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$GABA_A$ receptors in GtoPdb v.2023.1

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Abstract

The $GABA_A$ receptor is a ligand-gated ion channel of the Cys-loop family that includes the nicotinic acetylcholine, $5\text{-}HT_3$ and strychnine-sensitive glycine receptors. $GABA_A$ receptor-mediated inhibition within the CNS occurs by fast synaptic transmission, sustained tonic inhibition and temporally intermediate events that have been termed '$GABA_A$, slow' [45]. $GABA_A$ receptors exist as pentamers of 4TM subunits that form an intrinsic anion selective channel. Sequences of six α, three β, three γ, one δ, three ρ, one ε, one π and one θ $GABA_A$ receptor subunits have been reported in mammals [281, 237, 238, 288]. The π-subunit is restricted to reproductive tissue. Alternatively spliced versions of many subunits exist (e.g. α4- and α6- (both not functional) α5-, β2-, β3- and γ2), along with RNA editing of the α3 subunit [71]. The three ρ-subunits, (ρ1-3) function as either homo- or hetero-oligomeric assemblies [365, 50]. Receptors formed from ρ-subunits, because of their distinctive pharmacology that includes insensitivity to bicuculline, benzodiazepines and barbiturates, have sometimes been termed $GABA_C$ receptors [365], **but they are classified as $GABA_A$ receptors by NC-IUPHAR on the basis of structural and functional criteria [16, 237, 238]**.

Many $GABA_A$ receptor subtypes contain α-, β- and γ-subunits with the likely stoichiometry 2α.2β.1γ [170, 237]. It is thought that the majority of $GABA_A$ receptors harbour a single type of α- and β -subunit variant. The α1β2γ2 hetero-oligomer constitutes the largest population of $GABA_A$ receptors in the CNS, followed by the α2β3γ2 and α3β3γ2 isoforms. Receptors that incorporate the α4- α5-or α6-subunit, or the β1-, γ1-, γ3-, δ-, ε- and θ-subunits, are less numerous, but they may nonetheless serve important functions. For example, extrasynaptically located receptors that contain α6- and δ-subunits in cerebellar granule cells, or an α4- and δ-subunit in dentate gyrus granule cells and thalamic neurones, mediate a tonic current that is important for neuronal excitability in response to ambient concentrations of GABA [211, 275, 84, 19, 293]. GABA binding occurs at the β+/α- subunit interface and the homologous γ+/α- subunits interface creates the benzodiazepine site. A second site for benzodiazepine binding has recently been postulated to occur at the α+/β- interface ([257]; reviewed by [287]). The particular α-and γ-subunit isoforms exhibit marked effects on recognition and/or efficacy at the benzodiazepine site. Thus, receptors incorporating either α4- or α6-subunits are not recognised by ‘classical’ benzodiazepines, such as flunitrazepam (but see [362]). The trafficking, cell surface expression, internalisation and function of $GABA_A$ receptors and their subunits are discussed in detail in several recent reviews [52, 141, 190, 322] but one point worthy of note is that receptors incorporating the γ2 subunit (except when associated with α5) cluster at the postsynaptic membrane (but may distribute dynamically between synaptic and extrasynaptic locations), whereas those incorporating the δ subunit appear to be exclusively extrasynaptic.

NC-IUPHAR [16, 237, 3, 2] class the $GABA_A$ receptors according to their subunit structure, pharmacology and receptor function. Currently, eleven native $GABA_A$ receptors are classed as conclusively identified (*i.e.*, α1β2γ2, α2βγ2, α3βγ2, α4βγ2, α4β2δ, α4β3δ, α5βγ2, α6βγ2, α6β2δ, α6β3δ and ρ) with further receptor isoforms occurring with high probability, or only tentatively [237, 238]. It is beyond the scope of this Guide to discuss the pharmacology of individual $GABA_A$ receptor isoforms in detail; such information can be gleaned in the reviews [16, 96, 170, 175, 144, 281, 218, 237, 238, 284, 9, 10]. Agents that discriminate between α-subunit isoforms are noted in the table and additional agents that demonstrate selectivity between receptor isoforms, for example *via* β-subunit selectivity, are indicated in the text below. The distinctive agonist and antagonist pharmacology of ρ receptors is summarised in the table and additional aspects are reviewed in [365, 50, 146, 225].

Several high-resolution cryo-electron microscopy structures have been described in which the full-length human α1β3γ2L $GABA_A$ receptor in lipid nanodiscs is bound to the channel-blocker picrotoxin, the competitive antagonist bicuculline, the agonist GABA (γ-aminobutyric acid), and the classical benzodiazepines alprazolam and diazepam [200].

Contents

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$GABA_A$ receptors

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Introduction to $GABA_A$ receptors

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References

1. Albaugh PA, Marshall L, Gregory J, White G, Hutchison A, Ross PC, Gallagher DW, Tallman JF, Crago M and Cassella JV. (2002) Synthesis and biological evaluation of 7,8,9,10-tetrahydroimidazo[1,2-c]pyrido[3,4-e]pyrimdin-5(6H)-ones as functionally selective ligands of the benzodiazepine receptor site on the GABA(A) receptor. *J Med Chem* **45**: 5043-51 [PMID:12408715]
2. Alexander SP, Kelly E, Marrion N, Peters JA, Benson HE, Faccenda E, Pawson AJ, Sharman JL, Southan C and Davies JA *et al.*. (2015) The Concise Guide to PHARMACOLOGY 2015/16: Other ion channels. *Br J Pharmacol* **172**: 5942-55 [PMID:26650442]
3. Alexander SP, Kelly E, Marrion NV, Peters JA, Faccenda E, Harding SD, Pawson AJ, Sharman JL, Southan C and Davies JA *et al.*. (2017) THE CONCISE GUIDE TO PHARMACOLOGY 2017/18: Other ion channels. *Br J Pharmacol* **174 Suppl 1**: S195-S207 [PMID:29055039]
4. Alldred MJ, Mulder-Rosi J, Lingenfelter SE, Chen G and Lüscher B. (2005) Distinct gamma2 subunit domains mediate clustering and synaptic function of postsynaptic GABAA receptors and gephyrin. *J Neurosci* **25**: 594-603 [PMID:15659595]
5. Amin J. (1999) A single hydrophobic residue confers barbiturate sensitivity to gamma-aminobutyric acid type C receptor. *Mol Pharmacol* **55**: 411-23 [PMID:10051524]
6. Araki T and Tohyama M. (1992) Region-specific expression of GABAA receptor alpha 3 and alpha 4 subunits mRNAs in the rat brain. *Brain Res Mol Brain Res* **12**: 293-314 [PMID:1315904]
7. Arias AJ, Covault J, Feinn R, Pond T, Yang BZ, Ge W, Oncken C and Kranzler HR. (2014) A GABRA2 variant is associated with increased stimulation and 'high' following alcohol administration. *Alcohol Alcohol* **49**: 1-9 [PMID:24166645]
8. AstraZeneca. AZD7325. http://openinnovation.astrazeneca.com/what-we-offer/compound/azd7325/. Accessed on 11/09/2014.
9. Atack JR. (2008) GABA(A) receptor subtype-selective efficacy: TPA023, an alpha2/alpha3 selective non-sedating anxiolytic and alpha5IA, an alpha5 selective cognition enhancer. *CNS Neurosci Ther* **14**: 25-35 [PMID:18482097]

10. Atack JR. (2010) GABAA receptor alpha2/alpha3 subtype-selective modulators as potential nonsedating anxiolytics. *Curr Top Behav Neurosci* **2**: 331-60 [PMID:21309116]
11. Audenaert D, Schwartz E, Claeys KG, Claes L, Deprez L, Suls A, Van Dyck T, Lagae L, Van Broeckhoven C and Macdonald RL *et al.*. (2006) A novel GABRG2 mutation associated with febrile seizures. *Neurology* **67**: 687-90 [PMID:16924025]
12. Baer K, Essrich C, Balsiger S, Wick MJ, Harris RA, Fritschy JM and Lüscher B. (2000) Rescue of gamma2 subunit-deficient mice by transgenic overexpression of the GABAA receptor gamma2S or gamma2L subunit isoforms. *Eur J Neurosci* **12**: 2639-43 [PMID:10947838]
13. Baer K, Essrich C, Benson JA, Benke D, Bluethmann H, Fritschy JM and Lüscher B. (1999) Postsynaptic clustering of gamma-aminobutyric acid type A receptors by the gamma3 subunit in vivo. *Proc Natl Acad Sci USA* **96**: 12860-5 [PMID:10536013]
14. Bailey ME, Albrecht BE, Johnson KJ and Darlison MG. (1999) Genetic linkage and radiation hybrid mapping of the three human GABA(C) receptor rho subunit genes: GABRR1, GABRR2 and GABRR3. *Biochim Biophys Acta* **1447**: 307-12 [PMID:10542332]
15. Barnard EA. (1996) The transmitter-gated channels: a range of receptor types and structures. *Trends Pharmacol Sci* **17**: 305-9 [PMID:8885692]
16. Barnard EA, Skolnick P, Olsen RW, Mohler H, Sieghart W, Biggio G, Braestrup C, Bateson AN and Langer SZ. (1998) International Union of Pharmacology. XV. Subtypes of gamma-aminobutyric acidA receptors: classification on the basis of subunit structure and receptor function. *Pharmacol Rev* **50**: 291-313 [PMID:9647870]
17. Barnard EA.. (2001) The Molecular Architecture of GABAA Receptors. *In Pharmacology of GABA and Glycine Neurotransmission* Edited by Möhler H: Springer: 79-99
18. Baulac S, Huberfeld G, Gourfinkel-An I, Mitropoulou G, Beranger A, Prud'homme JF, Baulac M, Brice A, Bruzzone R and LeGuern E. (2001) First genetic evidence of GABA(A) receptor dysfunction in epilepsy: a mutation in the gamma2-subunit gene. *Nat Genet* **28**: 46-8 [PMID:11326274]
19. Belelli D, Harrison NL, Maguire J, Macdonald RL, Walker MC and Cope DW. (2009) Extrasynaptic GABAA receptors: form, pharmacology, and function. *J Neurosci* **29**: 12757-63 [PMID:19828786]
20. Belelli D and Lambert JJ. (2005) Neurosteroids: endogenous regulators of the GABA(A) receptor. *Nat Rev Neurosci* **6**: 565-75 [PMID:15959466]
21. Belelli D, Lambert JJ, Peters JA, Wafford K and Whiting PJ. (1997) The interaction of the general anesthetic etomidate with the gamma-aminobutyric acid type A receptor is influenced by a single amino acid. *Proc Natl Acad Sci USA* **94**: 11031-6 [PMID:9380754]
22. Belelli D, Pau D, Cabras G, Peters JA and Lambert JJ. (1999) A single amino acid confers barbiturate sensitivity upon the GABA rho 1 receptor. *Br J Pharmacol* **127**: 601-4 [PMID:10401548]
23. Belelli D, Peden DR, Rosahl TW, Wafford KA and Lambert JJ. (2005) Extrasynaptic GABAA receptors of thalamocortical neurons: a molecular target for hypnotics. *J Neurosci* **25**: 11513-20 [PMID:16354909]
24. Bencsits E, Ebert V, Tretter V and Sieghart W. (1999) A significant part of native gamma-aminobutyric AcidA receptors containing alpha4 subunits do not contain gamma or delta subunits. *J Biol Chem* **274**: 19613-6 [PMID:10391897]
25. Benke D, Fritschy JM, Trzeciak A, Bannwarth W and Mohler H. (1994) Distribution, prevalence, and drug binding profile of gamma-aminobutyric acid type A receptor subtypes differing in the beta-subunit variant. *J Biol Chem* **269**: 27100-7 [PMID:7929453]
26. Benke D, Mertens S, Trzeciak A, Gillessen D and Mohler H. (1991) Identification and immunohistochemical mapping of GABAA receptor subtypes containing the delta-subunit in rat brain. *FEBS Lett* **283**: 145-9 [PMID:1645294]
27. Bianchi MT and Macdonald RL. (2003) Neurosteroids shift partial agonist activation of GABA(A) receptor channels from low- to high-efficacy gating patterns. *J Neurosci* **23**: 10934-43 [PMID:14645489]
28. Bierut LJ, Agrawal A, Bucholz KK, Doheny KF, Laurie C, Pugh E, Fisher S, Fox L, Howells W and Bertelsen S *et al.*. (2010) A genome-wide association study of alcohol dependence. *Proc Natl Acad Sci USA* **107**: 5082-7 [PMID:20202923]
29. Birnir B, Tierney ML, Dalziel JE, Cox GB and Gage PW. (1997) A structural determinant of desensitization and allosteric regulation by pentobarbitone of the GABAA receptor. *J Membr Biol* **155**: 157-66 [PMID:9049109]
30. Blake JA, Bult CJ, Kadin JA, Richardson JE, Eppig JT and Mouse Genome Database Group. (2011) The Mouse Genome Database (MGD): premier model organism resource for mammalian genomics and

