

The influence of glucocorticoids and catecholamines on the neuromuscular transmission

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Abstract

The review surveys the impact of "stress hormones" - glucocorticoids and catecholamines - on the functioning of the neuromuscular synapse. The review brings together the data on the influence of the main agents of stress - Cortisol and norepinephrine - on the intensity and timing of the acetylcholine release, as well as signaling effect of its co-mediator ATP.

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Keywords

Catecholamines, Cortisol, Glucocorticoids, Muscle contraction, Neuromuscular synapse, Noradrenaline, Stress hormones, Synaptic modulators

References

- [1] Selye H.A. 1936. Syndrome produced by diverse nocuous agents. *Nature*. 138, 32.
- [2] Selye H. 1938. Experimental evidence supporting the conception of adaptation energy. *Am. J. Physiol.* 123, 758-765.
- [3] Malomouzh A.I., Petrov K.A., Nurullin L.F., Nikolsky E.E. 2015. Metabotropic GABAB receptors mediate GABA inhibition of acetylcholine release in the rat neuromuscular junction. *J. Neurochem.* 135 (6), 1149-1160.
- [4] Mukhamedyarov M.A., Grishin S.N., Yusupova E.R., Zefirov A.L., Palotis A. 2009. Alzheimer's β -Amyloid- induced depolarization of skeletal muscle fibers: implications for motor dysfunctions in dementia. *Cell. Physiol. Biochem.* 23 (1-3), 109-114.
- [5] Mukhamedyarov M.A., Leushina A.V., Zefirov A.L., Teplov A.Y., Grishin S.N., Palotás A. 2011. Extraneu- ronal toxicity of Alzheimer's p-Amyloid peptide: comparative study on vertebrate skeletal muscles. *Muscle Nerve.* 43 (6), 872-877.
- [6] Goffart M. 1952. Investigations relative to the action of adrenalin on mammalian striated muscle. IV. Mode of action of adrenalin on muscle contraction. *Arch. Int. Physiol.* 60 (3), 385-409.
- [7] Goffart M., Ritchie J.M. 1952. The effect of adrenaline on the contraction of mammalian skeletal muscle. *J. Physiol.* 116 (3), 357-371.
- [8] Hutter O.F., Loewenstein W.R. 1955. Nature of neuromuscular facilitation by sympathetic stimulation in the frog. *J. Physiol.* 130 (3), 559-571.
- [9] Bowman W.C., Zaimis E. 1958. The effects of adrenaline, noradrenaline and isoprenaline on skeletal muscle contractions in the cat. *J. Physiol.* 144 (1), 92-107.
- [10] Bowman W.C., Goldberg A.A., Raper C. 1962. A comparison between the effects of a tetanus and the effects of sympathomimetic amines on fast-And slow- contracting mammalian muscles. *Br.J. Pharmacol. Chemother.* 19, 464-484.
- [11] Dahlberg E., Snochowski M., Gustafsson J.A. 1981. Regulation of the androgen and glucocorticoid receptors in rat and mouse skeletal muscle cytosol. *Endocrinology.* 108 (4), 1431-1440.
- [12] Puro D.G. 1983. Glucocorticoid regulation of synaptic development. *Brain Res.* 284 (2-3), 283-290.

