone receptors: determinants in leucine-rich repeats responsible for ligand specificity. *EMBO J.* **22**: 2692-703 [PMID:12773385]
127. Smits G, Govaerts C, Nubourgh I, Pardo L, Vassart G and Costagliola S. (2002) Lysine 183 and glutamic acid 157 of the TSH receptor: two interacting residues with a key role in determining specificity toward TSH and human CG. *Mol. Endocrinol.* **16**: 722-35 [PMID:11923469]
128. Smits G, Olatunbosun O, Delbaere A, Pierson R, Vassart G and Costagliola S. (2003) Ovarian hyperstimulation syndrome due to a mutation in the follicle-stimulating hormone receptor. *N. Engl. J. Med.* **349**: 760-6 [PMID:12930928]
129. Sonoda N, Katabuchi H, Tashiro H, Ohba T, Nishimura R, Minegishi T and Okamura H. (2005) Expression of variant luteinizing hormone/chorionic gonadotropin receptors and degradation of chorionic gonadotropin in human chorionic villous macrophages. *Placenta* **26**: 298-307 [PMID:15823616]
130. Sprengel R, Braun T, Nikolics K, Segaloff DL and Seeburg PH. (1990) The testicular receptor for follicle stimulating hormone: structure and functional expression of cloned cDNA. *Mol. Endocrinol.* **4**: 525-30 [PMID:2126341]
131. Stein SA, Oates EL, Hall CR, Grumbles RM, Fernandez LM, Taylor NA, Puett D and Jin S. (1994) Identification of a point mutation in the thyrotropin receptor of the hyt/hyt hypothyroid mouse. *Mol. Endocrinol.* **8**: 129-38 [PMID:8170469]
132. Stevis PE, Deecher DC, Lopez FJ and Frail DE. (1999) Pharmacological characterization of soluble human FSH receptor extracellular domain: facilitated secretion by coexpression with FSH. *Endocrine* **10**: 153-60 [PMID:10451224]
133. Stilley JA, Christensen DE, Dahlem KB, Guan R, Santillan DA, England SK, Al-Hendy A, Kirby PA and Segaloff DL. (2014) FSH receptor (FSHR) expression in human extragonadal reproductive tissues and the developing placenta, and the impact of its deletion on pregnancy in mice. *Biol. Reprod.* **91**: 74 [PMID:25100706]
134. Stilley JA, Guan R, Duffy DM and Segaloff DL. (2014) Signaling through FSH receptors on human umbilical vein endothelial cells promotes angiogenesis. *J. Clin. Endocrinol. Metab.* **99**: E813-20 [PMID:24527712]
135. Sykiotis GP, Neumann S, Georgopoulos NA, Sgourou A, Papachatzopoulou A, Markou KB, Kyriazopoulou V, Paschke R, Vagenakis AG and Papavassiliou AG. (2003) Functional significance of the thyrotropin receptor germline polymorphism D727E. *Biochem. Biophys. Res. Commun.* **301**: 1051-6 [PMID:12589819]
136. Szkudlinski MW, Fremont V, Ronin C and Weintraub BD. (2002) Thyroid-stimulating hormone and thyroid-stimulating hormone receptor structure-function relationships. *Physiol. Rev.* **82**: 473-502 [PMID:11917095]
137. Tanaka K, Chazenbalk GD, McLachlan SM and Rapoport B. (1999) Subunit structure of thyrotropin receptors expressed on the cell surface. *J. Biol. Chem.* **274**: 33979-84 [PMID:10567361]
138. Tao YX, Johnson NB and Segaloff DL. (2004) Constitutive and agonist-dependent self-association of the cell surface human lutropin receptor. *J. Biol. Chem.* **279**: 5904-14 [PMID:14594799]
139. Tao YX and Segaloff DL. (2009) Follicle stimulating hormone receptor mutations and reproductive disorders. *Prog Mol Biol Transl Sci* **89**: 115-31 [PMID:20374735]