genetics. *Nucleic Acids Res* **39**: D842-8 [PMID:21051359]
31. Blednov YA, Jung S, Alva H, Wallace D, Rosahl T, Whiting PJ and Harris RA. (2003) Deletion of the alpha1 or beta2 subunit of GABAA receptors reduces actions of alcohol and other drugs. *J Pharmacol Exp Ther* **304**: 30-6 [PMID:12490572]
32. Bohlhalter S, Weinmann O, Mohler H and Fritschy JM. (1996) Laminar compartmentalization of GABAA-receptor subtypes in the spinal cord: an immunohistochemical study. *J Neurosci* **16**: 283-97 [PMID:8613794]
33. Bonin RP, Martin LJ, MacDonald JF and Orser BA. (2007) Alpha5GABAA receptors regulate the intrinsic excitability of mouse hippocampal pyramidal neurons. *J Neurophysiol* **98**: 2244-54 [PMID:17715197]
34. Bonin RP and Orser BA. (2008) GABA(A) receptor subtypes underlying general anesthesia. *Pharmacol Biochem Behav* **90**: 105-12 [PMID:18201756]
35. Bonnert TP, McKernan RM, Farrar S, le Bourdellès B, Heavens RP, Smith DW, Hewson L, Rigby MR, Sirinathsinghji DJ, Brown N, Wafford KA and Whiting PJ. (1999) theta, a novel gamma-aminobutyric acid type A receptor subunit. *Proc Natl Acad Sci USA* **96**: 9891-6 [PMID:10449790]
36. Bosker FJ, Hartman CA, Nolte IM, Prins BP, Terpstra P, Posthuma D, van Veen T, Willemsen G, DeRijk RH and de Geus EJ *et al.*. (2011) Poor replication of candidate genes for major depressive disorder using genome-wide association data. *Mol Psychiatry* **16**: 516-32 [PMID:20351714]
37. Bovolin P, Santi MR, Memo M, Costa E and Grayson DR. (1992) Distinct developmental patterns of expression of rat alpha 1, alpha 5, gamma 2S, and gamma 2L gamma-aminobutyric acidA receptor subunit mRNAs in vivo and in vitro. *J Neurochem* **59**: 62-72 [PMID:1319473]
38. Brickley SG, Revilla V, Cull-Candy SG, Wisden W and Farrant M. (2001) Adaptive regulation of neuronal excitability by a voltage-independent potassium conductance. *Nature* **409**: 88-92 [PMID:11343119]
39. Brooks-Kayal AR, Shumate MD, Jin H, Rikhter TY and Coulter DA. (1998) Selective changes in single cell GABA(A) receptor subunit expression and function in temporal lobe epilepsy. *Nat Med* **4**: 1166-72 [PMID:9771750]
40. Brown N, Kerby J, Bonnert TP, Whiting PJ and Wafford KA. (2002) Pharmacological characterization of a novel cell line expressing human alpha(4)beta(3)delta GABA(A) receptors. *Br J Pharmacol* **136**: 965-74 [PMID:12145096]
41. Buckle VJ, Fujita N, Ryder-Cook AS, Derry JM, Barnard PJ, Lebo RV, Schofield PR, Seeburg PH, Bateson AN and Darlison MG. (1989) Chromosomal localization of GABAA receptor subunit genes: relationship to human genetic disease. *Neuron* **3**: 647-54 [PMID:2561974]
42. Buettelmann B, Jakob-Roetne R, Knust H, Lucas MC and Thomas A. (2009) Isoxazolo-pyridine derivatives Patent number: WO2009071476A1. Assignee: Hoffmann-La Roche. Priority date: 04/12/2007. Publication date: 11/06/2009.
43. Buhr A, Bianchi MT, Baur R, Courtet P, Pignay V, Boulenger JP, Gallati S, Hinkle DJ, Macdonald RL and Sigel E. (2002) Functional characterization of the new human GABA(A) receptor mutation beta3(R192H). *Hum Genet* **111**: 154-60 [PMID:12189488]
44. Buneman P, Christie G, Davies JA, Dimitrellou R, Harding SD, Pawson AJ, Sharman JL and Wu Y. (2020) Why data citation isn't working, and what to do about it *Database* **2020** [PMID:32367113]
45. Capogna M and Pearce RA. (2011) GABA A,slow: causes and consequences. *Trends Neurosci* **34**: 101-12 [PMID:21145601]
46. Caraiscos VB, Elliott EM, You-Ten KE, Cheng VY, Belelli D, Newell JG, Jackson MF, Lambert JJ, Rosahl TW and Wafford KA *et al.*. (2004) Tonic inhibition in mouse hippocampal CA1 pyramidal neurons is mediated by alpha5 subunit-containing gamma-aminobutyric acid type A receptors. *Proc Natl Acad Sci USA* **101**: 3662-7 [PMID:14993607]
47. Caraiscos VB, Newell JG, You-Ten KE, Elliott EM, Rosahl TW, Wafford KA, MacDonald JF and Orser BA. (2004) Selective enhancement of tonic GABAergic inhibition in murine hippocampal neurons by low concentrations of the volatile anesthetic isoflurane. *J Neurosci* **24**: 8454-8 [PMID:15456818]
48. Chandra D, Jia F, Liang J, Peng Z, Suryanarayanan A, Werner DF, Spigelman I, Houser CR, Olsen RW and Harrison NL *et al.*. (2006) GABAA receptor alpha 4 subunits mediate extrasynaptic inhibition in thalamus and dentate gyrus and the action of gaboxadol. *Proc Natl Acad Sci USA* **103**: 15230-5 [PMID:17005728]
49. Chang Y, Wang R, Barot S and Weiss DS. (1996) Stoichiometry of a recombinant GABAA receptor. *J Neurosci* **16**: 5415-24 [PMID:8757254]
50. Chebib M. (2004) GABAC receptor ion channels. *Clin Exp Pharmacol Physiol* **31**: 800-4 [PMID:15566397]

51. Chen Z, Jin N, Narasaraju T, Chen J, McFarland LR, Scott M and Liu L. (2004) Identification of two novel markers for alveolar epithelial type I and II cells. *Biochem Biophys Res Commun* **319**: 774-80 [PMID:15184050]
52. Chen ZW and Olsen RW. (2007) GABAA receptor associated proteins: a key factor regulating GABAA receptor function. *J Neurochem* **100**: 279-94 [PMID:17083446]
53. Cheng VY, Martin LJ, Elliott EM, Kim JH, Mount HT, Taverna FA, Roder JC, Macdonald JF, Bhambri A and Collinson N *et al.*. (2006) Alpha5GABAA receptors mediate the amnestic but not sedative-hypnotic effects of the general anesthetic etomidate. *J Neurosci* **26**: 3713-20 [PMID:16597725]
54. Cirone J, Rosahl TW, Reynolds DS, Newman RJ, O'Meara GF, Hutson PH and Wafford KA. (2004) Gamma-aminobutyric acid type A receptor beta 2 subunit mediates the hypothermic effect of etomidate in mice. *Anesthesiology* **100**: 1438-45 [PMID:15166563]
55. Claes L, Del-Favero J, Ceulemans B, Lagae L, Van Broeckhoven C and De Jonghe P. (2001) De novo mutations in the sodium-channel gene SCN1A cause severe myoclonic epilepsy of infancy. *Am J Hum Genet* **68**: 1327-32 [PMID:11359211]
56. Clarkson AN, Huang BS, Macisaac SE, Mody I and Carmichael ST. (2010) Reducing excessive GABA-mediated tonic inhibition promotes functional recovery after stroke. *Nature* **468**: 305-9 [PMID:21048709]
57. Collins AL, Ma D, Whitehead PL, Martin ER, Wright HH, Abramson RK, Hussman JP, Haines JL, Cuccaro ML and Gilbert JR *et al.*. (2006) Investigation of autism and GABA receptor subunit genes in multiple ethnic groups. *Neurogenetics* **7**: 167-74 [PMID:16770606]
58. Collinson N, Kuenzi FM, Jarolimek W, Maubach KA, Cothliff R, Sur C, Smith A, Otu FM, Howell O and Atack JR *et al.*. (2002) Enhanced learning and memory and altered GABAergic synaptic transmission in mice lacking the alpha 5 subunit of the GABAA receptor. *J Neurosci* **22**: 5572-80 [PMID:12097508]
59. Cook EH, Lindgren V, Leventhal BL, Courchesne R, Lincoln A, Shulman C, Lord C and Courchesne E. (1997) Autism or atypical autism in maternally but not paternally derived proximal 15q duplication. *Am J Hum Genet* **60**: 928-34 [PMID:9106540]
60. Cox ED, Diaz-Arauzo H, Huang Q, Reddy MS, Ma C, Harris B, McKernan R, Skolnick P and Cook JM. (1998) Synthesis and evaluation of analogues of the partial agonist 6-(propyloxy)-4-(methoxymethyl)-beta-carboline-3-carboxylic acid ethyl ester (6-PBC) and the full agonist 6-(benzyloxy)-4-(methoxymethyl)-beta-carboline-3-carboxylic acid ethyl ester (Zk 93423) at wild type and recombinant GABAA receptors. *J Med Chem* **41**: 2537-52 [PMID:9651158]
61. Craddock N, Jones L, Jones IR, Kirov G, Green EK, Grozeva D, Moskvina V, Nikolov I, Hamshere ML and Vukcevic D *et al.*. (2010) Strong genetic evidence for a selective influence of GABAA receptors on a component of the bipolar disorder phenotype. *Mol Psychiatry* **15**: 146-53 [PMID:19078961]
62. Crestani F, Keist R, Fritschy JM, Benke D, Vogt K, Prut L, Blüthmann H, Möhler H and Rudolph U. (2002) Trace fear conditioning involves hippocampal alpha5 GABA(A) receptors. *Proc Natl Acad Sci USA* **99**: 8980-5 [PMID:12084936]
63. Crestani F, Lorez M, Baer K, Essrich C, Benke D, Laurent JP, Belzung C, Fritschy JM, Lüscher B and Mohler H. (1999) Decreased GABAA-receptor clustering results in enhanced anxiety and a bias for threat cues. *Nat Neurosci* **2**: 833-9 [PMID:10461223]
64. Crestani F, Löw K, Keist R, Mandelli M, Möhler H and Rudolph U. (2001) Molecular targets for the myorelaxant action of diazepam. *Mol Pharmacol* **59**: 442-5 [PMID:11179437]
65. Crunelli V and Leresche N. (2002) Childhood absence epilepsy: genes, channels, neurons and networks. *Nat Rev Neurosci* **3**: 371-82 [PMID:11988776]
66. Culiat CT, Stubbs L, Nicholls RD, Montgomery CS, Russell LB, Johnson DK and Rinchik EM. (1993) Concordance between isolated cleft palate in mice and alterations within a region including the gene encoding the beta 3 subunit of the type A gamma-aminobutyric acid receptor. *Proc Natl Acad Sci USA* **90**: 5105-9 [PMID:8389469]
67. Culiat CT, Stubbs LJ, Montgomery CS, Russell LB and Rinchik EM. (1994) Phenotypic consequences of deletion of the gamma 3, alpha 5, or beta 3 subunit of the type A gamma-aminobutyric acid receptor in mice. *Proc Natl Acad Sci USA* **91**: 2815-8 [PMID:8146195]
68. Culiat CT, Stubbs LJ, Woychik RP, Russell LB, Johnson DK and Rinchik EM. (1995) Deficiency of the beta 3 subunit of the type A gamma-aminobutyric acid receptor causes cleft palate in mice. *Nat Genet* **11**: 344-6 [PMID:7581464]
69. Cutting GR, Curristin S, Zoghbi H, O'Hara B, Seldin MF and Uhl GR. (1992) Identification of a putative

gamma-aminobutyric acid (GABA) receptor subunit rho2 cDNA and colocalization of the genes encoding rho2 (GABRR2) and rho1 (GABRR1) to human chromosome 6q14-q21 and mouse chromosome 4. *Genomics* **12**: 801-6 [PMID:1315307]

70. Cutting GR, Lu L, O'Hara BF, Kasch LM, Montrose-Rafizadeh C, Donovan DM, Shimada S, Antonarakis SE, Guggino WB and Uhl GR. (1991) Cloning of the gamma-aminobutyric acid (GABA) rho 1 cDNA: a GABA receptor subunit highly expressed in the retina. *Proc Natl Acad Sci USA* **88**: 2673-7 [PMID:1849271]
71. Daniel C and Ohman M. (2009) RNA editing and its impact on GABAA receptor function. *Biochem Soc Trans* **37**: 1399-403 [PMID:19909284]
72. Daniel C, Wahlstedt H, Ohlson J, Björk P and Ohman M. (2011) Adenosine-to-inosine RNA editing affects trafficking of the gamma-aminobutyric acid type A (GABA(A)) receptor. *J Biol Chem* **286**: 2031-40 [PMID:21030585]
73. Davies PA, Hanna MC, Hales TG and Kirkness EF. (1997) Insensitivity to anaesthetic agents conferred by a class of GABA(A) receptor subunit. *Nature* **385**: 820-3 [PMID:9039914]
74. Davies PA, McCartney MR, Wang W, Hales TG and Kirkness EF. (2002) Alternative transcripts of the GABA(A) receptor epsilon subunit in human and rat. *Neuropharmacology* **43**: 467-75 [PMID:12367593]
75. Delong R. (2007) GABA(A) receptor alpha5 subunit as a candidate gene for autism and bipolar disorder: a proposed endophenotype with parent-of-origin and gain-of-function features,with or without oculocutaneous albinism. *Autism* **11**: 135-47 [PMID:17353214]
76. Dibbens LM, Feng HJ, Richards MC, Harkin LA, Hodgson BL, Scott D, Jenkins M, Petrou S, Sutherland GR, Scheffer IE, Berkovic SF, Macdonald RL and Mulley JC. (2004) GABRD encoding a protein for extra- or peri-synaptic GABAA receptors is a susceptibility locus for generalized epilepsies. *Hum Mol Genet* **13**: 1315-9 [PMID:15115768]
77. Drescher DG, Green GE, Khan KM, Hajela K, Beisel KW, Morley BJ and Gupta AK. (1993) Analysis of gamma-aminobutyric acidA receptor subunits in the mouse cochlea by means of the polymerase chain reaction. *J Neurochem* **61**: 1167-70 [PMID:8395561]
78. Earnheart JC, Schweizer C, Crestani F, Iwasato T, Itohara S, Mohler H and Lüscher B. (2007) GABAergic control of adult hippocampal neurogenesis in relation to behavior indicative of trait anxiety and depression states. *J Neurosci* **27**: 3845-54 [PMID:17409249]
79. Emberger W, Windpassinger C, Petek E, Kroisel PM and Wagner K. (2000) Assignment of the human GABAA receptor delta-subunit gene (GABRD) to chromosome band 1p36.3 distal to marker NIB1364 by radiation hybrid mapping. *Cytogenet Cell Genet* **89**: 281-2 [PMID:10965146]
80. Enz R, Brandstätter JH, Hartveit E, Wässle H and Bormann J. (1995) Expression of GABA receptor rho 1 and rho 2 subunits in the retina and brain of the rat. *Eur J Neurosci* **7**: 1495-501 [PMID:7551175]
81. Enz R and Cutting GR. (1999) GABAC receptor rho subunits are heterogeneously expressed in the human CNS and form homo- and heterooligomers with distinct physical properties. *Eur J Neurosci* **11**: 41-50 [PMID:9987010]
82. Essrich C, Lorez M, Benson JA, Fritschy JM and Lüscher B. (1998) Postsynaptic clustering of major GABAA receptor subtypes requires the gamma 2 subunit and gephyrin. *Nat Neurosci* **1**: 563-71 [PMID:10196563]
83. Fabjan J, Koniuszewski F, Schaar B and Ernst M. (2020) Structure-Guided Computational Methods Predict Multiple Distinct Binding Modes for Pyrazoloquinolinones in $GABA_A$ Receptors. *Front Neurosci* **14**: 611953 [PMID:33519364]
84. Farrant M and Nusser Z. (2005) Variations on an inhibitory theme: phasic and tonic activation of GABA(A) receptors. *Nat Rev Neurosci* **6**: 215-29 [PMID:15738957]
85. Fatemi SH, Reutiman TJ, Folsom TD and Thuras PD. (2009) GABA(A) receptor downregulation in brains of subjects with autism. *J Autism Dev Disord* **39**: 223-30 [PMID:18821008]
86. Faure-Halley C, Graham D, Arbilla S and Langer SZ. (1993) Expression and properties of recombinant alpha 1 beta 2 gamma 2 and alpha 5 beta 2 gamma 2 forms of the rat GABAA receptor. *Eur J Pharmacol* **246**: 283-7 [PMID:8223951]
87. Feng HJ, Bianchi MT and Macdonald RL. (2004) Pentobarbital differentially modulates alpha1beta3delta and alpha1beta3gamma2L GABAA receptor currents. *Mol Pharmacol* **66**: 988-1003 [PMID:15247320]
88. Ferguson C, Hardy SL, Werner DF, Hileman SM, Delorey TM and Homanics GE. (2007) New insight into the role of the beta3 subunit of the GABAA-R in development, behavior, body weight regulation, and anesthesia revealed by conditional gene knockout. *BMC Neurosci* **8**: 85 [PMID:17927825]