- [13] Cairns S.P., Borrani F. 2015. P-Adrenergic modulation of skeletal muscle contraction: key role of excitation-contraction coupling. *J. Physiol.* 593 (21), 4713-4727.
- [14] Bukharaeva E., Samigullin D., Nikolsky E., Vyskocil F. 2002. Protein kinase A cascade regulates quantal release dispersion at frog muscle endplate. *J. Physiol.* 538 (Pt3), 837-848.
- [15] McGrath J.A., Goldspink D.F. 1982. Glucocorticoid action on protein synthesis and protein breakdown in isolated skeletal muscles. *Biochem. J.* 206(3), 641-645.
- [16] Lu N.Z., Wardell S.E., Burnstein K.L., Defranco D., Fuller P.J., Giguere V., Hochberg R.B., McKay L., Renoir J.M., Weigel N.L., Wilson E.M., McDonnell D.P., Cidlowski J.A. 2006. International Union of Pharmacology. LXV. The pharmacology and classification of the nuclear receptor superfamily: glucocorticoid, mineralocorticoid, progesterone, and androgen receptors. *Pharmacol. Rev.* 58 (4), 782-797.
- [17] Rhen T., Cidlowski J.A. 2005. Anti-inflammatory action of glucocorticoids-new mechanisms for old drugs. *N. Engl. J. Med.* 353 (16), 1711-1723.
- [18] Newton R. 2000. Molecular mechanisms of glucocorticoid action: What is important? *Thorax.* 55 (7), 603-613.
- [19] Hafezi-Moghadam A., Simoncini T., Yang Z., Limbourg F.P., Plumier J.C., Rebsamen M.C., Hsieh C.M., Chui D.S., Thomas K.L., Prorock A.J., Laubach V.E., Moskowitz M.A., French B.A., Ley K., Liao J.K. 2002. Acute cardiovascular protective effects of corticosteroids are mediated by non-Transcriptional activation of endothelial nitric oxide synthase. *Nat. Med.* 8 (5), 473-479.
- [20] Cato A.C., Nestl A., Mink S. 2002. Rapid actions of steroid receptors in cellular signaling pathways. *Sci. Stke.* 2002 (138), 9.
- [21] Gametchu B., Watson C.S., Pasko D. 1991. Size and steroid-binding characterization of membrane-Associated glucocorticoid receptor in S-49 lymphoma cells. *Steroids.* 56 (8), 402-410.
- [22] Gametchu B., Watson C.S., Shih C.C., Dashew B. 1991. Studies on the arrangement of glucocorticoid receptors in the plasma membrane of S-49 lymphoma cells. *Steroids.* 56 (8), 411-419.
- [23] Croxtall J.D., van Hal P.T., Choudhury Q., Gilroy D.W., Rower R.J. 2002. Different glucocorticoids vary in their genomic and non-genomic mechanism of action in A549 cells. *Br. J. Pharmacol.* 135 (2), 511-519.
- [24] Sun H.W., Miao C.Y., Liu L., Zhou J., Su D.F., Wang Y.X., Jiang C. L. 2006. Rapid inhibitory effect of glucocorticoids on airway smooth muscle contractions in guinea pigs. *Steroids.* 71 (2), 154-159.
- [25] Liu L., Wang Y.X., Zhou J., Long F., Sun H.W., Liu Y., Chen Y.Z., Jiang C.L. 2005. Rapid non-genomic inhibitory effects of glucocorticoids on human neutrophil degranulation. *J. Inflamm. Res.* 54 (1), 37-41.
- [26] Urbach V., Walsh D.E., Mainprice B., Bousquet J., Harvey B.J. 2002. Rapid non-genomic inhibition of ATP-induced Cl⁻ secretion by dexamethasone in human bronchial epithelium. *Physiol.* 545 (Pt 3), 869-878.
- [27] Sutter-Dub M.T. 2002. Rapid non-genomic and genomic responses to progestogens, estrogens, and glucocorticoids in the endocrine pancreatic B cell, the adipocyte and other cell types. *Steroids.* 67 (2), 77-93.
- [28] Johnson L.R., Farb C., Morrison J.H., McEwen B.S., Le Doux J.E. 2005. Localization of glucocorticoid receptors at postsynaptic membranes in the lateral amygdala. *Neuroscience.* 136 (1), 289-299.
- [29] Makara G.B., Haller J. 2001. Non-genomic effects of glucocorticoids in the neural system. Evidence, mechanisms and implications. *Prog. Neurobiol.* 65(4), 367-390.
- [30] Haller J., Mikics E., Makara G.B. 2008. The effects of non-genomic glucocorticoid mechanisms on bodily functions and the central neural system. A critical evaluation of findings. *Front. Neuroendocrinol.* 29 (2), 273-291.
- [31] Dreyer F., Peper K., Sterz R., Bradley R.J., Muller K.D. 1979. Drug-receptor interaction at the frog neuromuscular junction. *Prog. Brain. Res.* 49, 213-223.
- [32] Peper K., Bradley R.J., Dreyer F. 1982. The acetylcholine receptor at the neuromuscular junction. *Physiol. Rev.* 62(4 Pt 1), 1271-1340.
- [33] Giniatullin A.R., Grishin S.N., Giniatullin R.A. 2000. Effect of hydrocortisone on ATP receptors in the neuromuscular junction of the frog. *Neurophysiology.* 32(3), 217.
- [34] Hall E.D. 1982. Glucocorticoid effects on central nervous excitability and synaptic transmission. *Int. Rev. Neurobiol.* 23, 165-195.
- [35] Dlouhd H., Vyskocil F. 1979. The effect of Cortisol on the excitability of the rat muscle fibre membrane and neuromuscular transmission. *Physiol. Bohemoslov.* 28 (6), 485-494.
- [36] Gruener R., Stern L.Z. 1972. Corticosteroids. Effects on muscle membrane excitability. *Arch. Neurol.* 26 (2), 181-185.
- [37] Kim Y.I., Goldner M.M., Sanders D.B. 1979. Short-Term effects of prednisolone on neuromuscular transmission in normal rats and those with experimental autoimmune myasthenia gravis. *J. Neurol. Sci.* 41, 223-234.
- [38] Van Wilgenburg H. 1979. The effect of prednisolone on neuromuscular transmission in the rat diaphragm. *Eur. J. Pharmacol.* 55 (4), 355-361.
- [39] Van Wilgenburg H., Njio K.D., Belling G.A., Van den Hoven S. 1982. Effects of corticosteroids on the myoneural junction. A morphometric and electrophysiological study. *Eur. J. Pharmacol.* 84 (3-4), 129-137.