140. Tena-Sempere M, Manna PR and Huhtaniemi I. (1999) Molecular cloning of the mouse follicle-stimulating hormone receptor complementary deoxyribonucleic acid: functional expression of alternatively spliced variants and receptor inactivation by a C566T transition in exon 7 of the coding sequence. *Biol. Reprod.* **60**: 1515-27 [PMID:10330114]
141. Themmen APN and Huhtaniemi IT. (2000) Mutations of gonadotropins and gonadotropin receptors:

elucidating the physiology and pathophysiology of pituitary-gonadal function. *Endocr. Rev.* **21**: 551-83 [PMID:11041448]
142. Tonacchera M, Agretti P, Pinchera A, Rosellini V, Perri A, Collecchi P, Vitti P and Chiovato L. (2000) Congenital hypothyroidism with impaired thyroid response to thyrotropin (TSH) and absent circulating thyroglobulin: evidence for a new inactivating mutation of the TSH receptor gene. *J. Clin. Endocrinol. Metab.* **85**: 1001-8 [PMID:10720030]
143. Tonacchera M, Chiovato L, Pinchera A, Agretti P, Fiore E, Cetani F, Rocchi R, Viacava P, Miccoli P and Vitti P. (1998) Hyperfunctioning thyroid nodules in toxic multinodular goiter share activating thyrotropin receptor mutations with solitary toxic adenoma. *J. Clin. Endocrinol. Metab.* **83**: 492-8 [PMID:9467563]
144. Tonacchera M, Perri A, De Marco G, Agretti P, Banco ME, Di Cosmo C, Grasso L, Vitti P, Chiovato L and Pinchera A. (2004) Low prevalence of thyrotropin receptor mutations in a large series of subjects with sporadic and familial nonautoimmune subclinical hypothyroidism. *J. Clin. Endocrinol. Metab.* **89**: 5787-93 [PMID:15531543]
145. Tonacchera M, Van Sande J, Cetani F, Swillens S, Schvartz C, Winiszewski P, Portmann L, Dumont JE, Vassart G and Parma J. (1996) Functional characteristics of three new germline mutations of the thyrotropin receptor gene causing autosomal dominant toxic thyroid hyperplasia. *J. Clin. Endocrinol. Metab.* **81**: 547-54 [PMID:8636266]
146. Tonacchera M, Vitti P, Agretti P, Giulianetti B, Mazzi B, Cavaliere R, Ceccarini G, Fiore E, Viacava P and Naccarato A *et al.*. (1998) Activating thyrotropin receptor mutations in histologically heterogeneous hyperfunctioning nodules of multinodular goiter. *Thyroid* **8**: 559-64 [PMID:9709907]
147. Touraine P, Beau I, Gougeon A, Meduri G, Desroches A, Pichard C, Detoeuf M, Paniel B, Prieur M and Zorn JR *et al.*. (1999) New natural inactivating mutations of the follicle-stimulating hormone receptor: correlations between receptor function and phenotype. *Mol. Endocrinol.* **13**: 1844-54 [PMID:10551778]
148. Urizar E, Montanelli L, Loy T, Bonomi M, Swillens S, Gales C, Bouvier M, Smits G, Vassart G and Costagliola S. (2005) Glycoprotein hormone receptors: link between receptor homodimerization and negative cooperativity. *EMBO J.* **24**: 1954-64 [PMID:15889138]
149. Van Damme MP, Robertson DM and Diczfalusy E. (1974) An improved in vitro bioassay method for measuring luteinizing hormone (LH) activity using mouse Leydig cell preparations. *Acta Endocrinol (Copenh)* **77**: 655-671 [PMID:4372842]