89. Filipek PA, Juranek J, Smith M, Mays LZ, Ramos ER, Bocian M, Masser-Frye D, Laulhere TM, Modahl C and Spence MA *et al.*. (2003) Mitochondrial dysfunction in autistic patients with 15q inverted duplication. *Ann Neurol* **53**: 801-4 [PMID:12783428]
90. Fiorelli R, Rudolph U, Straub CJ, Feldon J and Yee BK. (2008) Affective and cognitive effects of global deletion of alpha3-containing gamma-aminobutyric acid-A receptors. *Behav Pharmacol* **19**: 582-96 [PMID:18690113]
91. Fisher JL. (2009) The anti-convulsant stiripentol acts directly on the GABA(A) receptor as a positive allosteric modulator. *Neuropharmacology* **56**: 190-7 [PMID:18585399]
92. Fisher JL. (2002) Amiloride inhibition of gamma-aminobutyric acid(A) receptors depends upon the alpha subunit subtype. *Mol Pharmacol* **61**: 1322-8 [PMID:12021393]
93. Fritschy JM, Benke D, Johnson DK, Mohler H and Rudolph U. (1997) GABAA-receptor alpha-subunit is an essential prerequisite for receptor formation in vivo. *Neuroscience* **81**: 1043-53 [PMID:9330366]
94. Fritschy JM, Johnson DK, Mohler H and Rudolph U. (1998) Independent assembly and subcellular targeting of GABA(A)-receptor subtypes demonstrated in mouse hippocampal and olfactory neurons in vivo. *Neurosci Lett* **249**: 99-102 [PMID:9682826]
95. Fritschy JM and Mohler H. (1995) GABAA-receptor heterogeneity in the adult rat brain: differential regional and cellular distribution of seven major subunits. *J Comp Neurol* **359**: 154-94 [PMID:8557845]
96. Frølund B, Ebert B, Kristiansen U, Liljefors T and Krogsgaard-Larsen P. (2002) GABA(A) receptor ligands and their therapeutic potentials. *Curr Top Med Chem* **2**: 817-32 [PMID:12171573]
97. Fujii E and Mellon SH. (2001) Regulation of uterine gamma-aminobutyric acid(A) receptor subunit expression throughout pregnancy. *Endocrinology* **142**: 1770-7 [PMID:11316740]
98. Gade-Andavolu R, MacMurray JP, Blake H, Muhleman D, Tourtellotte W and Comings DE. (1998) Association between the gamma-aminobutyric acid A3 receptor gene and multiple sclerosis. *Arch Neurol* **55**: 513-6 [PMID:9561979]
99. Garret M, Bascles L, Boue-Grabot E, Sartor P, Charron G, Bloch B and Margolskee RF. (1997) An mRNA encoding a putative GABA-gated chloride channel is expressed in the human cardiac conduction system. *J Neurochem* **68**: 1382-9 [PMID:9084408]
100. Garrett KM, Duman RS, Saito N, Blume AJ, Vitek MP and Tallman JF. (1988) Isolation of a cDNA clone for the alpha subunit of the human GABA-A receptor. *Biochem Biophys Res Commun* **156**: 1039-45 [PMID:2847710]
101. Gerdjikov TV, Rudolph U, Keist R, Möhler H, Feldon J and Yee BK. (2008) Hippocampal alpha 5 subunit-containing GABA A receptors are involved in the development of the latent inhibition effect. *Neurobiol Learn Mem* **89**: 87-94 [PMID:17638582]
102. Glykys J, Mann EO and Mody I. (2008) Which GABA(A) receptor subunits are necessary for tonic inhibition in the hippocampus? *J Neurosci* **28**: 1421-6 [PMID:18256262]
103. Glykys J and Mody I. (2006) Hippocampal network hyperactivity after selective reduction of tonic inhibition in GABA A receptor alpha5 subunit-deficient mice. *J Neurophysiol* **95**: 2796-807 [PMID:16452257]
104. Glykys J, Peng Z, Chandra D, Homanics GE, Houser CR and Mody I. (2007) A new naturally occurring GABA(A) receptor subunit partnership with high sensitivity to ethanol. *Nat Neurosci* **10**: 40-8 [PMID:17159992]
105. Greger V, Knoll JH, Woolf E, Glatt K, Tyndale RF, DeLorey TM, Olsen RW, Tobin AJ, Sikela JM and Nakatsu Y. (1995) The gamma-aminobutyric acid receptor gamma 3 subunit gene (GABRG3) is tightly linked to the alpha 5 subunit gene (GABRA5) on human chromosome 15q11-q13 and is transcribed in the same orientation. *Genomics* **26**: 258-64 [PMID:7601451]
106. Groves JO, Guscott MR, Hallett DJ, Rosahl TW, Pike A, Davies A, Wafford KA and Reynolds DS. (2006) The role of GABAbeta2 subunit-containing receptors in mediating the anticonvulsant and sedative effects of loreclezole. *Eur J Neurosci* **24**: 167-74 [PMID:16882014]
107. Günther U, Benson J, Benke D, Fritschy JM, Reyes G, Knoflach F, Crestani F, Aguzzi A, Arigoni M and Lang Y. (1995) Benzodiazepine-insensitive mice generated by targeted disruption of the gamma 2 subunit gene of gamma-aminobutyric acid type A receptors. *Proc Natl Acad Sci USA* **92**: 7749-53 [PMID:7644489]
108. Hadingham KL, Garrett EM, Wafford KA, Bain C, Heavens RP, Sirinathsinghji DJ and Whiting PJ. (1996) Cloning of cDNAs encoding the human gamma-aminobutyric acid type A receptor alpha 6 subunit and characterization of the pharmacology of alpha 6-containing receptors. *Mol Pharmacol* **49**: 253-9

[PMID:8632757]
109. Hadingham KL, Wafford KA, Thompson SA, Palmer KJ and Whiting PJ. (1995) Expression and pharmacology of human GABAA receptors containing gamma 3 subunits. *Eur J Pharmacol* **291**: 301-9 [PMID:8719414]
110. Hadingham KL, Wingrove P, Le Bourdelles B, Palmer KJ, Ragan CI and Whiting PJ. (1993) Cloning of cDNA sequences encoding human alpha 2 and alpha 3 gamma-aminobutyric acidA receptor subunits and characterization of the benzodiazepine pharmacology of recombinant alpha 1-, alpha 2-, alpha 3-, and alpha 5-containing human gamma-aminobutyric acidA receptors. *Mol Pharmacol* **43**: 970-5 [PMID:8391122]
111. Halliwell RF, Thomas P, Patten D, James CH, Martinez-Torres A, Miledi R and Smart TG. (1999) Subunit-selective modulation of GABAA receptors by the non-steroidal anti-inflammatory agent, mefenamic acid. *Eur J Neurosci* **11**: 2897-905 [PMID:10457186]
112. Hanchar HJ, Dodson PD, Olsen RW, Otis TS and Wallner M. (2005) Alcohol-induced motor impairment caused by increased extrasynaptic GABA(A) receptor activity. *Nat Neurosci* **8**: 339-45 [PMID:15696164]
113. Harkin LA, Bowser DN, Dibbens LM, Singh R, Phillips F, Wallace RH, Richards MC, Williams DA, Mulley JC and Berkovic SF *et al.*. (2002) Truncation of the GABA(A)-receptor gamma2 subunit in a family with generalized epilepsy with febrile seizures plus. *Am J Hum Genet* **70**: 530-6 [PMID:11748509]
114. Harris D, Clayton T, Cook J, Sahbaie P, Halliwell RF, Furtmüller R, Huck S, Sieghart W and DeLorey TM. (2008) Selective influence on contextual memory: physiochemical properties associated with selectivity of benzodiazepine ligands at GABAA receptors containing the alpha5 subunit. *J Med Chem* **51**: 3788-803 [PMID:18537233]
115. Harvey RJ, Chinchetru MA and Darlison MG. (1994) Alternative splicing of a 51-nucleotide exon that encodes a putative protein kinase C phosphorylation site generates two forms of the chicken gamma-aminobutyric acidA receptor beta 2 subunit. *J Neurochem* **62**: 10-6 [PMID:7505310]
116. Harvey RJ, Kim HC and Darlison MG. (1993) Molecular cloning reveals the existence of a fourth gamma subunit of the vertebrate brain GABAA receptor. *FEBS Lett* **331**: 211-6 [PMID:8397108]
117. Hauser J, Rudolph U, Keist R, Möhler H, Feldon J and Yee BK. (2005) Hippocampal alpha5 subunit-containing GABAA receptors modulate the expression of prepulse inhibition. *Mol Psychiatry* **10**: 201-7 [PMID:15263904]
118. Hedblom E and Kirkness EF. (1997) A novel class of GABAA receptor subunit in tissues of the reproductive system. *J Biol Chem* **272**: 15346-50 [PMID:9182563]
119. Hemmings HC, Akabas MH, Goldstein PA, Trudell JR, Orser BA and Harrison NL. (2005) Emerging molecular mechanisms of general anesthetic action. *Trends Pharmacol Sci* **26**: 503-10 [PMID:16126282]
120. Henkel V, Baghai TC, Eser D, Zill P, Mergl R, Zwanzger P, Schüle C, Bottlender R, Jäger M and Rupprecht R *et al.*. (2004) The gamma amino butyric acid (GABA) receptor alpha-3 subunit gene polymorphism in unipolar depressive disorder: a genetic association study. *Am J Med Genet B Neuropsychiatr Genet* **126B**: 82-7 [PMID:15048654]
121. Herb A, Wisden W, Lüddens H, Puia G, Vicini S and Seeburg PH. (1992) The third gamma subunit of the gamma-aminobutyric acid type A receptor family. *Proc Natl Acad Sci USA* **89**: 1433-7 [PMID:1311098]
122. Herd MB, Belelli D and Lambert JJ. (2007) Neurosteroid modulation of synaptic and extrasynaptic GABA(A) receptors. *Pharmacol Ther* **116**: 20-34 [PMID:17531325]
123. Herd MB, Haythornthwaite AR, Rosahl TW, Wafford KA, Homanics GE, Lambert JJ and Belelli D. (2008) The expression of GABAA beta subunit isoforms in synaptic and extrasynaptic receptor populations of mouse dentate gyrus granule cells. *J Physiol (Lond.)* **586**: 989-1004 [PMID:18079158]
124. Herman GE, Faust CJ, Darlison MG and Barnard EA. (1991) Genetic mapping of the mouse X chromosome in the region homologous to human Xq27-Xq28. *Genomics* **9**: 670-7 [PMID:1674728]
125. Hicks AA, Bailey ME, Riley BP, Kamphuis W, Siciliano MJ, Johnson KJ and Darlison MG. (1994) Further evidence for clustering of human GABAA receptor subunit genes: localization of the alpha 6-subunit gene (GABRA6) to distal chromosome 5q by linkage analysis. *Genomics* **20**: 285-8 [PMID:8020978]
126. Hirose S. (2006) A new paradigm of channelopathy in epilepsy syndromes: intracellular trafficking abnormality of channel molecules. *Epilepsy Res* **70 Suppl 1**: S206-17 [PMID:16860540]
127. Hogart A, Leung KN, Wang NJ, Wu DJ, Driscoll J, Vallero RO, Schanen NC and LaSalle JM. (2009) Chromosome 15q11-13 duplication syndrome brain reveals epigenetic alterations in gene expression not predicted from copy number. *J Med Genet* **46**: 86-93 [PMID:18835857]
128. Hogart A, Nagarajan RP, Patzel KA, Yasui DH and Lasalle JM. (2007) 15q11-13 GABAA receptor genes are