- [40] Dengler R., Rudel R., Warelas J., Birnberger K.L. 1979. Corticosteroids and neuromuscular transmission: Electrophysiological investigation of the effects of prednisolone on normal and anticholinesterase-Treated neuromuscular junction. *Pflugers Arch.* 380 (2), 145-151.
- [41] Yamate S., Nishigori H., Kishimoto S., Tezuka Y., Fukushima A., Sugiyama T., Nishigori H. 2010. Effects of glucocorticoid on brain acetylcholinesterase of developing chick embryos. *J. Obstet. Gynaecol. Res.* 36(1), 11-18.
- [42] Brank ML, Zajc-Kreft K., Kreft S., Komel R., Grubic Z. 1998. Biogenesis of acetylcholinesterase is impaired, although its mRNA level remains normal, in the glucocorticoid-Treated rat skeletal muscle. *Eur. J. Biochem.* 251 (1-2), 374-381.
- [43] Bu J., Zu H. 2014. Effects of pregnenolone intervention on the cholinergic system and synaptic protein 1 in aged rats. *Int. J. Neurosci.* 124 (2), 117-124.
- [44] Burnstock G. 1972. Purinergic nerves. *Pharmacol. Rev.* 24(3), 509-581.
- [45] Burnstock G., Arnett T.R., Orriss I.R. 2013. Purinergic signalling in the musculoskeletal system. *Purinergic Signal.* 9(4), 541-572.
- [46] Alexander S.P., Benson H.E., Faccenda E., Pawson A.J., Sharman J.L., Spedding M., Peters J.A., Harmar A.J. 2013. The concise guide to pharmacology 2013/14: G protein-coupled receptors. *Br.J. Pharmacol.* 170(8), 1459-1581.
- [47] Burnstock G., Knight G.E. 2004. Cellular distribution and functions of P2 receptor subtypes in different systems. *Int. Rev. Cytol.* 240, 31-304.
- [48] Koles L., Gerevich Z., Oliveira J.F., Zadori Z.S., Wirkner K., Hies P. 2008. Interaction of P2 purinergic receptors with cellular macromolecules. *Naunyn Schmiedebergs Arch. Pharmacol.* 377(1), 1-33.
- [49] Jacobson K.A., Jayasekara M.P., Costanzi S. 2012. Molecular structure of P2Y receptors: mutagenesis, modeling, and chemical probes. *Wiley Interdiscip. Rev. Membr. Transp. Signal.* 1(6) WMTS68.
- [50] Grishin S.N., Ziganshin A.U. 2013. Modulatory role of purines in neuromuscular transmission. *Biochem. (Mosc.)* 7 (3), 183-191.
- [51] Giniatullin A.R., Grishin S.N., Giniatullin R.A. 2000. Effect of hydrocortisone on atp receptors in the neuromuscular junction of the frog. *Neurophysiology.* 32(3), 217.
- [52] Ziganshin A.U., Kamaliev R.R., Grishin S.N., Ziganshin B.A., Burnstock G. 2009. Interaction of hydrocortisone with ATP and adenosine on nerve- mediated contractions of frog skeletal muscle. *Eur. J. Pharmacol.* 607, 54-59.
- [53] Sokolova E.M., Grishin S.N., Shakirzyanova A.V., Talantova M.V., Giniatullin R.A. 2003. Distinct receptors and different transduction mechanisms for ATP and adenosine at the frog motor nerve endings. *Eur. J. Neuroscience.* 18, 1254-1264.
- [54] Solito E., Parente L. 1989. Modulation of phospholipase A2 activity in human fibroblasts. *Br.J. Pharmacol.* 96(3), 656-660.
- [55] Zor U., Her E., Braquet P., Ferber E., Reiss N. 1991. A novel mechanism of glucocorticosteroid (GC) action in suppression of phospholipase A2 (PLA2) activity stimulated by Caionophore A23187: induction of protein phosphatases. *Adv. Prostaglandin Thromboxane Leukot. Res.* 21, 265-271.
- [56] Ralevic V., Burnstock G. 1998. Receptors for purines and pyrimidines. *Pharmacol. Rev.* 48, 113-167.
- [57] Arkhipova O.V., Grishin S.N., Sitdikova G.F., Zefirov A.L. 2006. The presynaptic effects of arachidonic acid and prostaglandin E2 at the frog neuromuscular junction. *Neurosci. Behav. Physiol.* 36 (3), 307-312.
- [58] Braun S., Askanas V., Engel W.K., Ibrahim E.N. 1993. Long-Term treatment with glucocorticoids increases synthesis and stability of junctional acetylcholine receptors on innervated cultured human muscle. *J. Neurochem.* 60, 1929-1935.
- [59] Elliot T.R. 1905. The action of adrenalin. *J. Physiol. Lond.* 32, 401-467.
- [60] Sobol K.V., Belostotskaya G.B., Nesterov V.P., Nasledov G.A. 2006. Adrenergic and cholinergic activation of calcium signals in cultured postnatal skeletal myocytes of the rat. *Dokl. Biol. Sci.* 406, 27-31.
- [61] Orbeli L.A. 1923. Die sympathische Innervation der Skelettmuskeln. *Bull. Indt. Sci. Leshaft.* 6, 194-197.
- [62] Jenkinson D.H., Stamenovid B.A., Whitaker B.D. 1968. The effect of noradrenaline on the end-plate potential in twitch fibres of the frog. *J. Physiol.* 195 (3), 743-754.
- [63] Hidaka T., Kuriyama H. 1969. Effects of catecholamines on the cholinergic neuromuscular transmission in fish red muscle. *J. Physiol.* 201 (1), 61-71.
- [64] Kuba K. 1970. Effects of catecholamines on the neuromuscular junction in the rat diaphragm. *J. Physiol.* 211 (3), 551-570.
- [65] Kuba K., Tomita T. 1971. Noradrenaline action on nerve terminal in the rat diaphragm. *J. Physiol.* 217 (1), 19-31.
- [66] Wessler I., Holzer G., Kunster A. 1990. Stimulation of beta 1-Adrenoceptors enhances electrically evoked [3H]-Acetylcholine release from rat phrenic nerve. *Clin. Exp. Pharmacol. Physiol.* 17 (1), 23-32.
- [67] Vizi E.S. 1991. Evidence that catecholamines increase acetylcholine release from neuromuscular junction through stimulation of alpha-1 adrenoceptors. *Naunyn Schmiedebergs Arch. Pharmacol.* 343 (5), 435-438.