150. van Straten NC, Schoonus-Gerritsma GG, van Someren RG, Draaijer J, Adang AE, Timmers CM, Hanssen RG and van Boeckel CA. (2002) The first orally active low molecular weight agonists for the LH receptor: thienopyr(im)idines with therapeutic potential for ovulation induction. *Chembiochem* **3**: 1023-6 [PMID:12362369]
151. van Straten NC, van Berkel TH, Demont DR, Karstens WJ, Merkx R, Oosterom J, Schulz J, van Someren RG, Timmers CM and van Zandvoort PM. (2005) Identification of substituted 6-amino-4-phenyltetrahydroquinoline derivatives: potent antagonists for the follicle-stimulating hormone receptor. *J. Med. Chem.* **48**: 1697-700 [PMID:15771412]
152. Vassart G, Pardo L and Costagliola S. (2004) A molecular dissection of the glycoprotein hormone receptors. *Trends Biochem. Sci.* **29**: 119-26 [PMID:15003269]
153. Vasseur C, Rodien P, Beau I, Desroches A, Gérard C, de Poncheville L, Chaplot S, Savagner F, Croué A and Mathieu E *et al.*. (2003) A chorionic gonadotropin-sensitive mutation in the follicle-stimulating hormone receptor as a cause of familial gestational spontaneous ovarian hyperstimulation syndrome. *N. Engl. J. Med.* **349**: 753-9 [PMID:12930927]
154. Vitti P, Rotella CM, Valente WA, Cohen J, Aloj SM, Laccetti P, Ambesi-Impiombato FS, Grollman EF, Pinchera A and Toccafondi R *et al.*. (1983) Characterization of the optimal stimulatory effects of graves' monoclonal and serum immunoglobulin G on adenosine 3',5'-monophosphate production in fRTL-5 thyroid cells: a potential clinical assay. *J. Clin. Endocrinol. Metab.* **57**: 782-91 [PMID:6136523]
155. Wang C, Hsueh AJ and Erickson GF. (1981) LH stimulation of estrogen secretion by cultured rat granulosa cells. *Mol. Cell. Endocrinol.* **24**: 17-28 [PMID:6799341]
156. Welsh MJ and Ireland ME. (1992) The second messenger pathway for germ cell-mediated stimulation of Sertoli cells. *Biochem. Biophys. Res. Commun.* **184**: 217-24 [PMID:1314584]
157. Wrobel J, Green D, Jetter J, Kao W, Rogers J, Pérez MC, Hardenburg J, Deecher DC, López FJ and Arey BJ *et al.*. (2002) Synthesis of (bis)sulfonic acid, (bis)benzamides as follicle-stimulating hormone (FSH) antagonists. *Bioorg. Med. Chem.* **10**: 639-56 [PMID:11814852]
158. Zeleznik AJ, Saxena D and Little-Ihrig L. (2003) Protein kinase B is obligatory for follicle-stimulating hormone-induced granulosa cell differentiation. *Endocrinology* **144**: 3985-94 [PMID:12933673]
159. Zhang FP, Poutanen M, Wilbertz J and Huhtaniemi I. (2001) Normal prenatal but arrested postnatal sexual development of luteinizing hormone receptor knockout (LuRKO) mice. *Mol. Endocrinol.* **15**: 172-83 [PMID:11145748]
160. Zhang M, Shi H, Segaloff DL, Van Voorhis BJ and Zheng M. (2001) Expression and localization of luteinizing hormone receptor in the female mouse reproductive tract. *Biol. Reprod.* **64**: 179-87 [PMID:11133673]
161. Zhang W, Morris QD, Chang R, Shai O, Bakowski MA, Mitsakakis N, Mohammad N, Robinson MD, Zirngibl R and Somogyi E *et al.*. (2004) The functional landscape of mouse gene expression.*J. Biol.* **3**: 21 [PMID:15588312]
162. Zhu LL, Blair H, Cao J, Yuen T, Latif R, Guo L, Tourkova IL, Li J, Davies TF and Sun L*et al.*. (2012) Blocking antibody to the β-subunit of FSH prevents bone loss by inhibiting bone resorption and stimulating bone synthesis. *Proc. Natl. Acad. Sci. U.S.A.* **109**: 14574-9 [PMID:22908268]