normally biallelically expressed in brain yet are subject to epigenetic dysregulation in autism-spectrum disorders. *Hum Mol Genet* **16**: 691-703 [PMID:17339270]
129. Hogenkamp DJ, Tahir SH, Hawkinson JE, Upasani RB, Alauddin M, Kimbrough CL, Acosta-Burruel M, Whittemore ER, Woodward RM and Lan NC *et al.*. (1997) Synthesis and in vitro activity of 3 beta-substituted-3 alpha-hydroxypregnan-20-ones: allosteric modulators of the GABAA receptor. *J Med Chem* **40**: 61-72 [PMID:9016329]
130. Homanics GE, Ferguson C, Quinlan JJ, Daggett J, Snyder K, Lagenaur C, Mi ZP, Wang XH, Grayson DR and Firestone LL. (1997) Gene knockout of the alpha6 subunit of the gamma-aminobutyric acid type A receptor: lack of effect on responses to ethanol, pentobarbital, and general anesthetics. *Mol Pharmacol* **51**: 588-96 [PMID:9106623]
131. Hood HM, Metten P, Crabbe JC and Buck KJ. (2006) Fine mapping of a sedative-hypnotic drug withdrawal locus on mouse chromosome 11. *Genes Brain Behav* **5**: 1-10 [PMID:16436183]
132. Hosie AM, Wilkins ME and Smart TG. (2007) Neurosteroid binding sites on GABA(A) receptors. *Pharmacol Ther* **116**: 7-19 [PMID:17560657]
133. Huang Q, He X, Ma C, Liu R, Yu S, Dayer CA, Wenger GR, McKernan R and Cook JM. (2000) Pharmacophore/receptor models for GABA(A)/BzR subtypes (alpha1beta3gamma2, alpha5beta3gamma2, and alpha6beta3gamma2) via a comprehensive ligand-mapping approach. *J Med Chem* **43**: 71-95 [PMID:10633039]
134. HUGO Gene Nomenclature Committee at the European Bioinformatics Institute. . http://www.genenames.org/. Accessed on 06/12/2011.
135. Huh KH, Endo S and Olsen RW. (1996) Diazepam-insensitive GABAA receptors in rat cerebellum and thalamus. *Eur J Pharmacol* **310**: 225-33 [PMID:8884221]
136. Huntsman MM, Leggio MG and Jones EG. (1996) Nucleus-specific expression of GABA(A) receptor subunit mRNAs in monkey thalamus. *J Neurosci* **16**: 3571-89 [PMID:8642403]
137. Huntsman MM, Woods TM and Jones EG. (1995) Laminar patterns of expression of GABA-A receptor subunit mRNAs in monkey sensory motor cortex. *J Comp Neurol* **362**: 565-82 [PMID:8636468]
138. Inada T, Koga M, Ishiguro H, Horiuchi Y, Syu A, Yoshio T, Takahashi N, Ozaki N and Arinami T. (2008) Pathway-based association analysis of genome-wide screening data suggest that genes associated with the gamma-aminobutyric acid receptor signaling pathway are involved in neuroleptic-induced, treatment-resistant tardive dyskinesia. *Pharmacogenet Genomics* **18**: 317-23 [PMID:18334916]
139. Irnaten M, Walwyn WM, Wang J, Venkatesan P, Evans C, Chang KS, Andresen MC, Hales TG and Mendelowitz D. (2002) Pentobarbital enhances GABAergic neurotransmission to cardiac parasympathetic neurons, which is prevented by expression of GABA(A) epsilon subunit. *Anesthesiology* **97**: 717-24 [PMID:12218540]
140. Itsara A, Cooper GM, Baker C, Girirajan S, Li J, Absher D, Krauss RM, Myers RM, Ridker PM and Chasman DI *et al.*. (2009) Population analysis of large copy number variants and hotspots of human genetic disease. *Am J Hum Genet* **84**: 148-61 [PMID:19166990]
141. Jacob TC, Moss SJ and Jurd R. (2008) GABA(A) receptor trafficking and its role in the dynamic modulation of neuronal inhibition. *Nat Rev Neurosci* **9**: 331-43 [PMID:18382465]
142. Jechlinger M, Pelz R, Tretter V, Klausberger T and Sieghart W. (1998) Subunit composition and quantitative importance of hetero-oligomeric receptors: GABAA receptors containing alpha6 subunits. *J Neurosci* **18**: 2449-57 [PMID:9502805]
143. Johnson SK and Haun RS. (2005) The gamma-aminobutyric acid A receptor pi subunit is overexpressed in pancreatic adenocarcinomas. *JOP* **6**: 136-42 [PMID:15767729]
144. Johnston GA. (2005) GABA(A) receptor channel pharmacology. *Curr Pharm Des* **11**: 1867-85 [PMID:15974965]
145. Johnston GA. (1996) GABAc receptors: relatively simple transmitter -gated ion channels? *Trends Pharmacol Sci* **17**: 319-23 [PMID:8885697]
146. Johnston GA, Chebib M, Hanrahan JR and Mewett KN. (2010) Neurochemicals for the investigation of GABA(C) receptors. *Neurochem Res* **35**: 1970-7 [PMID:20963487]
147. Jones A, Korpi ER, McKernan RM, Pelz R, Nusser Z, Mäkelä R, Mellor JR, Pollard S, Bahn S, Stephenson FA, Randall AD, Sieghart W, Somogyi P, Smith AJ and Wisden W. (1997) Ligand-gated ion channel subunit partnerships: GABAA receptor alpha6 subunit gene inactivation inhibits delta subunit expression. *J Neurosci* **17**: 1350-62 [PMID:9006978]
148. Jones BL and Henderson LP. (2007) Trafficking and potential assembly patterns of epsilon-containing

GABAA receptors. *J Neurochem* **103**: 1258-71 [PMID:17714454]
149. Jones MV, Harrison NL, Pritchett DB and Hales TG. (1995) Modulation of the GABAA receptor by propofol is independent of the gamma subunit. *J Pharmacol Exp Ther* **274**: 962-8 [PMID:7636760]
150. Jongjaroenprasert W, Chanprasertyotin S, Butadej S, Nakasatien S, Charatcharoenwitthaya N, Himathongkam T and Ongphiphadhanakul B. (2008) Association of genetic variants in GABRA3 gene and thyrotoxic hypokalaemic periodic paralysis in Thai population. *Clin Endocrinol (Oxf)* **68**: 646-51 [PMID:17970773]
151. Kamatchi GL, Kofuji P, Wang JB, Fernando JC, Liu Z, Mathura JR and Burt DR. (1995) GABAA receptor beta 1, beta 2, and beta 3 subunits: comparisons in DBA/2J and C57BL/6J mice. *Biochim Biophys Acta* **1261**: 134-42 [PMID:7893750]
152. Kananura C, Haug K, Sander T, Runge U, Gu W, Hallmann K, Rebstock J, Heils A and Steinlein OK. (2002) A splice-site mutation in GABRG2 associated with childhood absence epilepsy and febrile convulsions. *Arch Neurol* **59**: 1137-41 [PMID:12117362]
153. Karim N, Wellendorph P, Absalom N, Johnston GA, Hanrahan JR and Chebib M. (2013) Potency of GABA at human recombinant GABA(A) receptors expressed in Xenopus oocytes: a mini review. *Amino Acids* **44**: 1139-49 [PMID:23385381]
154. Kato K. (1990) Novel GABAA receptor alpha subunit is expressed only in cerebellar granule cells. *J Mol Biol* **214**: 619-24 [PMID:2167378]
155. Kawaharada S, Nakanishi M, Nakanishi N, Hazama K, Higashino M, Yasuhiro T, Lewis A, Clark GS, Chambers MS and Maidment SA *et al.*. (2018) ONO-8590580, a Novel $GABA_A\alpha5$ Negative Allosteric Modulator Enhances Long-Term Potentiation and Improves Cognitive Deficits in Preclinical Models. *J Pharmacol Exp Ther* **366**: 58-65 [PMID:29674331]
156. Keir WJ, Kozak CA, Chakraborti A, Deitrich RA and Sikela JM. (1991) The cDNA sequence and chromosomal location of the murine GABAA alpha 1 receptor gene. *Genomics* **9**: 390-5 [PMID:1848528]
157. Khom S, Baburin I, Timin EN, Hohaus A, Sieghart W and Hering S. (2006) Pharmacological properties of GABAA receptors containing gamma1 subunits. *Mol Pharmacol* **69**: 640-9 [PMID:16272224]
158. Khom S, Strommer B, Ramharter J, Schwarz T, Schwarzer C, Erker T, Ecker GF, Mulzer J and Hering S. (2010) Valerenic acid derivatives as novel subunit-selective GABAA receptor ligands - in vitro and in vivo characterization. *Br J Pharmacol* **161**: 65-78 [PMID:20718740]
159. Khrestchatisky M, MacLennan AJ, Chiang MY, Xu WT, Jackson MB, Brecha N, Sternini C, Olsen RW and Tobin AJ. (1989) A novel alpha subunit in rat brain GABAA receptors. *Neuron* **3**: 745-53 [PMID:2561977]
160. Khrestchatisky M, MacLennan AJ, Tillakaratne NJ, Chiang MY and Tobin AJ. (1991) Sequence and regional distribution of the mRNA encoding the alpha 2 polypeptide of rat gamma-aminobutyric acidA receptors. *J Neurochem* **56**: 1717-22 [PMID:1849552]
161. Kirkness EF and Fraser CM. (1993) A strong promoter element is located between alternative exons of a gene encoding the human gamma-aminobutyric acid-type A receptor beta 3 subunit (GABRB3). *J Biol Chem* **268**: 4420-8 [PMID:8382702]
162. Kirkness EF, Kusiak JW, Fleming JT, Menninger J, Gocayne JD, Ward DC and Venter JC. (1991) Isolation, characterization, and localization of human genomic DNA encoding the beta 1 subunit of the GABAA receptor (GABRB1). *Genomics* **10**: 985-95 [PMID:1655634]
163. Knabl J, Witschi R, Hösl K, Reinold H, Zeilhofer UB, Ahmadi S, Brockhaus J, Sergejeva M, Hess A and Brune K *et al.*. (2008) Reversal of pathological pain through specific spinal GABAA receptor subtypes. *Nature* **451**: 330-4 [PMID:18202657]
164. Knabl J, Zeilhofer UB, Crestani F, Rudolph U and Zeilhofer HU. (2009) Genuine antihyperalgesia by systemic diazepam revealed by experiments in GABAA receptor point-mutated mice. *Pain* **141**: 233-8 [PMID:19091469]
165. Knoflach F, Benke D, Wang Y, Scheurer L, Lüddens H, Hamilton BJ, Carter DB, Mohler H and Benson JA. (1996) Pharmacological modulation of the diazepam-insensitive recombinant gamma-aminobutyric acidA receptors alpha 4 beta 2 gamma 2 and alpha 6 beta 2 gamma 2. *Mol Pharmacol* **50**: 1253-61 [PMID:8913357]
166. Knoflach F, Rhyner T, Villa M, Kellenberger S, Drescher U, Malherbe P, Sigel E and Möhler H. (1991) The gamma 3-subunit of the GABAA-receptor confers sensitivity to benzodiazepine receptor ligands. *FEBS Lett* **293**: 191-4 [PMID:1660002]
167. Kofuji P, Wang JB, Moss SJ, Huganir RL and Burt DR. (1991) Generation of two forms of the gamma-aminobutyric acidA receptor gamma 2-subunit in mice by alternative splicing. *J Neurochem* **56**: 713-5