- [68] Bowman W.C. 1980. Effects of adrenergic activators and inhibitors on the skeletal muscles. In Handbook of Pharmacology: Adrenergic Activators and Inhibitors. Ed. Szekeres L, pp. 47-128.
- [69] Khan M.M., Lustrino D., Silveira W.A., Wild F, Straka T., Issop Y., O'Connor E., Cox D., Reischl M., Marquardt T., Labeit D., Labeit S., Benoit E., Molgo J., Lochmuller H., Witzemann V., Kettelhut I.C., Navegantes L.C., Pozzan T., Rudolf R. 2016. Sympathetic innervation controls homeostasis of neuromuscular junctions in health and disease. *Proc. Natl. Acad. Sci. USA.* 113 (3), 746-750.
- [70] Bukharaeva E., Samigullin D., Nikolsky E., Vyskocil F. 2002. Protein kinase A cascade regulates quantal release dispersion at frog muscle endplate. *J. Physiol.* 538(Pt3), 837-848.
- [71] Gabdrakhmanov A.I., Khairullin A.E., Grishin S.N., Ziganshin A.U. 2015. ATP-induced changes in rat skeletal muscle contractility. *Int. J. Risk Saf. Med.* 27 Suppl. 1: 82-83. doi: 10.3233/JRS-150700.
- [72] Tsentsevitsky A., Kovyazina I., Nikolsky E., Bukharaeva E., Giniatullin R. 2013. Redox-sensitive synchronizing action of adenosine on transmitter release at the neuromuscular junction. *Neuroscience.* 248, 699-707.
- [73] Torda C., Wolff H.G. 1952. Effect of pituitary hormones, cortisone and adrenalectomy on some aspects of neuromuscular function and acetylcholine synthesis. *Am.J. Physiol.* 169 (1), 140-149.
- [74] Grishin S.N., Ziganshin A.U. 2015. Synaptic organization of tonic motor units in vertebrates. *Biochemistry (Moscow) Suppl. Ser. A: Membrane and Cell Biology.* 9 (1), 13-20.
- [75] Goulding N.J. 2004. The molecular complexity of glucocorticoid actions in inflammation -A four-ring circus. *Curr. Opin. Pharmacol.* 4 (6), 629-636.
- [76] Sinha A., Bagga A. 2008. Pulse steroid therapy. *Indian. J. Pediatr.* 75(10), 1057-1066.