[PMID:1846404]
168. Kopp C, Rudolph U, Keist R and Tobler I. (2003) Diazepam-induced changes on sleep and the EEG spectrum in mice: role of the alpha3-GABA(A) receptor subtype. *Eur J Neurosci* **17**: 2226-30 [PMID:12786990]
169. Korpi ER, Debus F, Linden AM, Malécot C, Leppä E, Vekovischeva O, Rabe H, Böhme I, Aller MI and Wisden W *et al.*. (2007) Does ethanol act preferentially via selected brain GABAA receptor subtypes? the current evidence is ambiguous. *Alcohol* **41**: 163-76 [PMID:17591542]
170. Korpi ER, Gründer G and Lüddens H. (2002) Drug interactions at GABA(A) receptors. *Prog Neurobiol* **67**: 113-59 [PMID:12126658]
171. Korpi ER, Kleingoor C, Kettenmann H and Seeburg PH. (1993) Benzodiazepine-induced motor impairment linked to point mutation in cerebellar GABAA receptor. *Nature* **361**: 356-9 [PMID:7678923]
172. Korpi ER, Koikkalainen P, Vekovischeva OY, Mäkelä R, Kleinz R, Uusi-Oukari M and Wisden W. (1999) Cerebellar granule-cell-specific GABAA receptors attenuate benzodiazepine-induced ataxia: evidence from alpha 6-subunit-deficient mice. *Eur J Neurosci* **11**: 233-40 [PMID:9987027]
173. Krasowski MD, Koltchine VV, Rick CE, Ye Q, Finn SE and Harrison NL. (1998) Propofol and other intravenous anesthetics have sites of action on the gamma-aminobutyric acid type A receptor distinct from that for isoflurane. *Mol Pharmacol* **53**: 530-8 [PMID:9495821]
174. Krishek BJ, Moss SJ and Smart TG. (1998) Interaction of H+ and Zn2+ on recombinant and native rat neuronal GABAA receptors. *J Physiol (Lond.)* **507 (Pt 3)**: 639-52 [PMID:9508826]
175. Krogsgaard-Larsen P, Frølund B and Liljefors T. (2002) Specific GABA(A) agonists and partial agonists. *Chem Rec* **2**: 419-30 [PMID:12469353]
176. Kultas-Ilinsky K, Leontiev V and Whiting PJ. (1998) Expression of 10 GABA(A) receptor subunit messenger RNAs in the motor-related thalamic nuclei and basal ganglia of Macaca mulatta studied with in situ hybridization histochemistry. *Neuroscience* **85**: 179-204 [PMID:9607711]
177. Lasham A, Vreugdenhil E, Bateson AN, Barnard EA and Darlison MG. (1991) Conserved organization of gamma-aminobutyric acidA receptor genes: cloning and analysis of the chicken beta 4-subunit gene. *J Neurochem* **57**: 352-5 [PMID:1646862]
178. Laurie DJ, Seeburg PH and Wisden W. (1992) The distribution of 13 GABAA receptor subunit mRNAs in the rat brain. II. Olfactory bulb and cerebellum. *J Neurosci* **12**: 1063-76 [PMID:1312132]
179. Laurie DJ, Wisden W and Seeburg PH. (1992) The distribution of thirteen GABAA receptor subunit mRNAs in the rat brain. III. Embryonic and postnatal development. *J Neurosci* **12**: 4151-72 [PMID:1331359]
180. Li GD, Chiara DC, Cohen JB and Olsen RW. (2009) Neurosteroids allosterically modulate binding of the anesthetic etomidate to gamma-aminobutyric acid type A receptors. *J Biol Chem* **284**: 11771-5 [PMID:19282280]
181. Li GD, Chiara DC, Sawyer GW, Husain SS, Olsen RW and Cohen JB. (2006) Identification of a GABAA receptor anesthetic binding site at subunit interfaces by photolabeling with an etomidate analog. *J Neurosci* **26**: 11599-605 [PMID:17093081]
182. Li RW, Yu W, Christie S, Miralles CP, Bai J, Loturco JJ and De Blas AL. (2005) Disruption of postsynaptic GABA receptor clusters leads to decreased GABAergic innervation of pyramidal neurons. *J Neurochem* **95**: 756-70 [PMID:16248887]
183. Liang J, Suryanarayanan A, Chandra D, Homanics GE, Olsen RW and Spigelman I. (2008) Functional consequences of GABAA receptor alpha 4 subunit deletion on synaptic and extrasynaptic currents in mouse dentate granule cells. *Alcohol Clin Exp Res* **32**: 19-26 [PMID:18070250]
184. Liang J, Zhang N, Cagetti E, Houser CR, Olsen RW and Spigelman I. (2006) Chronic intermittent ethanol-induced switch of ethanol actions from extrasynaptic to synaptic hippocampal GABAA receptors. *J Neurosci* **26**: 1749-58 [PMID:16467523]
185. Liu XB, Coble J, van Luijtelaar G and Jones EG. (2007) Reticular nucleus-specific changes in alpha3 subunit protein at GABA synapses in genetically epilepsy-prone rats. *Proc Natl Acad Sci USA* **104**: 12512-7 [PMID:17630284]
186. Liu Y, Guo F, Dai M, Wang D, Tong Y, Huang J, Hu J and Li G. (2009) Gammaaminobutyric acid A receptor alpha 3 subunit is overexpressed in lung cancer. *Pathol Oncol Res* **15**: 351-8 [PMID:19048400]
187. Liu Y, Li YH, Guo FJ, Wang JJ, Sun RL, Hu JY and Li GC. (2008) Gamma-aminobutyric acid promotes human hepatocellular carcinoma growth through overexpressed gamma-aminobutyric acid A receptor alpha 3 subunit. *World J Gastroenterol* **14**: 7175-82 [PMID:19084931]

188. Lolait SJ, O'Carroll AM, Kusano K, Muller JM, Brownstein MJ and Mahan LC. (1989) Cloning and expression of a novel rat GABAA receptor. *FEBS Lett* **246**: 145-8 [PMID:2540033]
189. Longson D, Longson CM and Jones EG. (1997) Localization of CAM II kinase-alpha, GAD, GluR2 and GABA(A) receptor subunit mRNAs in the human entorhinal cortex. *Eur J Neurosci* **9**: 662-75 [PMID:9153573]
190. Luscher B, Fuchs T and Kilpatrick CL. (2011) GABAA receptor trafficking-mediated plasticity of inhibitory synapses. *Neuron* **70**: 385-409 [PMID:21555068]
191. Löw K, Crestani F, Keist R, Benke D, Brünig I, Benson JA, Fritschy JM, Rülicke T, Bluethmann H and Möhler H *et al.*. (2000) Molecular and neuronal substrate for the selective attenuation of anxiety. *Science* **290**: 131-4 [PMID:11021797]
192. Lüddens H, Pritchett DB, Köhler M, Killisch I, Keinänen K, Monyer H, Sprengel R and Seeburg PH. (1990) Cerebellar GABAA receptor selective for a behavioural alcohol antagonist. *Nature* **346**: 648-51 [PMID:2166916]
193. Ma DQ, Whitehead PL, Menold MM, Martin ER, Ashley-Koch AE, Mei H, Ritchie MD, Delong GR, Abramson RK and Wright HH *et al.*. (2005) Identification of significant association and gene-gene interaction of GABA receptor subunit genes in autism. *Am J Hum Genet* **77**: 377-88 [PMID:16080114]
194. Macdonald RL and Olsen RW. (1994) GABAA receptor channels. *Annu Rev Neurosci* **17**: 569-602 [PMID:7516126]
195. Maison SF, Rosahl TW, Homanics GE and Liberman MC. (2006) Functional role of GABAergic innervation of the cochlea: phenotypic analysis of mice lacking GABA(A) receptor subunits alpha 1, alpha 2, alpha 5, alpha 6, beta 2, beta 3, or delta. *J Neurosci* **26**: 10315-26 [PMID:17021187]
196. Malherbe P, Sigel E, Baur R, Persohn E, Richards JG and Mohler H. (1990) Functional characteristics and sites of gene expression of the alpha 1, beta 1, gamma 2-isoform of the rat GABAA receptor. *J Neurosci* **10**: 2330-7 [PMID:2165521]
197. Marini C, Harkin LA, Wallace RH, Mulley JC, Scheffer IE and Berkovic SF. (2003) Childhood absence epilepsy and febrile seizures: a family with a GABA(A) receptor mutation. *Brain* **126**: 230-40 [PMID:12477709]
198. Martin LJ, Zurek AA, Bonin RP, Oh GH, Kim JH, Mount HT and Orser BA. (2011) The sedative but not the memory-blocking properties of ethanol are modulated by α5-subunit-containing γ-aminobutyric acid type A receptors. *Behav Brain Res* **217**: 379-85 [PMID:21070817]
199. Martin LJ, Zurek AA, MacDonald JF, Roder JC, Jackson MF and Orser BA. (2010) Alpha5GABAA receptor activity sets the threshold for long-term potentiation and constrains hippocampus-dependent memory. *J Neurosci* **30**: 5269-82 [PMID:20392949]
200. Masiulis S, Desai R, Uchański T, Serna Martin I, Laverty D, Karia D, Malinauskas T, Zivanov J, Pardon E and Kotecha A *et al.*. (2019) $GABA_A$ receptor signalling mechanisms revealed by structural pharmacology. *Nature* **565**: 454-459 [PMID:30602790]
201. Massat I, Souery D, Del-Favero J, Oruc L, Noethen MM, Blackwood D, Thomson M, Muir W, Papadimitriou GN and Dikeos DG *et al.*. (2002) Excess of allele1 for alpha3 subunit GABA receptor gene (GABRA3) in bipolar patients: a multicentric association study. *Mol Psychiatry* **7**: 201-7 [PMID:11840313]
202. McKinley DD, Lennon DJ and Carter DB. (1995) Cloning, sequence analysis and expression of two forms of mRNA coding for the human beta 2 subunit of the GABAA receptor. *Brain Res Mol Brain Res* **28**: 175-9 [PMID:7707873]
203. McLean PJ, Farb DH and Russek SJ. (1995) Mapping of the alpha 4 subunit gene (GABRA4) to human chromosome 4 defines an alpha 2-alpha 4-beta 1-gamma 1 gene cluster: further evidence that modern GABAA receptor gene clusters are derived from an ancestral cluster. *Genomics* **26**: 580-6 [PMID:7607683]
204. Mihalek RM, Banerjee PK, Korpi ER, Quinlan JJ, Firestone LL, Mi ZP, Lagenaur C, Tretter V, Sieghart W, Anagnostaras SG, Sage JR, Fanselow MS, Guidotti A, Spigelman I, Li Z, DeLorey TM, Olsen RW and Homanics GE. (1999) Attenuated sensitivity to neuroactive steroids in gamma-aminobutyrate type A receptor delta subunit knockout mice. *Proc Natl Acad Sci USA* **96**: 12905-10 [PMID:10536021]
205. Mihalek RM, Bowers BJ, Wehner JM, Kralic JE, VanDoren MJ, Morrow AL and Homanics GE. (2001) GABA(A)-receptor delta subunit knockout mice have multiple defects in behavioral responses to ethanol. *Alcohol Clin Exp Res* **25**: 1708-18 [PMID:11781502]
206. Mihic SJ and Harris RA. (1996) Inhibition of rho1 receptor GABAergic currents by alcohols and volatile anesthetics. *J Pharmacol Exp Ther* **277**: 411-6 [PMID:8613949]

207. Mihic SJ, Ye Q, Wick MJ, Koltchine VV, Krasowski MD, Finn SE, Mascia MP, Valenzuela CF, Hanson KK and Greenblatt EP *et al.*. (1997) Sites of alcohol and volatile anaesthetic action on GABA(A) and glycine receptors. *Nature* **389**: 385-9 [PMID:9311780]
208. Miller AD and Blaha CD. (2005) Midbrain muscarinic receptor mechanisms underlying regulation of mesoaccumbens and nigrostriatal dopaminergic transmission in the rat. *Eur J Neurosci* **21**: 1837-46 [PMID:15869479]
209. Miller DT, Shen Y, Weiss LA, Korn J, Anselm I, Bridgemohan C, Cox GF, Dickinson H, Gentile J and Harris DJ *et al.*. (2009) Microdeletion/duplication at 15q13.2q13.3 among individuals with features of autism and other neuropsychiatric disorders. *J Med Genet* **46**: 242-8 [PMID:18805830]
210. Miller PS and Aricescu AR. (2014) Crystal structure of a human GABAA receptor. *Nature* **512**: 270-5 [PMID:24909990]
211. Mody I and Pearce RA. (2004) Diversity of inhibitory neurotransmission through GABA(A) receptors. *Trends Neurosci* **27**: 569-75 [PMID:15331240]
212. Moody EJ, Knauer C, Granja R, Strakhova M and Skolnick P. (1997) Distinct loci mediate the direct and indirect actions of the anesthetic etomidate at GABA(A) receptors. *J Neurochem* **69**: 1310-3 [PMID:9282957]
213. Moore MD, Cushman J, Chandra D, Homanics GE, Olsen RW and Fanselow MS. (2010) Trace and contextual fear conditioning is enhanced in mice lacking the alpha4 subunit of the GABA(A) receptor. *Neurobiol Learn Mem* **93**: 383-7 [PMID:20018248]
214. Moragues N, Ciofi P, Lafon P, Odessa MF, Tramu G and Garret M. (2000) cDNA cloning and expression of a gamma-aminobutyric acid A receptor epsilon-subunit in rat brain. *Eur J Neurosci* **12**: 4318-30 [PMID:11122342]
215. Moragues N, Ciofi P, Lafon P, Tramu G and Garret M. (2003) GABAA receptor epsilon subunit expression in identified peptidergic neurons of the rat hypothalamus. *Brain Res* **967**: 285-9 [PMID:12650990]
216. Moragues N, Ciofi P, Tramu G and Garret M. (2002) Localisation of GABA(A) receptor epsilon-subunit in cholinergic and aminergic neurones and evidence for co-distribution with the theta-subunit in rat brain. *Neuroscience* **111**: 657-69 [PMID:12031352]
217. Mäkelä R, Uusi-Oukari M, Homanics GE, Quinlan JJ, Firestone LL, Wisden W and Korpi ER. (1997) Cerebellar gamma-aminobutyric acid type A receptors: pharmacological subtypes revealed by mutant mouse lines. *Mol Pharmacol* **52**: 380-8 [PMID:9281599]
218. Möhler H. (2007) Molecular regulation of cognitive functions and developmental plasticity: impact of GABAA receptors. *J Neurochem* **102**: 1-12 [PMID:17394533]
219. Nabbout R, Prud'homme JF, Herman A, Feingold J, Brice A, Dulac O and LeGuern E. (2002) A locus for simple pure febrile seizures maps to chromosome 6q22-q24. *Brain* **125**: 2668-80 [PMID:12429594]
220. Nakatsu Y, Tyndale RF, DeLorey TM, Durham-Pierre D, Gardner JM, McDanel HJ, Nguyen Q, Wagstaff J, Lalande M and Sikela JM. (1993) A cluster of three GABAA receptor subunit genes is deleted in a neurological mutant of the mouse p locus. *Nature* **364**: 448-50 [PMID:8392662]
221. Nayeem N, Green TP, Martin IL and Barnard EA. (1994) Quaternary structure of the native GABAA receptor determined by electron microscopic image analysis. *J Neurochem* **62**: 815-8 [PMID:7507518]
222. Neelands TR, Fisher JL, Bianchi M and Macdonald RL. (1999) Spontaneous and gamma-aminobutyric acid (GABA)-activated GABA(A) receptor channels formed by epsilon subunit-containing isoforms. *Mol Pharmacol* **55**: 168-78 [PMID:9882711]
223. Neelands TR and Macdonald RL. (1999) Incorporation of the pi subunit into functional gamma-aminobutyric Acid(A) receptors. *Mol Pharmacol* **56**: 598-610 [PMID:10462548]
224. Neelands TR, Zhang J and Macdonald RL. (1999) GABA(A) receptors expressed in undifferentiated human teratocarcinoma NT2 cells differ from those expressed by differentiated NT2-N cells. *J Neurosci* **19**: 7057-65 [PMID:10436060]
225. Ng CK, Kim HL, Gavande N, Yamamoto I, Kumar RJ, Mewett KN, Johnston GA, Hanrahan JR and Chebib M. (2011) Medicinal chemistry of ρ GABAC receptors. *Future Med Chem* **3**: 197-209 [PMID:21428815]
226. Nimmich ML, Heidelberg LS and Fisher JL. (2009) RNA editing of the GABA(A) receptor alpha3 subunit alters the functional properties of recombinant receptors. *Neurosci Res* **63**: 288-93 [PMID:19367790]
227. No authors listed. (1989) Proposal for revised classification of epilepsies and epileptic syndromes. Commission on Classification and Terminology of the International League Against Epilepsy. *Epilepsia* **30**: 389-99 [PMID:2502382]
228. Nusser Z, Ahmad Z, Tretter V, Fuchs K, Wisden W, Sieghart W and Somogyi P. (1999) Alterations in the

expression of GABAA receptor subunits in cerebellar granule cells after the disruption of the alpha6 subunit gene. *Eur J Neurosci* **11**: 1685-97 [PMID:10215922]
229. Nusser Z, Sieghart W and Somogyi P. (1998) Segregation of different GABAA receptors to synaptic and extrasynaptic membranes of cerebellar granule cells. *J Neurosci* **18**: 1693-703 [PMID:9464994]
230. Nusser Z, Sieghart W, Stephenson FA and Somogyi P. (1996) The alpha 6 subunit of the GABAA receptor is concentrated in both inhibitory and excitatory synapses on cerebellar granule cells. *J Neurosci* **16**: 103-14 [PMID:8613776]
231. Ogurusu T and Shingai R. (1996) Cloning of a putative gamma-aminobutyric acid (GABA) receptor subunit rho 3 cDNA. *Biochim Biophys Acta* **1305**: 15-8 [PMID:8605242]
232. Ogurusu T, Taira H and Shingai R. (1995) Identification of GABAA receptor subunits in rat retina: cloning of the rat GABAA receptor rho 2-subunit cDNA. *J Neurochem* **65**: 964-8 [PMID:7643126]
233. Ogurusu T, Yanagi K, Watanabe M, Fukaya M and Shingai R. (1999) Localization of GABA receptor rho 2 and rho 3 subunits in rat brain and functional expression of homooligomeric rho 3 receptors and heterooligomeric rho 2 rho 3 receptors. *Recept Channels* **6**: 463-75 [PMID:10635063]
234. Ohlson J, Pedersen JS, Haussler D and Ohman M. (2007) Editing modifies the GABA(A) receptor subunit alpha3. *RNA* **13**: 698-703 [PMID:17369310]
235. Ohmori I, Ouchida M, Ohtsuka Y, Oka E and Shimizu K. (2002) Significant correlation of the SCN1A mutations and severe myoclonic epilepsy in infancy. *Biochem Biophys Res Commun* **295**: 17-23 [PMID:12083760]
236. Olsen RW and Li GD. (2011) GABA(A) receptors as molecular targets of general anesthetics: identification of binding sites provides clues to allosteric modulation. *Can J Anaesth* **58**: 206-15 [PMID:21194017]
237. Olsen RW and Sieghart W. (2008) International Union of Pharmacology. LXX. Subtypes of gamma-aminobutyric acid(A) receptors: classification on the basis of subunit composition, pharmacology, and function. Update. *Pharmacol Rev* **60**: 243-60 [PMID:18790874]
238. Olsen RW and Sieghart W. (2009) GABA A receptors: subtypes provide diversity of function and pharmacology. *Neuropharmacology* **56**: 141-8 [PMID:18760291]
239. Omoto K, Owen RM, Pryde DC, Watson CAL and Takeuchi M. (2014) Imidazopyridazine derivatives as GABAA receptor modulators. Patent number: WO2014091368. Assignee: Pfizer Limited. Priority date: 14/12/2012. Publication date: 19/06/2014.
240. Otani K, Ujike H, Tanaka Y, Morita Y, Katsu T, Nomura A, Uchida N, Hamamura T, Fujiwara Y and Kuroda S. (2005) The GABA type A receptor alpha5 subunit gene is associated with bipolar I disorder. *Neurosci Lett* **381**: 108-13 [PMID:15882799]
241. Papadimitriou GN, Dikeos DG, Karadima G, Avramopoulos D, Daskalopoulou EG, Vassilopoulos D and Stefanis CN. (1998) Association between the GABA(A) receptor alpha5 subunit gene locus (GABRA5) and bipolar affective disorder. *Am J Med Genet* **81**: 73-80 [PMID:9514592]
242. Peng Z, Hauer B, Mihalek RM, Homanics GE, Sieghart W, Olsen RW and Houser CR. (2002) GABA(A) receptor changes in delta subunit-deficient mice: altered expression of alpha4 and gamma2 subunits in the forebrain. *J Comp Neurol* **446**: 179-97 [PMID:11932935]
243. Persohn E, Malherbe P and Richards JG. (1992) Comparative molecular neuroanatomy of cloned GABAA receptor subunits in the rat CNS. *J Comp Neurol* **326**: 193-216 [PMID:1336019]
244. Persohn E, Malherbe P and Richards JG. (1991) In situ hybridization histochemistry reveals a diversity of GABAA receptor subunit mRNAs in neurons of the rat spinal cord and dorsal root ganglia. *Neuroscience* **42**: 497-507 [PMID:1654537]
245. Pirker S, Schwarzer C, Wieselthaler A, Sieghart W and Sperk G. (2000) GABA(A) receptors: immunocytochemical distribution of 13 subunits in the adult rat brain. *Neuroscience* **101**: 815-50 [PMID:11113332]
246. Pollard S, Duggan MJ and Stephenson FA. (1993) Further evidence for the existence of alpha subunit heterogeneity within discrete gamma-aminobutyric acidA receptor subpopulations. *J Biol Chem* **268**: 3753-7 [PMID:8381438]
247. Porcello DM, Huntsman MM, Mihalek RM, Homanics GE and Huguenard JR. (2003) Intact synaptic GABAergic inhibition and altered neurosteroid modulation of thalamic relay neurons in mice lacking delta subunit. *J Neurophysiol* **89**: 1378-86 [PMID:12626617]
248. Poulsen CF, Christjansen KN, Hastrup S and Hartvig L. (2000) Identification and cloning of a gamma 3 subunit splice variant of the human GABA(A) receptor. *Brain Res Mol Brain Res* **78**: 201-3

[PMID:10891602]
249. Pritchett DB, Lüddens H and Seeburg PH. (1989) Type I and type II GABAA-benzodiazepine receptors produced in transfected cells. *Science* **245**: 1389-92 [PMID:2551039]
250. Pritchett DB and Seeburg PH. (1990) Gamma-aminobutyric acidA receptor alpha 5-subunit creates novel type II benzodiazepine receptor pharmacology. *J Neurochem* **54**: 1802-4 [PMID:2157817]
251. Pritchett DB, Sontheimer H, Shivers BD, Ymer S, Kettenmann H, Schofield PR and Seeburg PH. (1989) Importance of a novel GABAA receptor subunit for benzodiazepine pharmacology. *Nature* **338**: 582-5 [PMID:2538761]
252. Prut L, Prenosil G, Willadt S, Vogt K, Fritschy JM and Crestani F. (2010) A reduction in hippocampal GABAA receptor alpha5 subunits disrupts the memory for location of objects in mice. *Genes Brain Behav* **9**: 478-88 [PMID:20180861]
253. Puertollano R, Visedo G, Saiz-Ruiz J, Llinares C and Fernández-Piqueras J. (1995) Lack of association between manic-depressive illness and a highly polymorphic marker from GABRA3 gene. *Am J Med Genet* **60**: 434-5 [PMID:8546157]
254. Puia G, Ducić I, Vicini S and Costa E. (1993) Does neurosteroid modulatory efficacy depend on GABAA receptor subunit composition? *Recept Channels* **1**: 135-42 [PMID:8081717]
255. Puia G, Vicini S, Seeburg PH and Costa E. (1991) Influence of recombinant gamma-aminobutyric acid-A receptor subunit composition on the action of allosteric modulators of gamma-aminobutyric acid-gated Cl- currents. *Mol Pharmacol* **39**: 691-6 [PMID:1646944]
256. Ramerstorfer J, Furtmüller R, Vogel E, Huck S and Sieghart W. (2010) The point mutation gamma 2F77I changes the potency and efficacy of benzodiazepine site ligands in different GABAA receptor subtypes. *Eur J Pharmacol* **636**: 18-27 [PMID:20303942]
257. Ramerstorfer J, Furtmüller R, Sarto-Jackson I, Varagic Z, Sieghart W and Ernst M. (2011) The GABAA receptor alpha+beta- interface: a novel target for subtype selective drugs. *J Neurosci* **31**: 870-7 [PMID:21248110]
258. Rewal M, Jurd R, Gill TM, He DY, Ron D and Janak PH. (2009) Alpha4-containing GABAA receptors in the nucleus accumbens mediate moderate intake of alcohol. *J Neurosci* **29**: 543-9 [PMID:19144854]
259. Reynolds DS, Rosahl TW, Cirone J, O'Meara GF, Haythornthwaite A, Newman RJ, Myers J, Sur C, Howell O and Rutter AR *et al.*. (2003) Sedation and anesthesia mediated by distinct GABA(A) receptor isoforms. *J Neurosci* **23**: 8608-17 [PMID:13679430]
260. Rose M, Dütting E, Schröder N, Sticht H, Brandstätter JH and Enz R. (2008) PNUTS forms a trimeric protein complex with GABA(C) receptors and protein phosphatase 1. *Mol Cell Neurosci* **37**: 808-19 [PMID:18325784]
261. Rula EY, Lagrange AH, Jacobs MM, Hu N, Macdonald RL and Emeson RB. (2008) Developmental modulation of GABA(A) receptor function by RNA editing. *J Neurosci* **28**: 6196-201 [PMID:18550761]
262. Russek SJ and Farb DH. (1994) Mapping of the beta 2 subunit gene (GABRB2) to microdissected human chromosome 5q34-q35 defines a gene cluster for the most abundant GABAA receptor isoform. *Genomics* **23**: 528-33 [PMID:7851879]
263. Saba L, Porcella A, Sanna A, Congeddu E, Marziliano N, Mongeau R, Grayson D and Pani L. (2005) Five mutations in the GABA A alpha6 gene 5' flanking region are associated with a reduced basal and ethanol-induced alpha6 upregulation in mutated Sardinian alcohol non-preferring rats. *Brain Res Mol Brain Res* **137**: 252-7 [PMID:15950783]
264. Sanna E, Murgia A, Casula A and Biggio G. (1997) Differential subunit dependence of the actions of the general anesthetics alphaxalone and etomidate at gamma-aminobutyric acid type A receptors expressed in Xenopus laevis oocytes. *Mol Pharmacol* **51**: 484-90 [PMID:9058604]
265. Saxena NC and Macdonald RL. (1994) Assembly of GABAA receptor subunits: role of the delta subunit. *J Neurosci* **14**: 7077-86 [PMID:7525894]
266. Saxena NC and Macdonald RL. (1996) Properties of putative cerebellar gamma-aminobutyric acid A receptor isoforms. *Mol Pharmacol* **49**: 567-79 [PMID:8643098]
267. Saxena NC, Neelands TR and MacDonald RL. (1997) Contrasting actions of lanthanum on different recombinant gamma-aminobutyric acid receptor isoforms expressed in L929 fibroblasts. *Mol Pharmacol* **51**: 328-35 [PMID:9203639]
268. Scheffer IE and Berkovic SF. (1997) Generalized epilepsy with febrile seizures plus. A genetic disorder with heterogeneous clinical phenotypes. *Brain* **120 (Pt 3)**: 479-90 [PMID:9126059]
269. Schofield CM, Kleiman-Weiner M, Rudolph U and Huguenard JR. (2009) A gain in GABAA receptor

synaptic strength in thalamus reduces oscillatory activity and absence seizures. *Proc Natl Acad Sci USA* **106**: 7630-5 [PMID:19380748]
270. Schofield PR, Pritchett DB, Sontheimer H, Kettenmann H and Seeburg PH. (1989) Sequence and expression of human GABAA receptor alpha 1 and beta 1 subunits. *FEBS Lett* **244**: 361-4 [PMID:2465923]
271. Scholze P, Ebert V and Sieghart W. (1996) Affinity of various ligands for GABAA receptors containing alpha 4 beta 3 gamma 2, alpha 4 gamma 2, or alpha 1 beta 3 gamma 2 subunits. *Eur J Pharmacol* **304**: 155-62 [PMID:8813598]
272. Schwarzer C, Berresheim U, Pirker S, Wieselthaler A, Fuchs K, Sieghart W and Sperk G. (2001) Distribution of the major gamma-aminobutyric acid(A) receptor subunits in the basal ganglia and associated limbic brain areas of the adult rat. *J Comp Neurol* **433**: 526-49 [PMID:11304716]
273. Schweizer C, Balsiger S, Bluethmann H, Mansuy IM, Fritschy JM, Mohler H and Lüscher B. (2003) The gamma 2 subunit of GABA(A) receptors is required for maintenance of receptors at mature synapses. *Mol Cell Neurosci* **24**: 442-50 [PMID:14572465]
274. Seeburg PH, Wisden W, Verdoorn TA, Pritchett DB, Werner P, Herb A, Lüddens H, Sprengel R and Sakmann B. (1990) The GABAA receptor family: molecular and functional diversity. *Cold Spring Harb Symp Quant Biol* **55**: 29-40 [PMID:1966765]
275. Semyanov A, Walker MC, Kullmann DM and Silver RA. (2004) Tonically active GABA A receptors: modulating gain and maintaining the tone. *Trends Neurosci* **27**: 262-9 [PMID:15111008]
276. Sergeeva OA, Kletke O, Kragler A, Poppek A, Fleischer W, Schubring SR, Görg B, Haas HL, Zhu XR and Lübbert H *et al.*. (2010) Fragrant dioxane derivatives identify beta1-subunit-containing GABAA receptors. *J Biol Chem* **285**: 23985-93 [PMID:20511229]
277. Sharma R, Nakamura M, Neupane C, Jeon BH, Shin H, Melnick SM, Glenn KJ, Jang IS and Park JB. (2020) Positive allosteric modulation of $GABA_A$ receptors by a novel antiepileptic drug cenobamate. *Eur J Pharmacol* **879**: 173117 [PMID:32325146]
278. Shen Q, Lal R, Luellen BA, Earnheart JC, Andrews AM and Luscher B. (2010) gamma-Aminobutyric acid-type A receptor deficits cause hypothalamic-pituitary-adrenal axis hyperactivity and antidepressant drug sensitivity reminiscent of melancholic forms of depression. *Biol Psychiatry* **68**: 512-20 [PMID:20579975]
279. Shingai R, Sutherland ML and Barnard EA. (1991) Effects of subunit types of the cloned GABAA receptor on the response to a neurosteroid. *Eur J Pharmacol* **206**: 77-80 [PMID:1676682]
280. Shivers BD, Killisch I, Sprengel R, Sontheimer H, Köhler M, Schofield PR and Seeburg PH. (1989) Two novel GABAA receptor subunits exist in distinct neuronal subpopulations. *Neuron* **3**: 327-37 [PMID:2561970]
281. Sieghart W. (2006) Structure, pharmacology, and function of GABAA receptor subtypes. *Adv Pharmacol* **54**: 231-63 [PMID:17175817]
282. Sieghart W. (1995) Structure and pharmacology of gamma-aminobutyric acidA receptor subtypes. *Pharmacol Rev* **47**: 181-234 [PMID:7568326]
283. Sieghart W, Chiou LC, Ernst M, Fabjan J, M Savic; M and Lee MT. (2022) α 6-Containing $GABA_A$ Receptors: Functional Roles and Therapeutic Potentials. *Pharmacol Rev* **74**: 238-270 [PMID:35017178]
284. Sieghart W and Savić MM. (2018) International Union of Basic and Clinical Pharmacology. CVI: $GABA_A$ Receptor Subtype- and Function-selective Ligands: Key Issues in Translation to Humans. *Pharmacol Rev* **70**: 836-878 [PMID:30275042]
285. Siegwart R, Jurd R and Rudolph U. (2002) Molecular determinants for the action of general anesthetics at recombinant alpha(2)beta(3)gamma(2)gamma-aminobutyric acid(A) receptors. *J Neurochem* **80**: 140-8 [PMID:11796752]
286. Sigel E and Buhr A. (1997) The benzodiazepine binding site of GABAA receptors. *Trends Pharmacol Sci* **18**: 425-9 [PMID:9426470]
287. Sigel E and Lüscher BP. (2011) A closer look at the high affinity benzodiazepine binding site on GABAA receptors. *Curr Top Med Chem* **11**: 241-6 [PMID:21189125]
288. Sigel E and Steinmann ME. (2012) Structure, function, and modulation of GABA(A) receptors. *J Biol Chem* **287**: 40224-31 [PMID:23038269]
289. Singh R, Scheffer IE, Crossland K and Berkovic SF. (1999) Generalized epilepsy with febrile seizures plus: a common childhood-onset genetic epilepsy syndrome. *Ann Neurol* **45**: 75-81 [PMID:9894880]
290. Sinkkonen ST, Hanna MC, Kirkness EF and Korpi ER. (2000) GABA(A) receptor epsilon and theta

subunits display unusual structural variation between species and are enriched in the rat locus ceruleus. *J Neurosci* **20**: 3588-95 [PMID:10804200]

291. Skolnick P, Hu RJ, Cook CM, Hurt SD, Trometer JD, Liu R, Huang Q and Cook JM. (1997) [3H]RY 80: A high-affinity, selective ligand for gamma-aminobutyric acidA receptors containing alpha-5 subunits. *J Pharmacol Exp Ther* **283**: 488-93 [PMID:9353361]
292. Smith AJ, Oxley B, Malpas S, Pillai GV and Simpson PB. (2004) Compounds exhibiting selective efficacy for different beta subunits of human recombinant gamma-aminobutyric acid A receptors. *J Pharmacol Exp Ther* **311**: 601-9 [PMID:15210837]
293. Smith SS. (2013) α4βδ GABAA receptors and tonic inhibitory current during adolescence: effects on mood and synaptic plasticity. *Front Neural Circuits* **7**: 135 [PMID:24027497]
294. Sohal VS, Keist R, Rudolph U and Huguenard JR. (2003) Dynamic GABA(A) receptor subtype-specific modulation of the synchrony and duration of thalamic oscillations. *J Neurosci* **23**: 3649-57 [PMID:12736336]
295. Sommer B, Poustka A, Spurr NK and Seeburg PH. (1990) The murine GABAA receptor delta-subunit gene: structure and assignment to human chromosome 1. *DNA Cell Biol* **9**: 561-8 [PMID:2176788]
296. Sperk G, Schwarzer C, Tsunashima K, Fuchs K and Sieghart W. (1997) GABA(A) receptor subunits in the rat hippocampus I: immunocytochemical distribution of 13 subunits. *Neuroscience* **80**: 987-1000 [PMID:9284055]
297. Spigelman I, Li Z, Liang J, Cagetti E, Samzadeh S, Mihalek RM, Homanics GE and Olsen RW. (2003) Reduced inhibition and sensitivity to neurosteroids in hippocampus of mice lacking the GABA(A) receptor delta subunit. *J Neurophysiol* **90**: 903-10 [PMID:12702713]
298. Stell BM, Brickley SG, Tang CY, Farrant M and Mody I. (2003) Neuroactive steroids reduce neuronal excitability by selectively enhancing tonic inhibition mediated by delta subunit-containing GABAA receptors. *Proc Natl Acad Sci USA* **100**: 14439-44 [PMID:14623958]
299. Studer R, von Boehmer L, Haenggi T, Schweizer C, Benke D, Rudolph U and Fritschy JM. (2006) Alteration of GABAergic synapses and gephyrin clusters in the thalamic reticular nucleus of GABAA receptor alpha3 subunit-null mice. *Eur J Neurosci* **24**: 1307-15 [PMID:16987218]
300. Stórustovu SI and Ebert B. (2006) Pharmacological characterization of agonists at delta-containing GABAA receptors: Functional selectivity for extrasynaptic receptors is dependent on the absence of gamma2. *J Pharmacol Exp Ther* **316**: 1351-9 [PMID:16272218]
301. Sun H, Zhang Y, Liang J, Liu X, Ma X, Wu H, Xu K, Qin J, Qi Y and Wu X. (2008) SCN1A, SCN1B, and GABRG2 gene mutation analysis in Chinese families with generalized epilepsy with febrile seizures plus. *J Hum Genet* **53**: 769-74 [PMID:18566737]
302. Sur C, Farrar SJ, Kerby J, Whiting PJ, Atack JR and McKernan RM. (1999) Preferential coassembly of alpha4 and delta subunits of the gamma-aminobutyric acidA receptor in rat thalamus. *Mol Pharmacol* **56**: 110-5 [PMID:10385690]
303. Sur C, Wafford KA, Reynolds DS, Hadingham KL, Bromidge F, Macaulay A, Collinson N, O'Meara G, Howell O and Newman R *et al.*. (2001) Loss of the major GABA(A) receptor subtype in the brain is not lethal in mice. *J Neurosci* **21**: 3409-18 [PMID:11331371]
304. Szabó G, Éliás O, Erdélyi P, Potor A, Túrós GI, Károlyi BI, Varró G, Vaskó ÁG, Bata I and Kapus GL *et al.*. (2022) Multiparameter Optimization of Naphthyridine Derivatives as Selective α5-$GABA_A$ Receptor Negative Allosteric Modulators. *J Med Chem* **65**: 7876-7895 [PMID:35584373]
305. Tan HO, Reid CA, Single FN, Davies PJ, Chiu C, Murphy S, Clarke AL, Dibbens L, Krestel H and Mulley JC *et al.*. (2007) Reduced cortical inhibition in a mouse model of familial childhood absence epilepsy. *Proc Natl Acad Sci USA* **104**: 17536-41 [PMID:17947380]
306. Thomas JA, Johnson J, Peterson Kraai TL, Wilson R, Tartaglia N, LeRoux J, Beischel L, McGavran L and Hagerman RJ. (2003) Genetic and clinical characterization of patients with an interstitial duplication 15q11-q13, emphasizing behavioral phenotype and response to treatment. *Am J Med Genet A* **119A**: 111-20 [PMID:12749048]
307. Thompson SA, Bonnert TP, Cagetti E, Whiting PJ and Wafford KA. (2002) Overexpression of the GABA(A) receptor epsilon subunit results in insensitivity to anaesthetics. *Neuropharmacology* **43**: 662-8 [PMID:12367611]
308. Thompson SA, Smith MZ, Wingrove PB, Whiting PJ and Wafford KA. (1999) Mutation at the putative GABA(A) ion-channel gate reveals changes in allosteric modulation. *Br J Pharmacol* **127**: 1349-58 [PMID:10455284]

309. Thompson SA, Wheat L, Brown NA, Wingrove PB, Pillai GV, Whiting PJ, Adkins C, Woodward CH, Smith AJ and Simpson PB *et al.*. (2004) Salicylidene salicylhydrazide, a selective inhibitor of beta 1-containing GABAA receptors. *Br J Pharmacol* **142**: 97-106 [PMID:15100159]
310. Towers SK, Gloveli T, Traub RD, Driver JE, Engel D, Fradley R, Rosahl TW, Maubach K, Buhl EH and Whittington MA. (2004) Alpha 5 subunit-containing GABAA receptors affect the dynamic range of mouse hippocampal kainate-induced gamma frequency oscillations in vitro. *J Physiol (Lond.)* **559**: 721-8 [PMID:15284346]
311. Tretter V, Ehya N, Fuchs K and Sieghart W. (1997) Stoichiometry and assembly of a recombinant GABAA receptor subtype. *J Neurosci* **17**: 2728-37 [PMID:9092594]
312. Tretter V, Revilla-Sanchez R, Houston C, Terunuma M, Havekes R, Florian C, Jurd R, Vithlani M, Michels G and Couve A *et al.*. (2009) Deficits in spatial memory correlate with modified {gamma}-aminobutyric acid type A receptor tyrosine phosphorylation in the hippocampus. *Proc Natl Acad Sci USA* **106**: 20039-44 [PMID:19903874]
313. Twigger SN, Shimoyama M, Bromberg S, Kwitek AE, Jacob HJ and RGD Team. (2007) The Rat Genome Database, update 2007--easing the path from disease to data and back again. *Nucleic Acids Res* **35**: D658-62 [PMID:17151068]
314. Tögel M, Mossier B, Fuchs K and Sieghart W. (1994) gamma-Aminobutyric acidA receptors displaying association of gamma 3-subunits with beta 2/3 and different alpha-subunits exhibit unique pharmacological properties. *J Biol Chem* **269**: 12993-8 [PMID:8175718]
315. van Bon BW, Mefford HC, Menten B, Koolen DA, Sharp AJ, Nillesen WM, Innis JW, de Ravel TJ, Mercer CL and Fichera M *et al.*. (2009) Further delineation of the 15q13 microdeletion and duplication syndromes: a clinical spectrum varying from non-pathogenic to a severe outcome. *J Med Genet* **46**: 511-23 [PMID:19372089]
316. van Rijnsoever C, Täuber M, Choulli MK, Keist R, Rudolph U, Mohler H, Fritschy JM and Crestani F. (2004) Requirement of alpha5-GABAA receptors for the development of tolerance to the sedative action of diazepam in mice. *J Neurosci* **24**: 6785-90 [PMID:15282283]
317. Varecka L, Wu CH, Rotter A and Frostholm A. (1994) GABAA/benzodiazepine receptor alpha 6 subunit mRNA in granule cells of the cerebellar cortex and cochlear nuclei: expression in developing and mutant mice. *J Comp Neurol* **339**: 341-52 [PMID:8132866]
318. Vargas-Caballero M, Martin LJ, Salter MW, Orser BA and Paulsen O. (2010) alpha5 Subunit-containing GABA(A) receptors mediate a slowly decaying inhibitory synaptic current in CA1 pyramidal neurons following Schaffer collateral activation. *Neuropharmacology* **58**: 668-75 [PMID:19941877]
319. Veleiro AS and Burton G. (2009) Structure-activity relationships of neuroactive steroids acting on the GABAA receptor. *Curr Med Chem* **16**: 455-72 [PMID:19199916]
320. Verdoorn TA, Draguhn A, Ymer S, Seeburg PH and Sakmann B. (1990) Functional properties of recombinant rat GABAA receptors depend upon subunit composition. *Neuron* **4**: 919-28 [PMID:1694446]
321. Vicini S, Losi G and Homanics GE. (2002) GABA(A) receptor delta subunit deletion prevents neurosteroid modulation of inhibitory synaptic currents in cerebellar neurons. *Neuropharmacology* **43**: 646-50 [PMID:12367609]
322. Vithlani M, Terunuma M and Moss SJ. (2011) The dynamic modulation of GABA(A) receptor trafficking and its role in regulating the plasticity of inhibitory synapses. *Physiol Rev* **91**: 1009-22 [PMID:21742794]
323. Wafford KA, Bain CJ, Quirk K, McKernan RM, Wingrove PB, Whiting PJ and Kemp JA. (1994) A novel allosteric modulatory site on the GABAA receptor beta subunit. *Neuron* **12**: 775-82 [PMID:8161449]
324. Wafford KA, Thompson SA, Thomas D, Sikela J, Wilcox AS and Whiting PJ. (1996) Functional characterization of human gamma-aminobutyric acidA receptors containing the alpha 4 subunit. *Mol Pharmacol* **50**: 670-8 [PMID:8794909]
325. Wafford KA, van Niel MB, Ma QP, Horridge E, Herd MB, Peden DR, Belelli D and Lambert JJ. (2009) Novel compounds selectively enhance delta subunit containing GABA A receptors and increase tonic currents in thalamus. *Neuropharmacology* **56**: 182-9 [PMID:18762200]
326. Wafford KA, Whiting PJ and Kemp JA. (1993) Differences in affinity and efficacy of benzodiazepine receptor ligands at recombinant gamma-aminobutyric acidA receptor subtypes. *Mol Pharmacol* **43**: 240-4 [PMID:8381510]
327. Wagner DA, Goldschen-Ohm MP, Hales TG and Jones MV. (2005) Kinetics and spontaneous open probability conferred by the epsilon subunit of the GABAA receptor. *J Neurosci* **25**: 10462-8 [PMID:16280584]

328. Wagstaff J, Chaillet JR and Lalande M. (1991) The GABAA receptor beta 3 subunit gene: characterization of a human cDNA from chromosome 15q11q13 and mapping to a region of conserved synteny on mouse chromosome 7. *Genomics* **11**: 1071-8 [PMID:1664410]
329. Wagstaff J, Knoll JH, Fleming J, Kirkness EF, Martin-Gallardo A, Greenberg F, Graham JM, Menninger J, Ward D and Venter JC. (1991) Localization of the gene encoding the GABAA receptor beta 3 subunit to the Angelman/Prader-Willi region of human chromosome 15. *Am J Hum Genet* **49**: 330-7 [PMID:1714232]
330. Wallace RH, Marini C, Petrou S, Harkin LA, Bowser DN, Panchal RG, Williams DA, Sutherland GR, Mulley JC and Scheffer IE *et al.*. (2001) Mutant GABA(A) receptor gamma2-subunit in childhood absence epilepsy and febrile seizures. *Nat Genet* **28**: 49-52 [PMID:11326275]
331. Wallner M, Hanchar HJ and Olsen RW. (2006) Low dose acute alcohol effects on GABA A receptor subtypes. *Pharmacol Ther* **112**: 513-28 [PMID:16814864]
332. Wallner M, Hanchar HJ and Olsen RW. (2003) Ethanol enhances alpha 4 beta 3 delta and alpha 6 beta 3 delta gamma-aminobutyric acid type A receptors at low concentrations known to affect humans. *Proc Natl Acad Sci USA* **100**: 15218-23 [PMID:14625373]
333. Wang JB and Burt DR. (1991) Differential expression of two forms of GABAA receptor gamma 2-subunit in mice. *Brain Res Bull* **27**: 731-5 [PMID:1661635]
334. Wang JB, Liu ZF, Kofuji P and Burt DR. (1998) The GABA(A) receptor gamma1-subunit in seizure prone (DBA/2) and resistant (C57BL/6) mice. *Brain Res Bull* **45**: 421-5 [PMID:9527017]
335. Wegelius K, Pasternack M, Hiltunen JO, Rivera C, Kaila K, Saarma M and Reeben M. (1998) Distribution of GABA receptor rho subunit transcripts in the rat brain. *Eur J Neurosci* **10**: 350-7 [PMID:9753143]
336. Wei W, Faria LC and Mody I. (2004) Low ethanol concentrations selectively augment the tonic inhibition mediated by delta subunit-containing GABAA receptors in hippocampal neurons. *J Neurosci* **24**: 8379-82 [PMID:15385620]
337. Wei W, Zhang N, Peng Z, Houser CR and Mody I. (2003) Perisynaptic localization of delta subunit-containing GABA(A) receptors and their activation by GABA spillover in the mouse dentate gyrus. *J Neurosci* **23**: 10650-61 [PMID:14627650]
338. Whiting P, McKernan RM and Iversen LL. (1990) Another mechanism for creating diversity in gamma-aminobutyrate type A receptors: RNA splicing directs expression of two forms of gamma 2 phosphorylation site. *Proc Natl Acad Sci USA* **87**: 9966-70 [PMID:1702226]
339. Whiting PJ, McAllister G, Vassilatis D, Bonnert TP, Heavens RP, Smith DW, Hewson L, O'Donnell R, Rigby MR, Sirinathsinghji DJ, Marshall G, Thompson SA, Wafford KA and Vasilatis D. (1997) Neuronally restricted RNA splicing regulates the expression of a novel GABAA receptor subunit conferring atypical functional properties [corrected; erratum to be published]. *J Neurosci* **17**: 5027-37 [PMID:9185540]
340. Wieland HA and Lüddens H. (1994) Four amino acid exchanges convert a diazepam-insensitive, inverse agonist-preferring GABAA receptor into a diazepam-preferring GABAA receptor. *J Med Chem* **37**: 4576-80 [PMID:7799410]
341. Wieland HA, Lüddens H and Seeburg PH. (1992) A single histidine in GABAA receptors is essential for benzodiazepine agonist binding. *J Biol Chem* **267**: 1426-9 [PMID:1346133]
342. Wilcox AS, Warrington JA, Gardiner K, Berger R, Whiting P, Altherr MR, Wasmuth JJ, Patterson D and Sikela JM. (1992) Human chromosomal localization of genes encoding the gamma 1 and gamma 2 subunits of the gamma-aminobutyric acid receptor indicates that members of this gene family are often clustered in the genome. *Proc Natl Acad Sci USA* **89**: 5857-61 [PMID:1321425]
343. Wilke K, Gaul R, Klauck SM and Poustka A. (1997) A gene in human chromosome band Xq28 (GABRE) defines a putative new subunit class of the GABAA neurotransmitter receptor. *Genomics* **45**: 1-10 [PMID:9339354]
344. Wilson-Shaw D, Robinson M, Gambarana C, Siegel RE and Sikela JM. (1991) A novel gamma subunit of the GABAA receptor identified using the polymerase chain reaction. *FEBS Lett* **284**: 211-5 [PMID:1647983]
345. Wiltgen BJ, Sanders MJ, Ferguson C, Homanics GE and Fanselow MS. (2005) Trace fear conditioning is enhanced in mice lacking the delta subunit of the GABAA receptor. *Learn Mem* **12**: 327-33 [PMID:15897254]
346. Windpassinger C, Kroisel PM, Wagner K and Petek E. (2002) The human gamma-aminobutyric acid A receptor delta (GABRD) gene: molecular characterisation and tissue-specific expression. *Gene* **292**: 25-31 [PMID:12119096]

347. Wingrove P, Hadingham K, Wafford K, Kemp JA, Ragan CI and Whiting P. (1992) Cloning and expression of a cDNA encoding the human GABA-A receptor alpha 5 subunit. *Biochem Soc Trans* **20**: 18S [PMID:1321750]
348. Wingrove PB, Wafford KA, Bain C and Whiting PJ. (1994) The modulatory action of loreclezole at the gamma-aminobutyric acid type A receptor is determined by a single amino acid in the beta 2 and beta 3 subunit. *Proc Natl Acad Sci USA* **91**: 4569-73 [PMID:8183949]
349. Winsky-Sommerer R, Knapman A, Fedele DE, Schofield CM, Vyazovskiy VV, Rudolph U, Huguenard JR, Fritschy JM and Tobler I. (2008) Normal sleep homeostasis and lack of epilepsy phenotype in GABA A receptor alpha3 subunit-knockout mice. *Neuroscience* **154**: 595-605 [PMID:18485607]
350. Wisden W, Gundlach AL, Barnard EA, Seeburg PH and Hunt SP. (1991) Distribution of GABAA receptor subunit mRNAs in rat lumbar spinal cord. *Brain Res Mol Brain Res* **10**: 179-83 [PMID:1649370]
351. Wisden W, Herb A, Wieland H, Keinänen K, Lüddens H and Seeburg PH. (1991) Cloning, pharmacological characteristics and expression pattern of the rat GABAA receptor alpha 4 subunit. *FEBS Lett* **289**: 227-30 [PMID:1655526]
352. Wisden W, Laurie DJ, Monyer H and Seeburg PH. (1992) The distribution of 13 GABAA receptor subunit mRNAs in the rat brain. I. Telencephalon, diencephalon, mesencephalon. *J Neurosci* **12**: 1040-62 [PMID:1312131]
353. Woodward RM, Polenzani L and Miledi R. (1993) Characterization of bicuculline/baclofen-insensitive (rho-like) gamma-aminobutyric acid receptors expressed in Xenopus oocytes. II. Pharmacology of gamma-aminobutyric acidA and gamma-aminobutyric acidB receptor agonists and antagonists. *Mol Pharmacol* **43**: 609-25 [PMID:8386310]
354. Wulff P, Ponomarenko AA, Bartos M, Korotkova TM, Fuchs EC, Bähner F, Both M, Tort AB, Kopell NJ and Wisden W *et al.*. (2009) Hippocampal theta rhythm and its coupling with gamma oscillations require fast inhibition onto parvalbumin-positive interneurons. *Proc Natl Acad Sci USA* **106**: 3561-6 [PMID:19204281]
355. Wulff P, Schonewille M, Renzi M, Viltono L, Sassoè-Pognetto M, Badura A, Gao Z, Hoebeek FE, van Dorp S and Wisden W *et al.*. (2009) Synaptic inhibition of Purkinje cells mediates consolidation of vestibulo-cerebellar motor learning. *Nat Neurosci* **12**: 1042-9 [PMID:19578381]
356. Yang W, Drewe JA and Lan NC. (1995) Cloning and characterization of the human GABAA receptor alpha 4 subunit: identification of a unique diazepam-insensitive binding site. *Eur J Pharmacol* **291**: 319-25 [PMID:8719416]
357. Yee BK, Hauser J, Dolgov VV, Keist R, Möhler H, Rudolph U and Feldon J. (2004) GABA receptors containing the alpha5 subunit mediate the trace effect in aversive and appetitive conditioning and extinction of conditioned fear. *Eur J Neurosci* **20**: 1928-36 [PMID:15380015]
358. Yee BK, Keist R, von Boehmer L, Studer R, Benke D, Hagenbuch N, Dong Y, Malenka RC, Fritschy JM and Bluethmann H *et al.*. (2005) A schizophrenia-related sensorimotor deficit links alpha 3-containing GABAA receptors to a dopamine hyperfunction. *Proc Natl Acad Sci USA* **102**: 17154-9 [PMID:16284244]
359. Ymer S, Draguhn A, Köhler M, Schofield PR and Seeburg PH. (1989) Sequence and expression of a novel GABAA receptor alpha subunit. *FEBS Lett* **258**: 119-22 [PMID:2556293]
360. Ymer S, Draguhn A, Wisden W, Werner P, Keinänen K, Schofield PR, Sprengel R, Pritchett DB and Seeburg PH. (1990) Structural and functional characterization of the gamma 1 subunit of GABAA/benzodiazepine receptors. *EMBO J* **9**: 3261-7 [PMID:2170110]
361. Ymer S, Schofield PR, Draguhn A, Werner P, Köhler M and Seeburg PH. (1989) GABAA receptor beta subunit heterogeneity: functional expression of cloned cDNAs. *EMBO J* **8**: 1665-70 [PMID:2548852]
362. You H, Kozuska JL, Paulsen IM and Dunn SM. (2010) Benzodiazepine modulation of the rat GABAA receptor α4β3γ2L subtype expressed in Xenopus oocytes. *Neuropharmacology* **59**: 527-33 [PMID:20638393]
363. Zaman SH, Shingai R, Harvey RJ, Darlison MG and Barnard EA. (1992) Effects of subunit types of the recombinant GABAA receptor on the response to a neurosteroid. *Eur J Pharmacol* **225**: 321-30 [PMID:1323476]
364. Zezula J, Slany A and Sieghart W. (1996) Interaction of allosteric ligands with GABAA receptors containing one, two, or three different subunits. *Eur J Pharmacol* **301**: 207-14 [PMID:8773466]
365. Zhang D, Pan ZH, Awobuluyi M and Lipton SA. (2001) Structure and function of GABA(C) receptors: a comparison of native versus recombinant receptors. *Trends Pharmacol Sci* **22**: 121-32 [PMID:11239575]
366. Zhang D, Pan ZH, Zhang X, Brideau AD and Lipton SA. (1995) Cloning of a gamma-aminobutyric acid

type C receptor subunit in rat retina with a methionine residue critical for picrotoxinin channel block. *Proc Natl Acad Sci USA* **92**: 11756-60 [PMID:8524843]

367. Zhao C, Xu Z, Chen J, Yu Z, Tong KL, Lo WS, Pun FW, Ng SK, Tsang SY and Xue H. (2006) Two isoforms of GABA(A) receptor beta2 subunit with different electrophysiological properties: Differential expression and genotypical correlations in schizophrenia. *Mol Psychiatry* **11**: 1092-105 [PMID:16983389]
368. Zhao C, Xu Z, Wang F, Chen J, Ng SK, Wong PW, Yu Z, Pun FW, Ren L and Lo WS *et al.*. (2009) Alternative-splicing in the exon-10 region of GABA(A) receptor beta(2) subunit gene: relationships between novel isoforms and psychotic disorders. *PLoS ONE* **4**: e6977 [PMID:19763268]
369. Zhu WJ, Wang JF, Krueger KE and Vicini S. (1996) Delta subunit inhibits neurosteroid modulation of GABAA receptors. *J Neurosci* **16**: 6648-56 [PMID:8824305]
370. Zimprich F, Zezula J, Sieghart W and Lassmann H. (1991) Immunohistochemical localization of the alpha 1, alpha 2 and alpha 3 subunit of the GABAA receptor in the rat brain. *Neurosci Lett* **127**: 125-8 [PMID:1715535]